Precursor Systems Analyses of Automated Highway Systems

RESOURCE MATERIALS

Summary and Assessment of Findings

U.S. Department of Transportation
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FOREWORD

This report was a product of the Federal Highway Administration's Automated Highway System (AHS) Precursor Systems Analyses (PSA) studies. The AHS Program is part of the larger Department of Transportation (DOT) Intelligent Transportation Systems (ITS) Program and is a multi-year, multi-phase effort to develop the next major upgrade of our nation's vehicle-highway system.

The PSA studies were part of an initial Analysis Phase of the AHS Program and were initiated to identify the high level issues and risks associated with automated highway systems. Fifteen interdisciplinary contractor teams were selected to conduct these studies. The studies were structured around the following 16 activity areas:

> (A) Urban and Rural AHS Comparison, (B) Automated Check-In, (C) Automated Check-Out, (D) Lateral and Longitudinal Control Analysis, (E) Malfunction Management and Analysis, (F) Commercial and Transit AHS Analysis, (G) Comparable Systems Analysis, (H) AHS Roadway Deployment Analysis, (I) Impact of AHS on Surrounding Non-AHS Roadways, (J) AHS Entry/Exit Implementation, (K) AHS Roadway Operational Analysis, (L) Vehicle Operational Analysis, (M) Alternative Propulsion Systems Impact, (N) AHS Safety Issues, (O) Institutional and Societal Aspects, and (P) Preliminary Cost/Benefit Factors Analysis.

To provide diverse perspectives, each of these 16 activity areas was studied by at least three of the contractor teams. Also, two of the contractor teams studied all 16 activity areas to provide a synergistic approach to their analyses. The combination of the individual activity studies and additional study topics resulted in a total of 69 studies. Individual reports, such as this one, have been prepared for each of these studies. In addition, each of the eight contractor teams that studied more than one activity area produced a report that summarized all their findings.

Lyle Saxton
Director, Office of Safety and Traffic Operations Research and Development

NOTICE

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This material summarizes thoughts and inputs received from very many sources. Richard Bishop, the Automated Highway Systems (AHS) Program Manager at the Turner-Fairbank Highway Research Center of the U.S. Department of Transportation, provided overall guidance and key input to this paper. Each of the AHS Precursor Systems Analyses (PSA) program managers and activity area leaders (too numerous to mention) and their teams must be acknowledged as those who conducted the basic research of the PSA program.

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16. Abstract

In 1993. the Federal Highway Administration awarded a series of contracts under their Automated Highway Systems program. the contracts, which totaled 14.1 million, were awarded to 15 separate teams of researchers and were completed in late 1994. these contracts addressed the major issues and risks associated with automated vehicle control on our Nation’s highways. The results of these studies indicated that although there are a number of major challenges to be faced, there are no major “show stoppers” to be implementation of automated Highway Systems. this report is a summary and assessment of the major findings of the Precursor systems Analyses studies.

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TABLE OF CONTENTS

SECTION			PAGE

SECTION PAGE

SECTION PAGE

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

In the summer of 1993, the Federal Highway Administration (FHWA) awarded a series of contracts under their Automated Highway Systems (AHS) program. The purpose of these efforts, called the Precursor Systems Analyses (PSA), was to identify and analyze the major issues and risks associated with automated vehicle control on our Nation's highways. The program of work was structured to address 16 different activity areas. Fifteen separate teams of researchers were competitively selected to conduct the studies for a total of $14.1 million. All of the research efforts were completed by late 1994.

This report provides a comprehensive summary and evaluation of the PSA analyses. The findings are organized in the following major categories: system-related, transition-oriented, vehicle-related, roadway-related, institutional and societal, and benefits and costs. Two of the PSA teams--Calspan and Delco--were tasked to address all 16 study areas, and to provide an overview of their efforts; summaries are provided as appendices. Additionally, in April, 1994, all of the PSA researchers met in Chantilly, Virginia for a three day Interim Results Workshop. A summary of the proceedings from that workshop are included as an appendix to this report.

The 90 final reports (over 5,000 pages) are being made available through the National Technical Information Service (NTIS). In order to make the findings widely and readily accessible, the U.S. Department of Transportation (U.S. DOT) is transferring the reports onto CD-ROM, which will be available through the National AHS Consortium (NAHSC) or the U.S. DOT. Both the NAHSC and the U.S. DOT plan to make these reports available through a home page service as well. Finally, each researcher was asked to enter its major findings onto a PSA Results Database, which was developed and maintained by Calspan and is being used by the NAHSC participants. Directions for using the database are provided in an appendix.

AUTOMATED HIGHWAY SYSTEMS PROGRAM OVERVIEW

The AHS program was initiated in 1992 as part of U.S. DOT's Intelligent Transportation Systems (ITS) program. Within ITS, the AHS is a user service that applies modern electronics to provide fully automated (hands off and feet off) vehicle control; that is, the vehicle's throttle, braking and steering are controlled by the system. The AHS will be developed from and be compatible with the present highway system.

The promise of AHS is unique in that it offers major improvements in both the safety of highway travel and in the efficient operation of highways, in many cases using existing highway right-of-ways. The drivers will choose to use--or not use--the AHS lane. When a vehicle is accepted, the AHS will move the vehicle from the highway lane onto the AHS lane where the vehicle will be moved safely and efficiently to the driver's desired exit.
The objective of the AHS program is to assess AHS feasibility and to develop an affordable, safe, efficient system that enhances the quality of highway travel.

The Federal government will not be the eventual owner, operator or supplier of the AHS; these will be the roles of the major AHS stakeholders--state and local governments; vehicle, highway and electronics industries; and the system users. For this reason, in October, 1994 the U.S. DOT teamed with the NAHSC, a broad public/private partnership composed of major stakeholder organizations. It is this consortium that will implement the AHS program.

PRECURSOR SYSTEMS ANALYSES PROGRAM DESCRIPTION

The PSA contracts were focused upon the 16 activity areas described in table ES-1. Table 2-3 in the main body of the report lists the individual contractors and the activity areas they addressed. That table shows that all of the activity areas were addressed by at least three contractors. This overlap added value to the overall body of research since each discrete effort brought a different perspective and emphasis to bear on the analysis of issues and risks.

MAJOR PRECURSOR SYSTEMS ANALYSES FINDINGS

The PSA studies identified a number of significant challenges to be faced, but found no major "show stoppers" to the implementation of AHS. The major findings addressed in this report are summarized below.

System Related Findings

Vision

The broad vision for AHS is to move people and goods--not just vehicles--more safely and more efficiently; support transit vehicles, commercial vehicles, passenger vehicles, including high occupancy vehicle (HOV) operations; and support urban and rural operations.

Operating Parameters

The safety and operating parameters of AHS are those variables that may be determined by each locale as it installs an AHS. They may include spacing between vehicles, speed, strategy for dealing with varying vehicle types, and entry and exit rules. These parameters will vary from one community to the next to reflect each community's needs and transportation policies; from one highway to the next because of the highway design constraints; from one time period to another to reflect the community's demand management and congestion management policies; and from one minute to the next to reflect environmental factors such as weather conditions (e.g., slow down for rain) and/or traffic conditions (e.g., exit 17 closed because of a collision on the connecting roadway). A community's operating and safety policies will significantly effect the level of safety and efficiency achieved on its AHS.

Safety

The public's perception of AHS safety is critical. Even though AHS operation is expected to be significantly safer than travel on non-AHS roadways, if the public perceives that AHS travel is less safe, then AHS will be avoided. An example is air travel; even though statistics show that air travel is safer than driving, many drivers are afraid of air travel. An AHS can be designed and operated so that statistically it can be shown to be very safe; but if there are rare, catastrophic crashes (multiple vehicles and deaths), the public perception may be that AHS is unsafe. The safety-critical functions of AHS have been identified; the AHS design will need to provide high reliability in those safety-critical areas. A high level of safety also will involve dealing with outside intrusions through the use of obstacle detection, barriers and fences.

System Robustness

The system must be robust--it cannot have frequent traffic blockages. A basic design issue is whether to design for highly robust vehicles and occasional breakdown lanes or less robust vehicles and continuous breakdown lanes. Double or triple redundancy on vehicles may be costly; but continuous breakdown lanes will also be costly, and may not be possible in some urban areas. Another option is very rapid response in removing disabled vehicles in critical areas. A balance will need to be reached. A balance will also need to be identified between (1) on-the-fly (rapid) check-in and periodic off-premise inspections; and (2) thorough, slow-or-stop inspection on every entry with little, if any, off-premise inspections.

Traffic Operations

A concept of traffic operations will need to be determined by each community to handle the various vehicle types. Options could include mixed heavy and light vehicles in same lane with occasional passing lanes; one lane for light and one lane for heavy/light vehicles (light lane narrower?); or one for buses only and one “general purpose” lane. A general purpose lane--as a second lane--could be used for light and/or HOV vehicles in peak hours, and for truck-only in off-hours; it could be used for the breakdown lane when needed and for maintenance in off-hours; during inclement weather, it could be used for snow storage.

National Compatibility

The U.S. DOT visualizes the AHS as evolving to a nation-wide network so that a driver can cross the country using AHS and feel that the AHS in Los Angeles is as familiar as in New York. On the other hand, the AHS is envisioned as a tool to be used by an MPO and/or a state DOT to be tailored to help meet its local needs; an AHS in one city may be for transit and HOV vehicles only, while in another locale, the system use is unrestricted.

Table ES-1. Precursor Systems Analyses Activity Areas

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

Transition-Related Findings

The researchers mostly indicated that an "evolutionary transition" into AHS would be desirable; that is, the evolution should be planned, not occur by chance. A general vision of this evolution was that other partial automated vehicle control (AVC) services would precede the AHS to the marketplace; these services would allow the drivers to become more accustomed to AVC and would give designers more experience in designing AVC products. It was also noted that some of the components needed for these partial AVC services could possibly be used for an AHS; these vehicles would provide a certain level of "market penetration" of vehicles capable of traveling on the AHS lanes. Specific ITS services mentioned for evolution included adaptive cruise control, collision avoidance, and lane keeping. Several researchers, however, cautioned that tying AHS to these services might be risky. These services may not have as broad of an appeal as AHS because they cannot offer the same level of safety, throughput and user comfort. Also, it was noted that designing systems that will work on a roadway with manual drivers may be much more complicated (and expensive) than designing a system that will operate on a roadway dedicated to automated vehicles.

Researchers offered several possible approaches for establishing enough automated vehicles in an area to justify a dedicated AHS lane such as incentives for initial users, fleet conversions, free conversion of buses and HOV vehicles. They believed that once an AHS service began operation, other drivers would see the benefits, and the numbers of potential AHS users would rapidly increase. Once AHS becomes popular, a network of AHS lanes can be established and expanded levels of service can be offered in response to user demands.

Vehicle-Related Findings

Vehicle Design

The performance and reliability of an AHS will be directly influenced by the vehicles that operate on it. The AHS components will be installed on vehicles either at the factory or by retrofit in the field. The vehicles chosen to be equipped for AHS will need to meet certain criteria: they will need electronically actuated steering, braking and engine control; automatic transmissions; and "reasonable" performance. There could conceivably be other safety and performance related criteria as well such as tire type, bumper performance, suspension performance, and cabin-lock control. There will be specifications for both heavy and light vehicles. Initially, it would be expected that AHS-equipped vehicles will be newer models.

Check-In to AHS

Several researchers proposed that vehicles should have on-board self-checking systems that determine if all of the necessary vehicle systems are operative on a continuous basis. As the vehicle attempts to enter the AHS lanes, the roadside check-in processor will communicate with the vehicle to identify it and to verify its operating status (e.g., adequate fuel, sensors and processors operative, communications links open). Presumably the driver will have been given some indication if the system was not in a "Go" condition before he/she got to the AHS entry point. If the vehicle passes the roadside inspection, then control of the vehicle will be assumed by the AHS system, and the vehicle will be moved onto the AHS lanes. Vehicles that fail the check-in test will be denied entry, and the drivers will be directed to take an exit lane (they may be barred electronically or physically from entering the AHS). These checks will help increase overall AHS reliability, but they cannot detect all conditions such as structural integrity of the exhaust system. Required periodic off-site inspections can help catch some percentage of potential problems, and some researchers suggested that manual visual inspections of vehicles at check-in locations might help. It was suggested that the driver should be responsible for his/her vehicle--responsibilities could be agreed to when the driver is issued an "AHS drivers license".

Lateral Control

Several approaches were analyzed for automatically keeping a vehicle safely in its lane of travel--or lane keeping. The use of magnetic reference points along, or embedded in, the AHS lane appeared to be practical and the most economical; although the actual cost of reliable lane sensing and control will need to be established. Automated lane changing was identified as a potentially difficult maneuver.

Longitudinal Control

It was felt that many approaches exist for controlling a vehicle's throttle and brakes to maintain a safe following distance from the vehicle in front. Again, the ability to provide very high reliability at an economical cost will need to be determined. Safely controlling vehicles at close spacing to increase throughput adds additional design requirements for longitudinal control including more accurate and responsive sensing, faster processing and inter-vehicle communications. One issue is who should pay for components that provide a community with this greater throughput on a single lane?

Obstacle Detection

Detection of obstacles in the AHS roadway appears to be one of the more difficult problems to solve because of the wide variety of obstacles that could be disruptive to traffic flow. Many suggestions were given ranging from vehicle and roadway mounted sensors, to severe fines for drivers who carry items that fall in the roadway, to installation of fences and area detectors to detect animals and other intruders. This area requires further research to define the kinds of potential obstacles and the best way of dealing with them.

Reliability and Maintainability

Vehicle components that contribute to the control of a vehicle's lateral and longitudinal movement--sensors, processors, actuators--must have very reliable operation, and/or must be designed with adequate backup systems. For example, if a vehicle's sensors become inoperative, the system must be able to detect that and be able to switch to backup sensors that can operate until the vehicle is removed from the roadway. Ease of cleaning and repairing AHS components will help increase system attractiveness.

Roadway-Related Findings

Functions

The AHS roadway must be instrumented to some extent. At the least, it must have lane markers, communications beacons, and barriers to minimize the impact of adjacent manual traffic. It may also have processors to coordinate vehicle entry, vehicle exit, and merging and lane change maneuvers; and sensors to detect changing weather conditions, obstacles and incidents.

Roadway Design

An AHS could operate on one of today's highway lanes and, in fact, it is believed that many of the AHS lanes will be existing highway lanes that are converted to AHS. Entry and exit ramps for AHS will require additional construction on most roadways. Transition lanes that are located between the

AHS and non-AHS lanes were found to have many safety and throughput disadvantages. There is a large variety of roadway configurations that could be used for an AHS; these are very similar to configurations used for today's highways.

New AHS lane construction could vary substantially from today's roadways, however. Because of the highly accurate lateral control, AHS lanes could be narrower than today's lanes. This accurate control also means that vehicle wheels will always track accurately in the same paths; this means that special construction might be needed to help avoid "grooving". It also means that since the areas between the two tire tracks will not need to support heavy traffic, then fly-overs and below-grade AHS lanes could be constructed as guideways with two narrow concrete strips providing the vehicle support.

Barriers and Breakdown Lanes

Barriers between the AHS lanes and the manual lanes were strongly encouraged to protect the AHS from manual traffic. The barriers would be of particular value in keeping crashes in the manual lanes from impinging into the AHS lanes. Instrumented shoulders or breakdown lanes will be needed either occasionally or continuously, depending on the particulars of the highway. One issue is how to deal with the occupants of vehicles that break down on AHS. If they leave their vehicle, they might create a very dangerous situation unless the system is forewarned and is able to slow, divert or halt traffic flow. But if a vehicle is on fire, the occupants must be able to get out.

Impact on Non-AHS Roadways

The interaction of AHS lanes with the manual streets is a major concern that must be addressed locally; each interchange will have different characteristics. The concern is the volume of entering and exiting AHS traffic and the capacity of the existing surface street network to handle it. An example would be an AHS exit to a central business district that is congested every morning. Researchers demonstrated that the impact of the AHS volume can be mitigated through innovative entry and exit design, possible reconfiguration of the surface streets, and active demand management. The cost of manual roadway modifications will need to be addressed by each locality.

Deployment

The deployment process for a new AHS lane, other than the construction technique, will not differ substantially from deployment of a new manual roadway lane; conversion of an existing lane to AHS should be substantially easier. Support and opposition to the AHS may be similar to what would be experienced with a manual roadway.

Operation and Maintenance

AHS operation and maintenance crews will need to be expanded to encompass the new AHS technologies. The AHS is a sophisticated system that will require frequent and sometimes immediate repair of problems that range from potholes (that the vehicles may not detect and avoid) to communications beacons that become inoperative. In some cases those problems will mean that new skills will need to be added to the departments of transportation. This will also be true for the Traffic Management Centers where AHS monitoring will need to take on added urgency and rapid reaction to occurrences such as obstacles falling off vehicles to intruders that attempt to disrupt the system.

Societal and Institutional Findings

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

AHS must be recognized for what it can contribute to the total spectrum of regional surface transportation needs in traditional transit, commercial, rural and urban, private and evolving public para-transit environments; it should be viewed as a flexible tool available to transportation planners and decision makers when they address the complexities of doing more with what they have. Below, some of the leading societal concerns identified by the researchers are described.

Environmental Impacts

There is a need to continue efforts to understand how AHS can play a positive role regarding air and water quality, and noise. The concern remains that an AHS might encourage/induce more vehicle miles traveled (VMT). If so, then overall emissions and fuel consumption may increase even though emissions are reduced on a per-vehicle-mile basis. ISTEA has provided the framework for addressing these conflicting requirements in the expanded planning role given to MPOs. MPOs should be able to take advantage of special AHS characteristics as they incorporate AHS into their transportation plans. In non-attainment areas, AHS could be used to enhance transit, HOV traffic, congestion management and the introduction of alternative propulsion (low and zero mobile source emission) vehicles.

Equity

Should the system be available to the entire public or just for those who can afford the tolls and/or the AHS-equipped vehicles? A limiting (restrictive) deployment could be subject to criticism even though AHS is expected to reduce congestion on both AHS and non-AHS roads. Each region will need to consider the demographic and economic impacts of its AHS installations.

Land Use and Development.

There are concerns for direct and indirect impacts of AHS on land use. The direct impacts have to do with entry and exit facilities and general infrastructure improvements that will probably be undertaken when an AHS is deployed. Beyond the concerns for the environment and equity described above, there are practical issues for surface street operations, local traffic management, signaling, and maintenance. The researchers concluded that AHS deployment in relatively restricted rights-of-way could be achieved using current highway design practices, although their studies were highly site specific as any actual deployment will also be.

The indirect impacts on regional development are a larger question that the PSA efforts did not address. Planning analyses to identify the effects on land use that an AHS deployment may precipitate will be a necessary part of MPO level deliberations within the ISTEA planning framework. One need is to determine the different impacts (if any) that deploying AHS will bring compared to deploying regular highways and/or light rail. These will be very area-specific as are the predicted benefits such as trip-time value patterns and flexibility in regional development concepts.

Role of the Driver

Concerns identified by the PSA research include:

- To what extent will additional skills be required to use an AHS?
- Will the AHS be a significant aid for senior citizens and the physically impaired who sometimes avoid today's highways and their congestion and stress?
- Will the driver be checked in to AHS as well as the vehicle?
- What sort of responsibility will the driver and passenger have, if any, during regular and emergency conditions?

Who Pays for AHS?

There are numerous and varied options for financing an AHS, as with conventional transportation projects. Below are some of the significant findings:

- While there are many ways in which AHS costs can be covered, it is the structuring and division (this relates to the potential exclusivity of AHS) of these costs that will or will not give the perception of whether it is "worth it."
- To some extent, the AHS infrastructure could be paid for with fuel taxes.
- The financing and building of the AHS infrastructure could be handled by an entity that has the rights and privileges of a public utility.
- The Federal Government could provide support to States for operations and maintenance costs because of the increased level of funds required for these types of activities. The ISTEA of 1991 drew attention to the concept of funding for operations and maintenance.
- The question of who pays also impacts the issue of social equity; for example, would congestion pricing be punitive? Should AHS operation be free? Should only high-occupancy vehicles travel free in rush hours? Should the system offer discounts for use during non-peak periods?

Responsibility for Property Loss, Injury, or Death

When an AHS assumes control of the vehicles, "the system" must also assume some level of liability for the consequences of any malfunction. An AHS will include the instrumented AHS lane and the instrumented vehicles that travel on the AHS lanes. When a failure of the AHS lane occurs and there are losses, the owner and/or operator of the AHS lane may be responsible (i.e., government, utility, toll road operator, etc.). If a failure occurs on a vehicle, determining the responsible party may not be a simple process. The liability could be deemed to lie with the vehicle assembler, the component manufacturer, the vehicle owner (who is responsible for maintaining the equipment), the state and/or Federal government who establishes guidelines and procedures to ensure each vehicle's safe operation, or some, or all of the above. The preliminary reviews of the product liability costs for an AHS have indicated that it can be controlled through careful design, legislation, and cost transfer.

Tort liability is also not seen as a show stopper if costs are controlled and safety is secure. The ongoing ITS program will provide some basis for predetermining the conditions for AHS.

Some additional issues include:

- Should Federal legislative protection be sought to limit liability per transaction and the amount of punitive damages that can be awarded?
- Should the user be expected to accept limited liability through a “user agreement” format? Are there driver and vehicle performance indicators that would serve as probable cause for police intervention?
- Can or should a mediation process be established to avoid protracted lawsuits?

State and Regional Institutional Concerns

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

State transportation organizations are evolving. As planning for AHS begins, funds to build up and evolve the State’s transportation departments will need to be made available so that technical staff can be hired and trained. Career paths will need to be established, job descriptions created, etc. This front-end cost will increase State DOT costs long before the AHS becomes operational. Facilities management firms could be hired to provide full service management of the AHS infrastructure; however, this could introduce questions regarding the liability of these firms when incidents occur.

Another option raised by the researchers is that of private ownership of AHS roads such as a private toll road. Also, a separate public utility type of organization could be established to fund, build, and maintain AHS, even the part installed in vehicles.

Insurance companies and insurance regulators will need to assess the impact of AHS operation on rates, and programs for inspection of AHS vehicles will need to be established.

National Certification and/or Regulation

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

It will be necessary to certify that the vehicle manufacturers’ products meet the applicable standards. Similarly, as companies design roadside components, those will also need to be certified to ensure that they operate with the vehicles. A national organization or perhaps the U.S. DOT, will need to be designated as the certification agent.

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

Public Pressures Versus Engineering Realities

A major new system that will directly interact with the general public faces significant pressures from two sides. The engineering of such a system in the general public eye increases the need for very thorough testing to ensure safety, robustness and operability; virtually every possible way of breaking the system must be identified and designed around. The safety of the system must be demonstrated. Such systems are expensive and some may get impatient with its cost and development schedule.

SECTION 1

INTRODUCTION

1.1 PURPOSE

The purpose of this document is to provide an overview and assessment of the findings of the Precursor Systems Analyses (PSA) of Automated Highway Systems (AHS). These analyses consist of 15 research contracts that were funded for a total of $14.1 million to investigate the issues and risks related to the design, development and implementation of AHS. The contracts were awarded during the period of July through September 1993 by the AHS Program within the United States Department of Transportation (U.S. DOT). All of the contracts were completed by December, 1994. The complete list of PSA reports is given in table 1; each of these is accessible through the National Technical Information Service (NTIS). These reports, which total over 3,000 pages, provide an unusual variety and breadth of analysis on virtually every aspect of automated vehicle control and its use in an AHS.

The AHS program was initiated in 1992 by the Federal Highway Administration (FHWA) as part of the U.S. DOT's Intelligent Transportation Systems (ITS) program. This Program, which is responsive to the guidance contained in the Intelligent Vehicle Highway Systems (IVHS) portion of the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991, is a major government-industry-academia collaboration aimed at applying advanced vehicle control technology to the U.S. highway system in order to improve mobility and transportation productivity, enhance safety, maximize the use of existing transportation facilities, conserve energy resources, and reduce adverse environmental effects.

The PSA findings provide valuable information with which the FHWA has been able to further focus and define the scope, characteristics and benefits of automated vehicle control on our nation's highways. In 1993, as the studies were beginning, the FHWA had many unanswered questions such as:

- What is an automated highway?
- What are the benefits of such a system; that is, is our vision of increased efficiency and safety correct?
- Are there any major issues that would affect or inhibit its deployment?
- What are the perceived risks associated with the AHS concept, and to whom are they of concern?

The PSA research has provided a great deal of information on these and many other questions. In some cases, preliminary answers have been given, prompting increased confidence in the likely feasibility of AHS as a major supplement to the nation's surface transportation system in the twenty-first century.

The PSA findings also provide a substantial and credible baseline of AHS information from which the AHS program can be continued by the National Automated Highway Systems Consortium (NAHSC).

1.2 APPROACH FOR CATEGORIZING FINDINGS

This document provides synthesis and assessment—synthesis in that it gives an overall summary of the research; and assessment in that the report contains additional observations and assessments formed by MITRE and the U.S. DOT as the PSA research proceeded. There are many PSA findings that are not included; however, the report has attempted to describe and elaborate on the major findings in the 71 volumes of research results. The reader is referred to the individual reports summarized in Table 1-1 for more specific findings in a particular area.

1.2.1 Precursor Systems Analysis Database Reference

A database of the major PSA findings has also been created; it is called the PSA Database and is described in Appendix D. This database is available to researchers in electronic form. In building the database, a goal was to allow any given finding to be accessed from a variety of perspectives or views. These perspectives define the ways in which a finding can be categorized as follows:

- Program phase or aspect (e.g., deployment, 1997 demonstration)
- System perspective (e.g., safety, efficiency, human interface, user acceptance)
- System function (e.g., lateral control, check-in, flow control, operational mode)
- System component (e.g., infrastructure-surface, vehicle sensors)
- Concept boundary (e.g., location of control logic, type of lateral control, vehicle type)

A PSA finding is classified in the database as an issue, a concern, a conclusion, or a risk, where:

- Issues result from analyses, but are questions or differences of professional opinion that arise from the analyses. Issues are addressed and resolved through further investigation.

Table 1-1. List of AHS Reports

BATTELLE

- Contract Overview
  - A Urban and Rural AHS Analysis
  - E Malfunction Management and Analysis
  - H AHS Roadway Deployment
  - I Impact of AHS on Surrounding Non AHS Roadways
  - J AHS Entry/Exit Implementation
  - K AHS Roadway Operational Analysis
  - N AHS Safety Issues
  - O Institutional and Societal Aspects

BDM

- Contract Overview
  - F Commercial and Transit Aspects
  - O Institutional and Societal Issues

CALSPAN

Volume I	Overview Report
Volume II	AHS Comparable Systems Analyses
Volume III	AHS Roadway Analysis
Volume IV	AHS Systems Analysis
Volume V	AHS Malfunction Management and Safety Analyses
Volume VI	AHS Alternative Propulsion System Impact
Volume VII	Commercial and Transit AHS Analysis
Volume VIII	AHS Institutional, Societal and Cost Benefit Analysis

DELCO

- A Urban and Rural AHS Comparison
- B Automated Check-In
- C Automated Check-Out
- D Lateral and Longitudinal Control Analysis
- E Malfunction Management and Analysis
- I Impact of AHS on Surrounding Non-AHS Roadways
- J AHS Entry/Exit Implementation
- K AHS Roadway Operational Analysis
- L Vehicle Operational Analysis
- M Alternative Propulsion Systems Impact
- N AHS Safety Issues
- O Institutional and Societal Aspects
- P Preliminary Cost/Benefit Factors Analysis

Table 1-1. Continued

HONEYWELL

- Malfunction Management Activity Area Report for AHS Health Management Precursor Studies Analysis

MARTIN MARIETTA

Volume I	Executive Summary
Volume II	Maneuver Definition and Functional Requirements
Volume III	AHS System Concept Definition
Volume IV	AHS System Concept Evaluation

(Note: all in one report binder)

NORTHROP-GRUMMAN

- AHS Check-In Activity

PATH

- Overview
  - A Urban and Rural AHS Comparisons
  - H Roadway Deployment Analysis
  - J Entry/Exit Implementation
  - P Preliminary Cost/Benefit Factors Analyses:
    - Volume I Cost/Benefit Analysis of Automated Highway Systems
    - Volume II System Configurations: Evolutionary Deployment Considerations
    - Volume III Electronics Cost Analysis
    - Volume IV Roadway Costs
    - Volume V Analysis of Automated Highway System Risks and Uncertainties
    - Volume VI Review of Studies on AHS Benefits and Impacts
  - F Commercial and Transit AHS Analysis
  - G Comparable Systems Analysis
  - H AHS Roadway Deployment Analysis

RAYTHEON

Volume I	Executive Summary
Volume II	Automated Check-In
Volume III	Automated Check-Out
Volume IV	Lateral and Longitudinal Control
Volume V	Malfunction Management and Analysis
Volume VI	Commercial Vehicle and Transit AHS Analyses
Volume VII	Entry/Exit Implementation
Volume VIII	Vehicle Operational Analysis
Volume IX	AHS Safety Issues
Volume X	Knowledge Based Systems and Learning Methods for AHS

Table 1-1. Concluded

ROCKWELL • Overview • Vehicle Operations Analysis • Malfunction Management and Analysis • Lateral and Longitudinal Control Analysis
SAIC • Legal, Institutional and Societal Issues Related to the Deployment and Operation of an Automated Highway System
SRI • Use of Global Positioning Satellite (GPS) Carrier-Phase Integration for AHS Vehicle Control
TASC • HiVal: A Simulation and Decision Support System for AHS Concepts Analysis
TRW • Alternative Propulsion Systems Impact
U.C.-DAVIS • Automated Construction, Maintenance and Operational Requirements for AHS

- Concerns differ from issues in that not enough detail is credibly known for robust opinions to be debated and, given common intent, for a way to proceed to be negotiated. Concerns may be expressed by directly or indirectly interested parties. They may simply express the sense that similar, but not identical, conditions exist for AHS to some which caused difficulty in another project. A concern requires further study to resolve as a conclusion or issue.

- Conclusions are findings that are supported by analysis and provide guidance and direction to follow-on activities. They are findings which are complete enough to support a milestone or a certification. Conclusions may close out the line of research that they addressed.

- Risks are conclusions that identify potentially negative situations that, if they should happen, could result in system failure or major problems. Risks are managed.

1.2.2 Categorizing Approach in This Document

The category approach in this document views the system as two physical entities—vehicle and infrastructure. In addition, many findings apply to the system as a whole, not just the vehicle or infrastructure; these findings can, in turn, be categorized as systems design, transition, institutional and societal, and cost and benefit. There is a separate section for each of these categories.

1.3 REPRESENTATIVE SYSTEM CONFIGURATIONS

For the PSA to have maximum benefit to the U.S. DOT, some assumptions were made regarding the design of the eventual AHS system configuration. Since the purpose of the PSA was to identify issues, concerns, conclusions and risks, more than one design approach was assumed so that issues and risks of a variety of potential solutions could be examined.

There are many characteristics that distinguish one design approach from another; however, the scope of the PSA did not allow an examination of the full set of variations (this is the task of the NAHSC). Each of the contractor teams conducted their analyses under the influence of a few pre-defined sets of potential AHS system configurations, termed "representative system configurations" (RSCs). The RSCs were designed as boundaries of the major design characteristic categories defined above: for example, one design set could be a system in which there is minimum impact on the infrastructure since existing roadways are used; platoons with close headway are used; most instrumentation is in the vehicle; and most AHS lanes operate at normal speed, but selected lanes are operated at high speeds.

Since the use of the RSCs was only for the PSA, they are defined only to the level of detail needed to perform the analyses.

Throughout the individual activity area studies, the contractor teams applied their research within the framework of RSCs developed by their team or one of the other contractor teams. These RSCs gave the individual activity areas and the overall studies a broad framework from which to investigate issues and risks.

The RSCs used in the PSA are defined in table 1-2. Distinguishing characteristics of each RSC and the contractor team that developed and/or used them is highlighted in the table. The characteristics and the descriptors used in describing them all are defined below:

- Infrastructure Impact - Includes the sub-categories of Passive Infrastructure and Active Infrastructure.. Describes the changes required to implement the AHS. This includes factors such as modification of existing roadways, construction of new roadways and lanes, entry and exit point construction, and land acquisition

- Traffic Synchronization - Includes the sub-categories of Highly Synchronized, Asynchronous Operation, and Mixed. Describes the degree of synchronization of AHS traffic. Highly synchronized systems would encompass concepts such as platooning with short headway, or the assignment of space/time slots on the roadway by a supervisory system. Asynchronous operation would rely on each vehicle to negotiate with adjacent vehicles on an ad hoc basis to perform lateral and longitudinal control.

- Instrumentation Distribution - Includes the sub-categories of Smart Vehicle, Smart Roadway, and Mixed. Describes the degree of distribution of the AHS instrumentation between the vehicle and the roadway. This distribution can range between a system in which virtually all instrumentation is part of the AHS roadway, to a system in which the instrumentation is virtually all on the vehicles and the roadway has little if any instrumentation.

- Operating Speed - Includes the sub-categories of Low, High, and Variable by Conditions.. This refers to the maximum system operating speed up to which the AHS can safely perform.

- Vehicle Classes - Includes the sub-categories of Light and Heavy. Light vehicles include light trucks and vans. Heavy vehicles include heavy trucks and buses.

- Power - Includes the sub-categories of On-Board and Roadway Provided Electric. On-Board implies that the power requirements of the vehicle are supplied by power systems on-board the vehicle. Roadway Provided Electric implies that the roadway provides the power necessary for the vehicle to operate on the automated roadway.

- Headway Strategy - Includes the sub-categories of Single Vehicles Only and Platoons Possible. Single Vehicles Only implies that vehicles are not allowed to form into groups to travel along the automated highways. Platoons Possible implies that vehicles are allowed (or commanded) to form groups of two or more vehicles in which to travel along the automated highway.

- Lateral Control Strategy - Includes the sub-categories of Passive Infrastructure and Active Infrastructure. Passive Infrastructure means that lateral control of the vehicle is accomplished through detection of an infrastructure feature that is not electrically activated, such as a barrier, painted stripes or magnetic nails. Active Infrastructure means that lateral control is accomplished through interaction with an element of the infrastructure that is activated such as embedded wire or roadside beacons.

- Longitudinal Control Strategy - Includes the sub-categories of Rubber Tire and Pallet. Rubber Tire implies conventional vehicle/road interaction where each vehicle travels on its own rubber tires. Pallet implies that individual vehicles are transported on some type of pallet.

- Control Location - Includes the sub-categories of Mostly Vehicle, Mostly Infrastructure, and Combined. Mostly Vehicle implies that the overall control of the AHS system is accomplished mainly through functions performed within the individual vehicles traveling in the system. Mostly Infrastructure implies that the overall control of the AHS system is accomplished mainly through functions performed within the infrastructure. Combined implies that the overall control of the AHS system is shared between functions performed within the vehicles and functions performed within the infrastructure.

- AHS Lanes and Access - Includes the sub-categories of Transition Lane to Parallel AHS, Ramp to Dedicated AHS, and Mixed Partial, and Automated. Transition Lane to Parallel AHS implies that vehicles transition from manual to automated mode and from automated to manual mode through the use of a transition lane parallel and adjacent to an AHS lane. Ramp to Dedicated AHS implies that vehicles enter and exit from the AHS through the use of dedicated AHS ramps. Mixed Partial and Automated implies that vehicles freely transition between automated and partially automated or non-automated operation on the AHS. This includes the concept of individual automated vehicles operating on a non-dedicated AHS together with manually controlled vehicles.

Shaded cells in Table 1-2 indicate characteristics that distinguish the RSC identified by the column heading. Some of the AHS characteristic categories listed above are unshaded for certain RSCs. This indicates that the particular category was not specified in the RSC description.

1.4 ORGANIZATION OF THE REPORT

Section 2 provides an overview of the AHS program and how the PSA efforts fit into it. Section 3 synthesizes the findings that relate to the overall system design and operation; this includes the overall AHS vision, safety, malfunction management, and operations. Section 4 focuses on transition-related findings; these address the evolutionary aspects of controlling vehicles and vehicle types, and the introduction of levels and regional applications of services. Sections 5 and 6 synthesize the major findings that are specifically related to vehicle and infrastructure design and operation, respectively.

The balance of the report deals with specific institutional and societal aspects of AHS such as AHS management, emissions and user acceptance (section 7); and some early thoughts on benefits and costs (section 8).

Appendices contain summaries of the overview reports from the two largest PSA contractor teams, Delco and Calspan. Also included for completeness is a summary of the Interim Results Workshop Discussion and Findings from April 1994. Finally, Appendix D contains a description of the PSA Database.

1.5 REFERENCES

References are given throughout the text. These references provide pointers to work done by specific PSA researchers that relate to the subject issue, conclusion, or concern. The references, while not exhaustive, point to key research that relates to the material. When the material shown is a researcher statement, the material is shown in quotes.

Table 1-2. Summary of Representative System Configurations

AHS CHARACTERISTIC	Battelle	Battelle	Battelle	Battelle	BDM	Calspan	Calspan
	RSC#1	RSC#2	RSC#3	RSC#4		RSC#1 I1 C1 V1	RSC#2 I1 C1 V3
Infrastructure Impact					Using		
High					Battelle		
Low					RSCs		
Traffic Synchronization							
Highly synchronized							
Asynchronous operation							
Mixed							
Instrumentation Distrib.							
Smart Vehicle							
Smart Roadway							
Mixed							
Operating Speed							
Low							
High							
Variable by conditions							
Vehicle Classes							
Light							
Heavy							
Vehicle/Road Interaction							
Rubber Tire							
Pallet							

Table 1-2. (continued)

AHS CHARACTERISTIC	Battelle RSC#1 (con'd)	Battelle RSC#2 (con'd)	Battelle RSC#3 (con'd)	Battelle RSC#4 (con'd)	BDM (con'd)	Calspan RSC#1 (con'd) I1 C1 V1	Calspan RSC#2 (con'd) I1 C1 V3
Power					Using		
On-board					Battelle		
Roadway provided electric					RSCs		
Headway Strategy							
Single vehicles only							
Platoons possible							
Lat. Control Strategy							
Passive infrastructure							
Active infrastructure							
Long. Control Strategy							
Passive infrastructure							
Active infrastructure							
Control Location							
Mostly vehicle							
Mostly infrastructure							
Combined							
AHS Lanes and Access							
Transition lane to parallel AHS							
Ramp to dedicated AHS							
Mixed partial and automated							

Table 1-2. (continued)

AHS CHARACTERISTIC	Calspan RSC#3 I2 C1 V1	Calspan RSC#4 I2 C1 V2	Calspan RSC#5 I2 C2 V1	Calspan RSC#6 I2 C2 V2	Calspan RSC#7 I2 C2 V3	Calspan RSC#8 I3 C1 V1	Calspan RSC#9 I3 C2 V1
Infrastructure Impact							
High							
Low							
Traffic Synchronization							
Highly synchronized							
Asynchronous operation							
Mixed							
Instrumentation Distrib.							
Smart Vehicle							
Smart Roadway							
Mixed							
Operating Speed							
Low							
High							
Variable by conditions							
Vehicle Classes							
Light							
Heavy		segregated, except transitions		segregated, except transitions			
Vehicle/Road Interaction							
Rubber Tire							
Pallet							

Table 1-2. (continued)

AHS CHARACTERISTIC	Calspan RSC#3 (con'd) I2 C1 V1	Calspan RSC#4 (con'd) I2 C1 V2	Calspan RSC#5 (con'd) I2 C2 V1	Calspan RSC#6 (con'd) I2 C2 V2	Calspan RSC#7 (con'd) I2 C2 V3	Calspan RSC#8 (con'd) I3 C1 V1	Calspan RSC#9 (con'd) I3 C2 V1
Power							
On-board							
Roadway provided electric							
Headway Strategy							
Single vehicles only							
Platoons possible							
Lat. Control Strategy							
Passive infrastructure							
Active infrastructure							
Long. Control Strategy							
Passive infrastructure							
Active infrastructure							
Control Location							
Mostly vehicle							
Mostly infrastructure							
Combined							
AHS Lanes and Access							
Transition lane to parallel AHS							
Ramp to dedicated AHS							
Mixed partial and automated							

Table 1-2. (continued)

AHS CHARACTERISTIC	Calspan	Calspan	Calspan	Calspan	Delco	Delco	Delco
	RSC#10 I3 C2 V2	RSC#11 I3 C2 V3	RSC#12 I3 C3 V1	RSC#13 I3 C3 V4	RSC#1	RSC#2	RSC#3
Infrastructure Impact							
High							
Low							
Traffic Synchronization							
Highly synchronized							
Asynchronous operation							
Mixed							
Instrumentation Distrib.							
Smart Vehicle							
Smart Roadway							
Mixed							
Operating Speed							
Low							
High							
Variable by conditions							
Vehicle Classes							
Light							
Heavy	segregated, except transitions						
Vehicle/Road Interaction							
Rubber Tire							
Pallet							

Table 1-2. (continued)

AHS CHARACTERISTIC	Calspan RSC#10 (con'd) I3 C2 V2	Calspan RSC#11 (con'd) I3 C2 V3	Calspan RSC#12 (con'd) I3 C3 V1	Calspan RSC#13 (con'd) I3 C3 V4	Delco RSC#1 (con'd)	Delco RSC#2 (con'd)	Delco RSC#3 (con'd)
Power							
On-board				electric only			
Roadway provided electric							
Headway Strategy							
Single vehicles only							
Platoons possible							
Lat. Control Strategy							
Passive infrastructure							
Active infrastructure							
Long. Control Strategy							
Passive infrastructure							
Active infrastructure							
Control Location							
Mostly vehicle							
Mostly infrastructure							
Combined							
AHS Lanes and Access							
Transition lane to parallel AHS							
Ramp to dedicated AHS							
Mixed partial and automated							

Table 1-2. (continued)

AHS CHARACTERISTIC	Honeywell	Honeywell	Martin Marietta	Northrop	PATH
	RSC#1 Base Configuration	RSC#2 Alternate Configuration			Will vary the fol-lowing highlighted char-acteristics
Infrastructure Impact			Will	Will work	
High			review	within	
Low			RSCs of	other	
			Calspan	RSCs	
Traffic Synchronization			& Delco		
Highly synchronized			and use		
Asynchronous operation			modified		
Mixed			versions		
Instrumentation Distrib.					
Smart Vehicle					
Smart Roadway					
Mixed					
Operating Speed					
Low					
High					
Variable by conditions					
Vehicle Classes					
Light					
Heavy					
Vehicle/Road Interaction					
Rubber Tire					
Pallet					

Table 1-2. (continued)

AHS CHARACTERISTIC	Honeywell	Honeywell	Martin Marietta	Northrop	PATH
	RSC#1 (con'd) Base Configuration	RSC#2 (con'd) Alternate Configuration	(con'd)	(con'd)	(con'd) Will vary the following highlighted characteristics
Power			Will	Will work	
On-board			review	within	
Roadway provided electric			RSCs of	other	
			Calspan	RSCs	
Headway Strategy			& Delco		
Single vehicles only			and use		
Platoons possible			modified		
			versions		
Lat. Control Strategy					
Passive infrastructure					
Active infrastructure					
Long. Control Strategy					
Passive infrastructure					
Active infrastructure					
Control Location					
Mostly vehicle					
Mostly infrastructure					
Combined					
AHS Lanes and Access					
Transition lane to parallel AHS					
Ramp to dedicated AHS					
Mixed partial and automated					

Table 1-2. (continued)

AHS CHARACTERISTIC	Raytheon RSC#1 1) Designated Entry/Exit -- Low Infrastr.	Raytheon RSC#2 2) Continuous Entry/Exit -- Low Infrastr.	Raytheon RSC#3 3) Designated Entry/Exit -- High Infrastr.	Raytheon RSC#4 2a) Continuous Entry/Exit -- High Infrastr.	Rockwell RSC#1 IWSM/BT	Rockwell RSC#2 IWSM/DE
Infrastructure Impact						
High						
Low						
Traffic Synchronization						
Highly synchronized						
Asynchronous operation						
Mixed						
Instrumentation Distribution						
Smart Vehicle						
Smart Roadway						
Mixed						
Operating Speed						
Low						
High						
Variable by conditions						
Vehicle Classes						
Light						
Heavy						
Vehicle/Road Interaction						
Rubber Tire						
Pallet						

Table 1-2. (continued)

AHS CHARACTERISTIC	Raytheon RSC#1 (con'd) 1) Designated Entry/Exit -- Low Infrastr.	Raytheon RSC#2 (con'd) 2) Continuous Entry/Exit -- Low Infrastr.	Raytheon RSC#3 (con'd) 3) Designated Entry/Exit -- High Infrastr.	Raytheon RSC#4 (con'd) 2a) Continuous Entry/Exit -- High Infrastr.	Rockwell RSC#1 (con'd) IWSM/BT	Rockwell RSC#2 (con'd) IWSM/DE
Power						
On-board						
Roadway provided electric						
Headway Strategy						
Single vehicles only						
Platoons possible						
Lat. Control Strategy						
Passive infrastructure						
Active infrastructure						
Long. Control Strategy						
Passive infrastructure						
Active infrastructure						
Control Location						
Mostly vehicle						
Mostly infrastructure						
Combined						
AHS Lanes and Access						
Transition lane to parallel AHS						
Ramp to dedicated AHS					barrier transitions	
Mixed partial and automated						

Table 1-2. (continued)

AHS CHARACTERISTIC	Rockwell RSC#3 VWAM/BT	Rockwell RSC#4 VWAM/DE	SAIC RSC#1 Subordinate Control System	SAIC RSC#2 Autonomous Control System	SAIC RSC#3 Combined Control System
Infrastructure Impact					
High				for segregated	for segregated
Low					
Traffic Synchronization					
Highly synchronized					
Asynchronous operation					
Mixed					
Instrumentation Distrib.					
Smart Vehicle					
Smart Roadway					
Mixed					
Operating Speed					
Low					
High					
Variable by conditions					
Vehicle Classes					
Light					
Heavy					
Vehicle/Road Interaction					
Rubber Tire					
Pallet					

Table 1-2. (continued)

AHS CHARACTERISTIC	Rockwell RSC#3 (con'd) VWAM/BT	Rockwell RSC#4 (con'd) VWAM/DE	SAIC RSC#1 (con'd) Subordinate Control System	SAIC RSC#2 (con'd) Autonomous Control System	SAIC RSC#3 (con'd) Combined Control System
Power					
On-board					
Roadway provided electric					
Headway Strategy					
Single vehicles only					
Platoons possible					
Lat. Control Strategy					
Passive infrastructure					
Active infrastructure					
Long. Control Strategy					
Passive infrastructure					
Active infrastructure					
Control Location					
Mostly vehicle					
Mostly infrastructure					
Combined					
AHS Lanes and Access					
Transition lane to parallel AHS					
Ramp to dedicated AHS	barrier transitions				
Mixed partial and automated					

Table 1-2. (continued)

AHS CHARACTERISTIC	SRI	TRW	TASC	UC Davis
Infrastructure Impact	Will work	Will work	Will work	Will work
High	within	within	within	within
Low	other	other	other	other
	RSCs	RSCs	RSCs	RSCs
Traffic Synchronization				
Highly synchronized				
Asynchronous operation				
Mixed				
Instrumentation Distrib.				
Smart Vehicle				
Smart Roadway				
Mixed				
Operating Speed				
Low				
High				
Variable by conditions				
Vehicle Classes				
Light				
Heavy				
Vehicle/Road Interaction				
Rubber Tire				
Pallet				

Table 1-2. (concluded)

AHS CHARACTERISTIC	SRI	TRW	TASC	UC Davis
	(con'd)	(con'd)	(con'd)	(con'd)
Power	Will work	Will work	Will work	Will work
On-board	within	within	within	within
Roadway provided electric	other	other	other	other
	RSCs	RSCs	RSCs	RSCs
Headway Strategy				
Single vehicles only				
Platoons possible				
Lat. Control Strategy				
Passive infrastructure				
Active infrastructure				
Long. Control Strategy				
Passive infrastructure				
Active infrastructure				
Control Location				
Mostly vehicle				
Mostly infrastructure				
Combined				
AHS Lanes and Access				
Transition lane to parallel AHS				
Ramp to dedicated AHS				
Mixed partial and automated				

SECTION 2

BACKGROUND

2.1 AUTOMATED HIGHWAY SYSTEMS PROGRAM OVERVIEW

The AHS program was initiated in 1992 as part of the U.S. DOT's ITS Program. This program, which is responsive to the guidance contained in the IVHS portion of the ISTEA of 1991, is a major government-industry-academia collaboration aimed at applying advanced technology to the U.S. highway system in order to improve mobility and transportation productivity, enhance safety, maximize the use of existing transportation facilities, conserve energy resources, and reduce adverse environmental effects.

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

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

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

The AHS program responds to that guidance. The objective of the program is to develop an affordable, user-friendly, fully automated vehicle-highway system that has significantly better safety and efficiency of operation, and that enhances the quality of highway travel. The AHS is the first step toward automated vehicle-highway transportation in the twenty-first century, which will be realized through national deployment of compatible AHS systems.

The Federal government has a unique role since the government is not the eventual owner, operator or supplier of the AHS. These will be the roles of the major AHS stakeholders — state and local governments; vehicle, highway and electronics industries; and the system users. The U.S. DOT role is as AHS program facilitator, supporter of longer range research, and representative of the nation's transportation and societal needs.
The program is being conducted as a broad national public/private partnership between the Federal government and an AHS consortium composed of major stakeholder organizations to ensure their participation.

To undertake and manage the Federal aspects of the AHS program, the U.S. DOT established the AHS program office with the FHWA. The program is closely coordinated with the National Highway Traffic Safety Administration (NHTSA) and the Federal Transit Administration (FTA). One specific area of coordination is with NHTSA's program to develop performance guidelines for crash avoidance systems that may serve as the building blocks for major AHS subsystems and components.

2.2 PROGRAM STRATEGY

2.2.1 Public/Private Partnership

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

AHS will be compatible with, and operate within the National ITS Architecture being developed under U.S. DOT’s National ITS Architecture program. The AHS program is linked to and coordinated with this program.

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

The NAHSC is a shared-funding partnership (80 percent Federal funding, 20 percent private funding) that is implementing the AHS program and is providing leadership to the diverse interests involved in solving the nation’s transportation problems using automated vehicle control technology. The PSA studies addressed in this document are a set of independent studies which have given the consortium a head start in its activities. The PSA studies supplement earlier, as well as on-going, research into automated vehicle control.

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

2.2.2 Objective Decision-Making a Key

The selected AHS approach is being chosen collaboratively by the members of the consortium in concert with the U.S. DOT, with full consideration of all interested parties and their needs and concerns.

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

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

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

Once the preferred AHS system approach has been identified, a prototype of the system will be thoroughly tested to ensure its viability, and to refine the design for optimum safety and performance. At that point, the system will be specified so that contractors can design products for one or more AHS tests in operational environments.
Operational tests involving the public will show how well the AHS works under real operating conditions, and provide the basis for credible assessments of the robustness, ease of use, safety and efficiency, and public support for the system. They will also provide an indication of the extent to which the AHS can integrate into existing institutional, technological, and regulatory environments. Hence, test deployments will likely include regional solutions to urban corridor congestion (for which an accelerated AHS deployment could become a key strategic element), management of commuter flows, and other opportunities where analysis shows high potential benefits from the AHS.

2.2.3 Open Competition

The selected system will be specified to such a level that: (1) there is compatibility among all AHS systems installed throughout the nation; (2) the safety and robustness of all AHS systems in the Nation can be ensured; and (3) no single entity, industry, or company will have a monopoly, and all industry will be able to compete fairly with their AHS products.
Thus, the AHS deployment and operation will encourage healthy competition among companies for all aspects of the system, including vehicle electronics, roadway equipment, and perhaps even ownership of the roads themselves. In this way, the AHS program can help meet the ISTEA goals of establishing a significant presence in this emerging technology by establishing a broad technology base upon which to build the U.S. AHS system as well as provide AHS capabilities worldwide.

2.3 PROGRAM APPROACH

The AHS development program is broadly structured in three phases, as shown in figure 2-1. The Analysis phase, much of which is completed or near completion, is establishing the analytical foundation for the Systems Definition Phase of the program. The Analysis Phase consists of: (1) a human factors study, (2) multiple PSA studiesaddressing AHS requirements and issues, and (3) collision avoidance analyses to investigate avoidance-oriented vehicle warning and control services that may someday evolve into the AHS. The Systems Definition phase is being carried out by the NAHSC. The milestones of the consortium program are: (1) establishment of performance and design objectives; (2) a 1997 proof-of-technical feasibility demonstration; (3) identification and description of multiple feasible AHS system concepts; (4) selection of the preferred AHS system configuration; (5) completion of prototype testing; and (6) completion of system and supporting documentation. The Operational Test and Evaluation phase, which follows the Systems Definition phase, will include: (1) integrating the preferred AHS system configuration into the existing institutional, technological, and regulatory environment; (2) evaluating this configuration in a number of operational settings; and (3) establishing guidelines by which U.S. DOT will support AHS deployment.

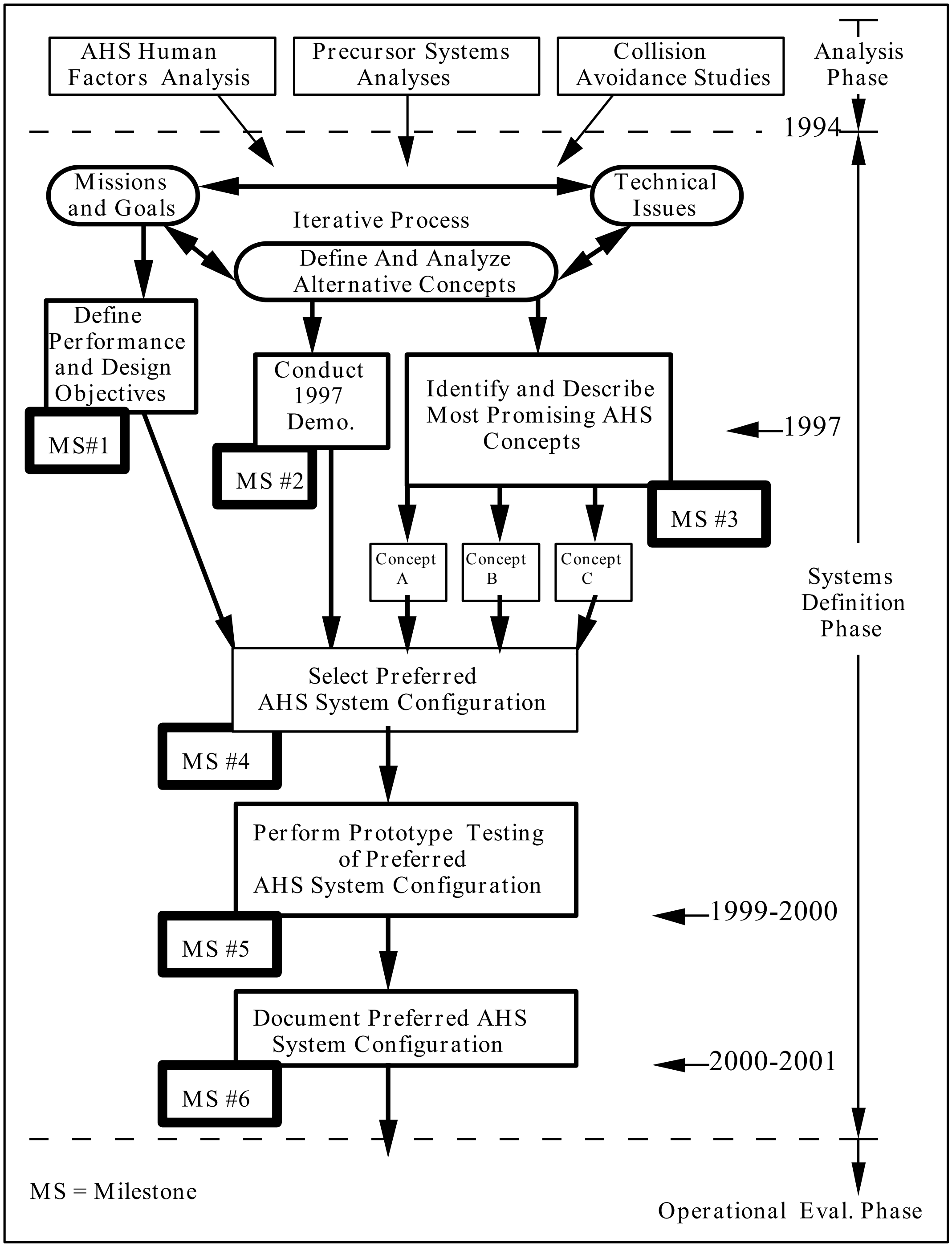

Figure 2-1. AHS Program Strategy

Following successful operational evaluation, U.S. DOT will begin support for the deployment of AHS systems across the nation.

The program encompasses passenger cars and light utility vehicles, heavy trucks, and transit (local and inter-city) vehicles, either intermixed or in dedicated lanes. The thrust of the research is towards fully automated control systems; however, partial control systems, such as adaptive cruise control (ACC), lane keeping, and other important spin-off collision avoidance systems, will be incorporated as the evolutionary stepping stones to a fully automated AHS.

2.4 PRECURSOR SYSTEMS ANALYSES PROGRAM DESCRIPTION

As part of the Analysis Phase, the FHWA awarded 15 PSA research contracts totaling $14.1 million to investigate the issues and risks related to the design, development, and implementation of AHS. These contracts of twelve to eighteen months duration, were awarded during the period July through September 1993, based on a Broad Agency Announcement (BAA) issued by FHWA in November 1992.

The 15 PSA contracts focused upon 16 activity areas that were defined in the original BAA. These activity areas are described in table 2-1. Table 2-2 provides details on the individual contractors and the activities they are addressing. Table 2-3 is a list of contractors and subcontractors for each contract team.

Several of the activity areas were addressed by more than one contractor (see table 2-2). This overlap added value to the overall body of research, in that each discrete effort provided a different perspective and emphasis in identifying and analyzing issues and risks. Furthermore, two teams, Calspan and Delco, were selected to address all 16 activity areas. These teams generated additional insights into the issues because of the extensive interdependencies across the activity areas, which are addressed most effectively within a single contract team. The perspectives and experience of Calspan and Delco were highly complementary, with Calspan providing a broad systems analysis and Delco providing added analysis from the perspective of the vehicle industry. Additional vehicle industry insights were gained by subcontractors on the various teams, including Daimler-Benz and the Ford Motor Company as part of the Raytheon team.

The perspectives and experience of the highway engineering profession was crucial to this research. Transportation consultants were well-represented within the contract teams performing the highway-based analyses. In addition, frequent contact was made with State and local highway officials in order to gain feedback on issues such as AHS deployment, operations and maintenance, and network-wide impacts. In particular, the Calspan team included several State-level transportation agencies for this purpose.

These analyses also benefited from the experience and expertise of the defense industry, as several of the contractors selected have had extensive involvement with complex defense systems on the scale of an AHS. For example, Martin Marietta is the system integrator for the United States Department of Defense (U.S. DOD) Demo II project involving autonomous ground vehicles for military applications.

There are four efforts shown in the "Other" column in table 2-3. The Raytheon team investigated the application of Knowledge-Based Systems to AHS requirements, and the Rockwell team proposed an evolutionary scenario. SRI investigated the application of the Global Positioning System (GPS)

Integrated Carrier Phase techniques to vehicle position monitoring, and TASC performed an analysis of the feasibility of integrating existing models in diverse areas such as vehicle dynamics, sensor characteristics, traffic flow, and environmental factors into a single modeling framework to enable researchers to evaluate high-level AHS concept alternatives.

At this early point in the program, it was felt that all major issues pertinent to AHS needed to be identified and addressed. This group of PSA researchers provided a broad range of perspective and expertise across both industry and government, in order to meet this objective.

The PSA analyses were meant to be conducted in a highly interactive and collaborative environment. By creating an atmosphere of collegiality among the individuals performing the research, the program benefited substantially from the resulting synergy. As a key part of this collaborative approach to the work, FHWA sponsored an Interim Results Workshop in April 1994 for the researchers to meet and share results with a wide array of invited transportation and technology professionals also participating to offer insight and perspective. In fall 1994, at the conclusion of all the contracts, FHWA sponsored a second conference to present final results. To further enhance this interactive approach, many of the interim research results were posted on the IVHS America Information Clearinghouse, which is an electronic bulletin board used by IVHS America members. A special section, called the AHS PSA Forum, was set up on the Clearinghouse for this purpose. Contract researchers used this means to review each other's work, and to gain insight into areas that they may not be directly addressing. This forum was also open to all users of the Clearinghouse to review and comment on the ongoing research.

Table 2-1. PSA Activity Areas

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

Table 2-2 AHS PSA Contracts and Activity Areas

Contractor	a urbn rurl	b auto ckin	c auto ckou	d lat long	e malf mgm	f com trnst	g cmpr sys	h rdwy depl	i ahs impt	j ntree exit	k rdwy anly	l vehl anly	m alt prop	n safty issu	o inst socl	p cost bnfit	q Othe
Battelle	λ		t		t λ			y χ	λ	λ	λ			λ	λ		
BDM						λ									λ		
Calspan	λ	λ	λ	λ	λ	λ	λ	λ	λ	λ	λ	λ	λ	λ	λ	λ	
Delco	λ	λ	λ	λ	λ	λ	λ	λ	λ	λ	λ	λ	λ	λ	λ	λ	
Honeywell		λ	λ		λ		λ										
Martin				λ													
Northrop		λ															
PATH	λ						λ		λ						λ		
Raytheon		λ	λ	λ	λ	λ				λ		λ		λ			λ
Rockwell				λ	λ							λ					λ
SAID															λ		
SRI																	λ
TASC																	λ
TRW												λ					
UC Davis										λ							

Table 2-3. List of Other Contract Team Members

Battelle Team
- BRW
- Massachusetts Institute of Technology
- Ohio State University
- Transportation Research Center

BDM Team
- Cambridge Systematics, Inc.
- George Mason University
- SNV
- Sverdrup Civil, Inc.

Calspan Team
- BMW
- Dunn Engineering
- Farradyne Systems, Inc.
- Parsons Brinckerhoff
- Princeton University
- TRANSCOM
- Connecticut Department of Transportation
- Massachusetts Department of Transportation
- New Jersey Department of Transportation
- New York State Department of Transportation
- New York State Thruway Authority

Delco Team
- DMJM
- Hughes Aircraft Company
- University of California (PATH)
- General Motors Corporation

Honeywell Team
- Purdue University
- University of California (PATH)

Martin Marietta Team

Northrop Team
- PATH

PATH Team
- Bechtel
- California Department of Transportation
- California Polytechnic State University
- Lawrence Livermore National. Laboratory
- University of Southern California

Raytheon Team
- Daimler Benz
- Ford Motor Company
- Georgia Institute of Technology
- Tufts University
- University of Southern California
- VHB

Rockwell Team
- University of California (PATH)
- Systems Technology, Inc.

SAIC Team
- McDermott, Will & Emery
- McGuire, Woods, Battle & Booth

SRI Team

TASC Team

TRW Team
- California Polytechnic State University

University of California. Davis Team
- California Department of Transportation

SECTION 3

SYSTEM-RELATED FINDINGS

The purpose of this section is to provide a system-oriented perspective of the AHS that is based upon the accumulation of the AHS research findings. System-oriented refers to those aspects of the system that users will view and consider as they think about AHS; and those aspects of AHS that cut across all of the system components. Additional summary-level conclusions, issues, risks, and concerns relating to this area can be found in the appendices.

3.1 THE BROAD SYSTEM VISION

The application of technology to the highway is a recent, but logical and important addition to the information technology revolution. The premise of the AHS is to use modern micro-computers, sensors, and communications to solve one of the nation's largest highway transportation problems--the human limitations of the drivers. An AHS addresses these problems by automatically controlling vehicles on selected lanes of interstate highways and freeways.

Most of the PSA research concluded that an AHS--marrying these modern technologies with our highways--may dramatically impact our nation's vehicle-highway transportation system by improving the safety and efficiency of highway travel for a broad spectrum of transportation users including passenger vehicles, heavy trucks, and transit vehicles, and by reducing emissions from highway travel. Projections of double or triple the safety and efficiency of today’s highways were made by several of the researchers (Calspan, Delco, Raytheon). This affect would be comparable to the impact the jet engine had on aviation 40 years ago, or the changes that word processor systems had on the office 15 years ago.

A broad concept of AHS operation is illustrated in figure 3-1. To use AHS, drivers of vehicles that are equipped for AHS pull onto special, designated lanes--perhaps similar to today's High Occupancy Vehicle (HOV) lanes--where control of the vehicle's forward and sideways movement is assumed by the system. The assumption of control could be somewhat similar to how the "cruise control" feature on today's vehicles assumes control of the vehicle's throttle. With AHS, control of the vehicle's braking system will also be assumed so that it can keep a safe distance from the AHS vehicle in front. And control of the vehicle's steering will be assumed so that the vehicle is kept in its lane. The driver can request an exit or an emergency stop as the vehicle travels on the AHS lane, but the driver cannot assume control. When the vehicle reaches the exit selected by the driver, the vehicle is moved into a transition area where the driver again assumes vehicle control and continues driving on his trip.

The AHS will not be implemented as a separate, free-standing system, but rather as an incremental supplement to the vehicle-highway system. AHS deployments may begin as early as the second decade of the twenty-first century. The areas chosen for initial AHS deployments will be those in which AHS will have a major, positive impact. As the value of

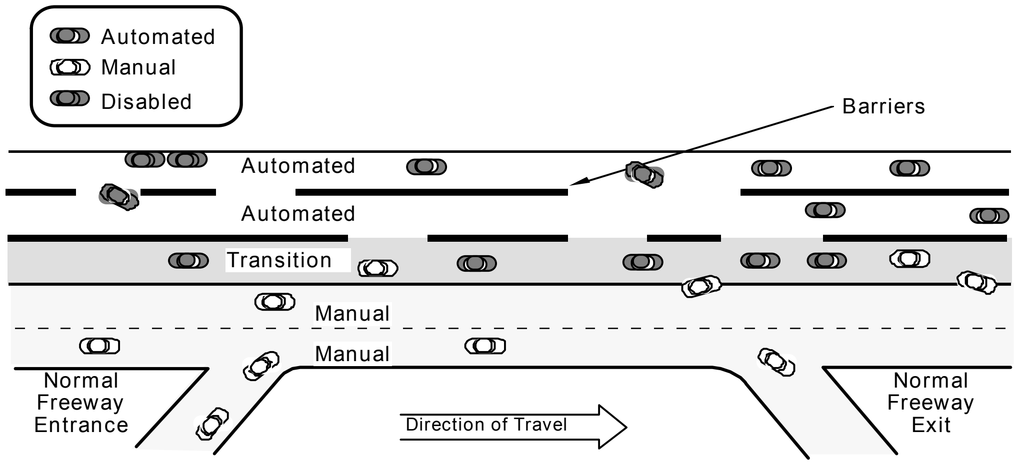

Figure 3-1. Illustration of AHS Concept of Operation (Honeywell, 1994)

AHS becomes apparent to other localities, then the number and variety of AHS deployments will expand, and a national system of AHS roadways will develop. Users will travel cross-country with AHS.

To put this AHS expansion into perspective, it took over 30 years to build the Interstate Highway System. By 1970, travel in the U.S. without the Interstate was unthinkable for many travelers; similarly, at some point in the twenty-first century, vehicle-highway travel without AHS capabilities may be unthinkable for many.

There will be national standards for AHS implementation and operation, but within a region, the AHS will be integrated with the region’s other transportation systems and will be tailored by state and regional transportation planners to meet their community's needs. Tailoring of AHS can be extensive since AHS technology can be adapted to a wide variety of transportation services. An AHS system can be designed to support any four-wheeled vehicle, either intermixed or on exclusive lanes, in a widely varied array of highway configurations in a full range of weather conditions. Some examples include:

- Heavily Congested Urban Highway.: AHS lanes could be implemented to alleviate the daily congestion found on many of the nation’s urban highways. The primary focus of these lanes could be to service the recurring congestion during morning and evening peak periods and beyond.

- Exclusive Transit Vehicle Lanes. Separate lanes could be set up for transit vehicles on certain highways; for example, a reversible express bus lane could be established on a major artery in a large urban area. AHS technology would allow the vehicles to operate more efficiently and safely, and with greater trip predictability; the exits could correspond to parking lots and/or to terminal points for local transit vehicles. Buses could function as rail systems in congested and/or constrained areas (e.g., pull close to loading platforms), but have the flexibility of a normal local bus system on non-AHS roads (BDM, Coogan).

- HOVs Only in Rush Hour. The transportation planners could decide that only vehicles with multiple passengers, including transit vehicles as well as van-pool and car-pool vehicles, could use the AHS lane(s) in rush hour. Perhaps these same AHS lanes could be used for commercial vehicles in off-peak hours.

- Exclusive Commercial Vehicle Lanes. In areas of high truck traffic such as between major east coast cities, separate lanes could be established for the heavy vehicles; as with the transit vehicle lane, the AHS technology would ensure safe, efficient movement of goods with far greater trip predictability. The entry and exit lanes could be located at distribution centers and intermodal docking facilities. Many of the heavy vehicles would be moved off of the passenger vehicle lanes.

- Dense Urban Areas. In a major urban, non-attainment area, the transportation planners could decide to limit center-city access on AHS to vehicles with alternative fuel sources, and/or of limited size; non-AHS roadways would be used by all other vehicles. Such a policy, albeit extreme by today's standards, could be supported with AHS technology.

- Passenger Vehicle Evolution. As more and more drivers use two of the early vehicle control services -- ACC and Lane-Keeping--the transportation planners could recommend to dedicate a separate lane to these vehicles so that some benefits of higher safety are realized.

- Sparse Rural Areas. AHS-equipped vehicles on rural roadways may operate intermixed with non-AHS vehicles by essentially operating as ACC and Lane Keeping services. The system would still maintain a safe distance from the vehicle in front, and it would keep the vehicle in its lane. The driver would need to stay alert, and could choose to turn the AHS service on or off as desired.

- Driverless Transit and Commercial Vehicles. AHS technology could be used to control driverless shuttle vehicles such as those at some of today's airports; these shuttles are, in fact, using technologies similar to AHS. It is conceivable that at some time in the future, these driverless vehicles could continue their travel on the AHS network. This would allow airline passengers, for example, to be taken directly to the central business district by the driverless shuttle. Similar shuttles for connecting intermodal freight terminals could also offer potential advantages.

3.2 OPERATING PARAMETERS

3.2.1 Travel Lanes

The operating parameters of an AHS will include specific directions to vehicles on the AHS The parameters will give directions to the vehicles in a zone or segment regarding factors such maximum speed, minimum space to the vehicle in front, platooning parameters if the system is operating with platooning, weather conditions (e.g., icing ahead--this may allow the vehicle to shift into four-wheel drive or to adjust suspension), braking or longitudinal and lateral movement profiles to follow to avoid an incident or situation ahead, and traffic conditions ahead (e.g., the requested exit is congested and/or closed).

During rush hours, the most congested part of the system should operate at the optimum speed and spacing for maximum throughput; once the system is “filled,” then no additional vehicles should be allowed to enter (i.e., squeeze a few more in) since that will slow the system down and reduce total system throughput. It appears that these optimum conditions are in the range of 80 to 100 kilometers per hour (km/h) with around 15 meter spacing if there is no platooning (Calspan), or one to three meter spacing if there is platooning (PATH). It can be envisioned that during certain situations, the system would operate below this optimum speed and spacing for benefits to the overall transportation network (e.g., special events to keep ramp queues from blocking lanes). In off-peak periods, the system could operate at the maximum system speed.

Maximum throughput (maximum number of vehicles per lane per hour) is achieved using platooning; that is, a serial cluster of vehicles (e.g., two to twenty) operating at very close spacing (e.g., one to three meters). Depending on the frequency of entry and exit points, and the characteristics of the vehicles and highways, platooning can achieve throughput rates of up to 6,000 vehicles per hour per lane. Throughput for non-platooned vehicles under similar conditions would be closer to 4,000 vehicles per hour. Of course, both rates represent a significant improvement over freeways with manual drivers where 2,200 vehicle per hour is maximum, and the actual sustainable average throughput is less than 2,000 vehicles per hour.
In uncongested conditions and dry weather, the maximum speed for each segment of a system will be determined by roadway topology, the maximum safe speed of the vehicles allowed onto the system, community acceptance and the acceptability to the system users. This speed could be 150 km/h or higher in some systems. In these circumstances, the spacing between vehicles could be spread beyond the safe distance if this policy were appealing to the users. This means that the AHS system must be designed to accommodate vehicles and highways capable of operating at 150 km/h or higher.

To avoid the creation of an incident, and/or the worsening of an existing incident, the weather, adhesion, and traffic flow conditions of the roadway must be known by the AHS traffic control function on a continuous basis. The location of the sensors to detect these conditions may vary depending on the AHS concept’s architecture. For example, icing conditions on road surfaces and bridges could be detected by sensors on the infrastructure; additionally, actual loss of traction could be instantaneously detected by the individual vehicles and transmitted to the roadside for broadcast to other approaching vehicles. Traffic flow and loading will be sensed by the roadside. Occurrences of incidents will probably first be broadcast by the vehicles involved; although crashes, unplanned slowdowns and roadway obstacles could be detected by roadway sensors in heavily congested areas.

3.2.2 Entry and Exit

Control of access and egress for AHS will be performed at the entry and exit points. The AHS traffic management function will adjust parameters for AHS entry based on current traffic conditions and current demand for AHS services. During off-peak or uncongested conditions, entry parameters to the AHS may be as simple as finding the appropriate slot and entry speed into the traffic flow. However, during congested periods, the AHS traffic management function should meter vehicles onto the AHS travel lane using logic similar to today’s ramp metering (Calspan/Dunn Engineering). This will ensure that users near the congested areas have as much opportunity to enter the AHS as those in outlying areas (and as today, those in outlying areas may protest that they are not allowed to enter even though there are openings). These metered AHS entry ramps will need the ability to stop and provide buffer storage for the waiting vehicles (Delco/DMJM, Battelle/BRW). It also means that vehicles attempting to enter a ramp where “buffer capacity” has been reached will be rejected. This, too, may cause complaints.

Initially, users attempting to enter a congested AHS may have an added frustration because their perception will be that the AHS has "plenty of room" when it is operating at optimum capacity. The AHS traffic will be flowing at a constant, fast speed, and spacing between vehicles will be even. It may not be apparent that adding more vehicles to the AHS lanes would actually slow the total traffic flow.

At these congested periods, the operating parameters given to these accelerating vehicles may need to consist of very specific acceleration, speed and movement profiles to ensure merging of the vehicle with the main traffic flow without slowing the flow down (Calspan, Delco, Raytheon). Depending on the system's sophistication, this acceleration profile could vary by vehicle (a Corvette versus a Sprint or tractor/trailer rig); if not, then the profile will be the one that the lowest-performance vehicle can meet (a fully-loaded Sprint?). As addressed in section 6, the system's entry ramp should be long enough to allow the acceleration of the least powerful vehicle to travel lane speed. This could mean that heavy vehicles would only be allowed to enter AHS at certain entry points (Delco/DMJM, Calspan). Delco pointed out that this could also mean that vehicle owners will be responsible for ensuring that their vehicle is capable of its normal acceleration rate (e.g., they have not overloaded it and it is running smoothly). Under operational concepts that use "normal length" entrance ramps, trucks (and other lower performance vehicles) could be allowed to enter the traffic flow at slower speeds under certain conditions (e.g., during off-peak hours) before ultimately reaching the system's targeted vehicle operating speed.

3.3 SYSTEM SAFETY

The U.S. DOT goal is for the AHS to be a very safe system. It is believed that this can be accomplished by eliminating driver-caused accidents for vehicles operating in the dedicated AHS lanes. Given that today's number of vehicle and system failures and external intrusions remains constant, the AHS should improve the safety of highway travel by 50 to 80 percent on AHS facilities (Calspan). Specific U.S. DOT safety goals include the following:

- Eliminate driver error by providing full vehicle control while it is in an AHS lane.
- Allow no collisions under normal operation (i.e., when there is no AHS malfunction).
- When there are incidents caused by AHS malfunctions or other factors, the AHS will, based on fail-soft and fail-safe designs;
  - Minimize the number of crashes that occur.
  - When crashes do occur, minimize their severity.

A broad, top-down safety analysis of the AHS system was conducted by Battelle in which the system threats were identified. This analysis can form the basis for continued, systematic AHS safety analysis. A thorough analysis was also conducted by Calspan regarding the types of crashes that occur on today's highways, and the potential reductions that could result from AHS (Calspan).

3.3.1 Level of Acceptable Risk

There are design and engineering trade-offs that must be addressed regarding the system safety. With almost any design approach that meets the U.S. DOT goals, the AHS will be far safer than today's highways or the state-of-the-art highways designed for manual vehicle control in the next century. But even so, a system can meet the U.S. DOT goals and still have crashes, albeit infrequently.

The issue is: what level of safety will the public expect from an automated highway? Will the public accept a system designed so that when a rare event happens, injury or death may be a consequence? The issue could be restated as what will the public's perception of AHS safety be?

Several researchers studied perceived versus actual safety (Battelle, BDM, Calspan, Delco). Today, the vast majority of drivers choose to travel in their vehicles without giving any thought to the 100 or more fatalities on the highways daily, or the thousands more per day that are seriously injured. Many of us have known someone who has been killed in a vehicle crash, and the large majority have been in a crash where there has been, at the least, property damage. Yet, the typical American will still choose to travel by automobile, sometimes in preference to airline travel, which statistically can be shown to be an order of magnitude safer than vehicular travel. Many Americans fear air travel--showing crash statistics to these people has no affect on their feelings.

The researchers' findings showed that the public's perception of AHS safety will be influenced by several factors. All agreed that AHS safety must be a given; that is, the public must feel as safe on AHS as climbing on-board a transit train or driving onto a freeway. If drivers' perception of AHS is that it is not as safe as the system they are used to, many will not use AHS, regardless of its advantages.

Researchers made some suggestions to avoid the reaction that some people have to air travel (Battelle, BDM, Delco, Calspan, Raytheon):

- Initially, highway automation (AHS) must be viewed as a logical extension and upgrade of the vehicle-highway system, not as a separate, high-tech system; it should not be over-sold.

- Under no circumstances should AHS be designed to allow a catastrophic (e.g., 20 cars with multiple deaths) crash, regardless of how infrequently it might happen.

- The AHS must not scare people; if some people are very uncomfortable with either very high speeds or very close spacing, then their apprehension will cause them to view the system with suspicion; then when a crash does occur, their suspicion will be "justified." As the system matures and people get used to the system, higher speeds and closer spacing (within safety bounds) may become more acceptable.

- AHS should be designed so that fender-benders are far less frequent then on the manual lanes; if the risk of a minor crash is so high that everyone knows someone who was in one, then distrust of the system will grow.

3.3.2 Safety Critical Functions

This area of research addressed what level of safety is attainable and sustainable within a realistic cost. Researchers (Calspan, Delco, Honeywell, Raytheon, Rockwell) identified the safety-critical functions of the system; that is, those functions whose failure might cause a safety degradation of the system. The analyses extended to the likelihood of failures of these critical functions and design approaches, such as redundancy, for reducing the probability of failure.

Studies showed that most system malfunctions would not result in safety concerns (see malfunction analysis below). A braking system failure in which braking capability is lost, could cause a crash if the vehicle in front of it slows or stops. If a rear-end crash occurred, property damage and personal injury could occur; death is less likely in rear-end crashes (Calspan). Most agreed that the more serious failure would be loss of steering, particularly if the steering failed in either a hard-left or hard-right position. This failure would cause a sudden lane change and a crash with either a barrier or a side collision with another vehicle. More serious injury or death would be likely. As with today's vehicles, either one of these types of failures is extremely unlikely (see Battelle and Calspan for failure analyses). And with required periodic inspections of AHS-capable vehicles, and with assessment of vehicle status at check-in, the likelihood of these kinds of failures becomes even less on AHS

A third kind of safety-related malfunction was defined for a system in which vehicle control was accomplished by roadside processing. In this kind of system, the communications link to the vehicles becomes safety-critical; redundancy and fail-soft design would be needed to deal with communications and processing failures.

The analysts agreed that redundant design of the safety-critical functions as well as those functions that would cause AHS traffic flow to stop would make sense. It was also shown that by using triple redundancy of the most critical functions, and by extending the distance between vehicles to allow "brick wall stopping" (i.e., if a ten ton safe falls in the road, the following AHS vehicle could stop without hitting it), virtually all crashes could be eliminated--Calspan, Delco. Most researchers felt that this extreme safety design is unwarranted because system cost would be driven up significantly and the number of crashes that would be eliminated would be very small (e.g., brick wall stops are extremely unlikely on any freeway, but particularly on the AHS). Calspan showed that the impact of a brick wall stopping policy on AHS would be to make it <u>less</u> efficient than today's highways.
Any heavy braking on AHS raises concerns about the relative braking capability between leader/follower vehicles; that is, can a collision be avoided if the leading vehicle has stronger braking capabilities than the following vehicle? Figure 3-2 illustrates that the gap that would need to be maintained between two vehicles varies significantly as the braking capabilities of the two vehicles vary; for example, if the lead vehicle is capable of braking at a 1.2 g rate (e.g., a sports car), and the following vehicle can only brake at a .72 g rate (e.g., a fully-loaded sub-compact), then at 100 km/h (62 mph), the inter-vehicle gap would need to be 37 meters (120 feet) to avoid the following vehicle from hitting the lead vehicle. Two strategies are (1) the lead vehicle never brakes at a rate greater than the weakest braking profile of the system except in an emergency; or (2) the following vehicle is given the lead vehicle's maximum braking capability, and adjusts its gap accordingly. The remaining issues to be
researched are (1) how well can any vehicle know its braking capability at any given point in time; and (2) how accurately can a vehicle be expected to follow a deceleration profile?

A safety concern was raised regarding platooning. When there is an incident, small-impact (i.e., low delta-velocity) collisions among the platooned vehicles can occur. At the least, drivers would be upset; but some researchers expressed concerns that slight off-setting angles of the vehicles in a string of low-velocity impacts could cause vehicles behind the third or fourth vehicle to crash with the barriers, and might cause significantly greater damage. More importantly, platooning opens the system to a potential "catastrophic crash" in which multiple fatalities in multiple vehicles occur. This would happen if a "brick wall" stopping
condition were to suddenly occur on the AHS lane in front of the platoon; for example, if a tractor-trailer from an adjacent lane were to break through the barrier separating the AHS from the non-AHS lanes, or if an earthquake were to cause a bridge to collapse on the roadway. As with the airline industry, even though statistics might show that overall, AHS is significantly safer, the publicity of a catastrophic crash would damage the reputation of AHS With an operating strategy where vehicles

are evenly spaced at around 15 meters, a brick wall stop would still be disastrous for the first two vehicles, and perhaps the third. One conclusion was that if platooning is used at all, it might be only during the peak periods in heavily-congested urban areas. At other times, an evenly-spaced vehicle strategy might offer the greater system safety and user comfort.

3.3.3 Outside Intrusions

All researchers agreed that the primary AHS safety concern is "outside intrusion;" that is, vehicles, objects or forces that intrude into, and impact the AHS. An intrusion could include crashes in near-by lanes that intrude onto AHS lanes, animals that jump into the lane, natural events such as earthquakes, and vandalism.

Given that the minimum set of Federal AHS safety design standards (yet to be determined) are met, the extent to which a deployed system includes added protection against certain types of outside intrusions will need to be decided locally. For example, PATH showed that crashes on near-by freeway lanes would be one of the leading causes of AHS crashes on one Los Angeles freeway; for this reason they recommended that barriers separate the AHS lanes from the manual lanes in circumstances like that. Battelle/BRW showed that deer are one of the major causes of crashes in rural Minnesota; fences or sensors to detect the presence of animals might be needed in some rural locations. Earthquake-prone areas (e.g., San Francisco peninsula) could include earthquake sensors or operating procedures to halt traffic flow in an earthquake.

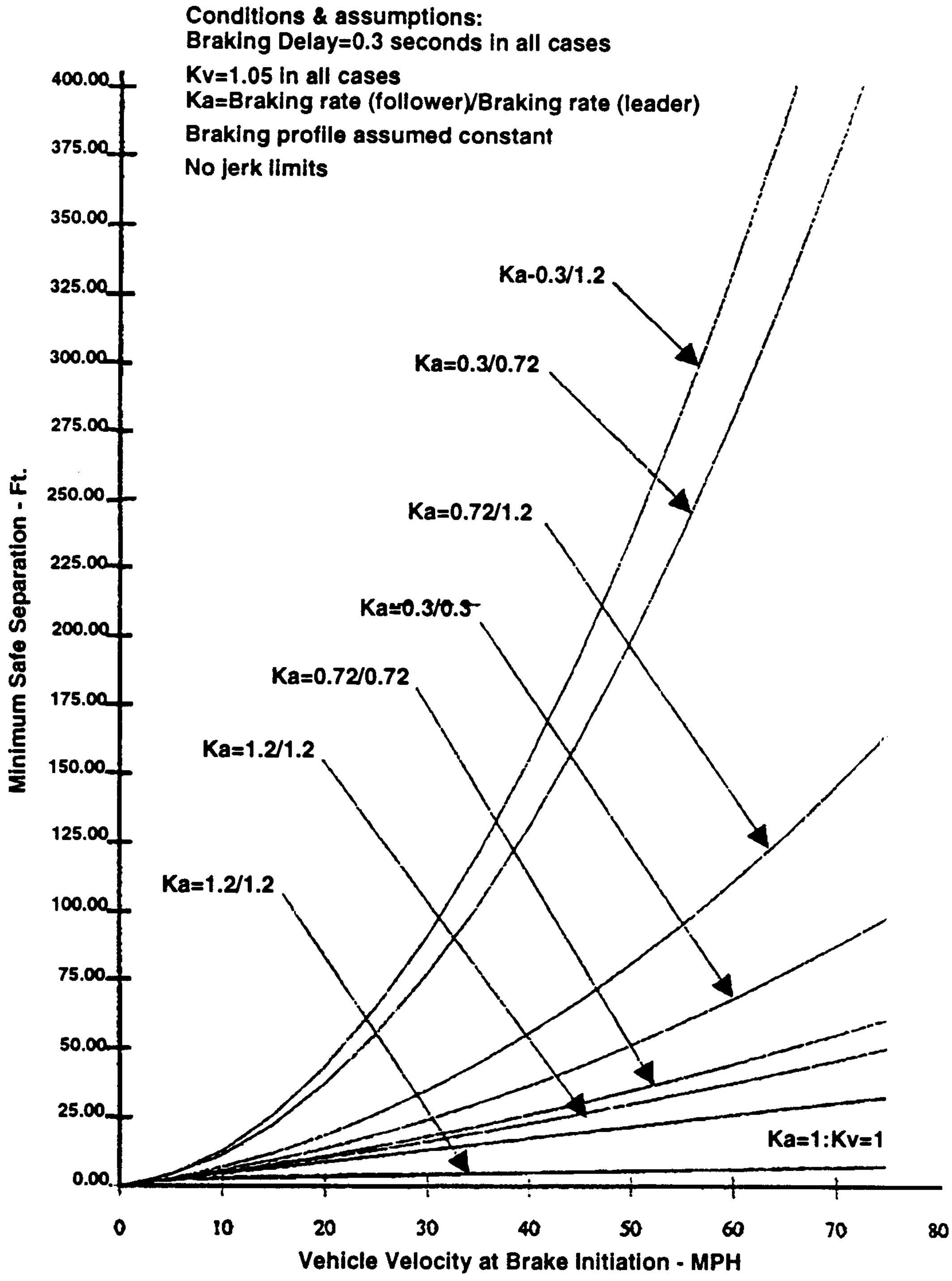

Figure 3-2. Minimum Separation Requirements Between Vehicles with Different Stopping Capabilities (Battelle)

3.3.4 Safety Impact on Non-Automated Highway Systems Driving

One concern is the effect that AHS travel will have on drivers when they leave the AHS. The most obvious is the driver who is drowsy after a long period of in-attentiveness on the AHS and who is alert enough to resume control of the vehicle, but may not be alert enough to suddenly be faced with heavy manual freeway traffic. Another concern is that drivers might become accustomed to the higher speeds and closer spacing of AHS and have a tendency to drive that way on the manual roadways.

Both are areas that need further research.

3.4 SYSTEM MALFUNCTIONS

Because of some of the projected high densities of traffic that may be handled by an AHS, any incident that results in a traffic delay at rush hour will become a major incident. Thus, the number of incidents that occur must be held to a minimum, and the response time to any incident must be very fast.

Six researchers (Battelle, Calspan, Delco, Honeywell, Raytheon, Rockwell) addressed the kinds of malfunctions that are likely to occur in an AHS system. The potential malfunctions were categorized by system component, likelihood of failure, impact severity of the malfunction on system operation, and approaches for managing the malfunctions.

3.4.1 Severity of Malfunctions

The most severe (and least numerous) malfunctions are those that cause system safety concerns, as addressed above. The next most serious malfunctions are those that cause the vehicle to come to a stop in the AHS lane either through braking or coasting (e.g., engine seizes up). The researchers believed that the AHS should be designed to safely accommodate failures of this nature; however, these types of malfunctions must be minimized because they could cause serious delays on the AHS lane. It was concluded that most malfunctions would be one of the following:

- Vehicle slows down until a breakdown lane or exit is reached (e.g., tire losing pressure)
- Vehicle travels at normal speed to the next breakdown lane or exit (e.g., over-heating)
- Vehicle travels to the next exit (e.g., back-up system failure or low fuel)

It was shown that vehicle malfunctions that cause problems on an AHS will be far fewer than today (Calspan, Delco) for a number of reasons:

- If present trends continue, the vehicles of 2020 will be significantly more reliable than today’s vehicles
- AHS will have newer-than-average vehicles--at least for the first 10 years of the system since it is unlikely that older vehicles will be AHS-equipped
- There will be fail-safe or fail-soft design of components whose failure would cause safety or system-slowdown problems

- Most researchers believe that regular inspections of AHS-capable vehicles will be required to ensure proper operation of key functions

- On-board status monitoring and system check-in procedures will provide an instantaneous check of the critical system components

In tuning a system to detect malfunctions, a concern is balancing between optimum system sensitivity to failures and false alarms. For example, if a fuel level sensor indicates a low fuel problem when the tank is half full, then this would be an annoyance of the driver. On the other hand, if low fuel is not indicated until there is only enough fuel to go five miles, then there is a significant risk that the vehicle may end up in a breakdown lane.

3.4.2 Forward-Looking Sensor Failures

The forward-looking vehicle-mounted sensors proposed for most AHS concepts are a vital link in the system operation. It is one of the areas in which there is very little existing data upon which to draw regarding accuracy and reliability. Approaches and technologies have been proposed, and some systems are available today. However, the feeling is that the sensors available 20 years from now will be far more robust. Even so, there are questions regarding just how robust these sensor systems can be, and the extent to which they can be detracted by ground clutter, weather, and/or signals from adjacent vehicles.

System redundancy offers one approach for providing added reliability (e.g., three sensors rather than two). Some feel that a different kind of sensor would provide even more assurance of reliability (e.g., laser based radar as a back-up to radar). Others have suggested that positioning information from an independent source would provide the best longitudinal control back-up. Some technologies suggested include inertial guidance with on-board maps, roadside beacon triangulation, input from surrounding vehicles, and carrier-phase-integrated GPS positioning (SRI).

3.4.3 Software Failures

Software is increasingly becoming a major part of a vehicle’s system control; this trend is expected to continue through the next 20 years. An AHS will significantly increase the amount of software needed on a vehicle; in addition, some of this added software will be safety-critical.

Ensuring software safety is very difficult (Rockwell). Unlike hardware, software cannot always be tested to failure. Software errors cannot be detected unless the testing exactly replicates the conditions that invoke the erroneous code. For larger software systems, the testing time required to do this is unreasonably high.

Formal specifications for software-critical software and rigidly enforced software engineering techniques (including modular design) can help to substantially reduce the number of errors; nevertheless, software with errors will occasionally be fielded.

To account for this, the overall system design must assume that software errors will occur; thus, the overall design must accommodate these errors on a fail-safe design approach so that virtually any software error will cause, at most, system delay but not safety risks.

3.5 MANAGEMENT OF MIXED VEHICLE TYPES

Mixing heavy and light vehicles together on an AHS poses certain problems because of the differences in performance and the perceptions of the drivers and passengers of the light vehicles. Similar, but not as severe problems may arise when electric and/or low performance alternative fuel vehicles are mixed with internal combustion engine vehicles. Below, various aspects of these differences are discussed.

3.5.1 Travel Lanes

Once on the AHS lanes, there are several strategies for dealing with mixed heavy and light vehicles. The most straight forward, of course, is to have a system that is dedicated to either light vehicles or heavy vehicles such as a transit bus system. In rural areas or in new systems where traffic volume does not yet justify separate lanes, mixed traffic can operate on the same lane. If the roadway topology includes steep grades and/or curves, passing lanes could be provided so that the faster-moving traffic is not unduly impeded. In this scenario, spacing between vehicles would need to consider the fact that occupants of light vehicles may find that being too close to the rear of a heavy vehicle is undesirable. Alternatively, the longer stopping distances of heavy vehicles would mean that they must keep a safe spacing from the faster-stopping vehicle in front. If platoons were used in this kind of mixed system, the heavy vehicle traffic can be separated from light vehicles by platoon. For entry to an AHS lane operating with homogeneous platoons, separate entry ramps for the heavy vehicles would allow for more efficient operation.

In theory, the heavy traffic could also be separated from light traffic by time period. For example, an HOV lane could be used for light vehicles only during peak hours, and for heavy commercial vehicles (plus any light vehicles that would choose to use it) during the off-peak hours (Calspan/Princeton). The disadvantage of this particular approach is that heavy transit vehicles would be excluded from AHS during peak hours.

If two or more lanes can be justified, then separately designated light and heavy vehicle lanes could be used. This approach opens up the operating options so the roadway configuration can vary with the traffic conditions. Some of the optional configurations include the following:

- One lane dedicated to light vehicles; the second primarily heavy vehicles or light vehicles transitioning to the light vehicle lane (Calspan, Delco, Battelle)

- The light vehicle lane could be a narrower lane so that less right-of-way is needed to add it; this lighter design should also offer more options for design of fly-over or elevated lanes (PATH)

- The “light vehicle” lane could be designed to handle both heavy and light vehicles to add more flexibility for the operation; this allows the light vehicle lane to be multi-purpose—in normal operation it could operate as a break down and/or passing lane; it could also be used to temporarily store snow and provide a by-pass during road construction and maintenance; in peak hours, it could be used as an HOV lane.

3.5.2 Entry and Exit

As discussed above, the slow acceleration of heavy vehicles will require much longer ramps. Drivers who are behind a fully loaded vehicle that is accelerating onto the AHS will become impatient and frustrated. For these reasons, entry ramps for heavy vehicles may be more infrequent and, where economically justified, exclusive. At the least, separate acceleration lanes could be provided for the heavy vehicles at entry points where both heavy and light vehicles are entering. Depending on the system implementation, these separate lanes could also be tied into other commercial or transit vehicle functions. For example, the commercial vehicle lane could include weigh-in-motion equipment and truck-specific vehicle identification equipment. For transit vehicles, the separate lanes could include passenger loading platforms.

Rural AHS systems with entry points every five or ten miles would probably have entry ramps that would be shared by both heavy and light vehicles since dedicated ramps could probably not be cost-justified. Dedicated heavy-vehicle entry lanes would more likely be justified in denser urban areas and near truck and/or intermodal distribution centers.

3.5.3 Special Vehicles

It is expected that most, if not all, alternate propulsion vehicles on the road in the next 20 years will have basic performance characteristics not unlike the lower-powered internal combustion vehicles of today (Delco, Calspan, TRW). Thus, it may not be necessary to provide special accommodations for them. There are some possible exceptions, however. No major leap forward is expected in battery technology that will significantly impact the marketplace over the next 20 years, so electric vehicles will have constricted speed/distance and hill-climbing performance envelopes. An assessment of an electric vehicle’s reserve power must be made as it enters AHS (a difficult and inexact task); this must then be compared to the known power needs between the entry and the desired destination. This assessment of reserve power is far from an exact measurement; thus, provisions must be made for electric vehicles that are near or at their last energy reserves and are unable to proceed. This could mean special “breakdown” lanes into which electric vehicles could be moved so that they can be recharged sufficiently to continue their trip. In general, however, it is believed that an electric vehicle could probably make most urban commuting trips without incident (TRW, Calspan).

An alternative approach could be roadway-powered electric vehicles that are able to recharge as they move along the AHS lane (Calspan). It was shown that this recharging would only need to occur every few miles (including on upward steep slopes) to extend the envelope of performance of an electric vehicle to be close to an internal combustion engine (300 to 400 miles at normal speeds and grades). Specially designed recharging lanes could be located every few miles. The problem with this approach is that the projected population of electric vehicles, especially those that could be recharged as they move, will be very low for the next 20 years. So dedicating a separate lane for recharging would be difficult--the lane would also need to be useful to non-electric vehicles, too.

It is conceivable that in the next 20 years, a major city could choose to restrict its central business district to specially designed vehicles that are both small (narrow, short) and clean. This would be done to help alleviate problems of pollution, congestion and parking. An AHS system would support such a system very well by allowing very narrow lanes to be built. The AHS lanes could be specially designed, light weight and modular. These narrow vehicles would need to be able to operate on regular AHS lanes as well. If the operational performance of these vehicles were too low, they could dampen the AHS roadway operations of surrounding AHS lanes. An alternative would be that these special vehicles would only operate during certain hours on selected AHS roadways.

3.5.4 Temporary Performance Changes

Vehicles pulling trailers, vehicles equipped with trailer mirrors, vehicles with baggage carriers or bikes on top, etc., could create hazards for the AHS system. The dimensions of the vehicle can be determined at check-in using light beams so that oversize vehicles can be diverted away from the AHS

A larger problem would be those vehicles that temporarily do not meet minimum acceleration and/or braking standards either because they are overloaded or because they are not operationally sound. If the system knows about the changed performance in advance, then it could either reject the vehicle or accommodate it. If drivers with recreational trailers are required to get approval in advance, then the vehicle's identifying characteristics could be temporarily modified so the system would treat it as a heavy vehicle. Another option would be for the system to detect a vehicle's inability to respond to the performance profile it has been given for system entry. In this case, the system can still avoid an incident by slowing other traffic to accommodate the vehicle; however, the driver could be held responsible and be subject to a stiff fine for not maintaining his or her vehicle properly or for not meeting vehicle loading restrictions (Delco).

3.6 MIXED AUTOMATED HIGHWAY SYSTEMS AND NON-AUTOMATED HIGHWAY SYSTEMS VEHICLES

Several of the researchers (Raytheon, Calspan, Battelle, Delco) examined the potential for AHS vehicle operation on non-dedicated AHS lanes; that is, the AHS vehicle would operate under some level of automated control. This mode of operation was examined for these reasons:

- Limited automated vehicle control will soon be available to the public on products such as ACC and collision avoidance; many believe that these services will form an evolutionary path to AHS and that one step along the path to full automation might be an AHS vehicle that provides both lateral and longitudinal control that operates intermixed with manually operated vehicles.

- Initial AHS deployments may well be in urban areas with significant congestion problems; most other roadways will not have the supplemental AHS lane. This will be particularly true in rural areas where there is relatively light traffic. An AHS vehicle that can offer some safety and convenience to drivers on the non-AHS roadway could be a valuable and desired service; for example, an AHS-equipped vehicle could operate as a vehicle with ACC and collision avoidance; and on roadways equipped with AHS lane markers, the vehicle could also provide lane-keeping.

- Some felt that the feasibility of a mixed manual and automated traffic scenario was worth investigating as a possible alternative to fully automated operation.

3.6.1 Mode of Operation

There was considerable discussion about the mode of this "mixed control" operation. It was felt that the user would need to retain control of the vehicle and, for example, be responsible for turn-on/turn-off control in mixed traffic. This was for two reasons:

- The partial control products are expected to evolve this way; that is, as with cruise control, the driver will choose to turn on and turn off the ACC and the collision avoidance features. Similarly, the driver will choose to turn on the lane-keeping feature when he or she enters a section of highway with lane-markers.

- The driver will have responsibility for the vehicle operation, even while these features are on. Because there are still unpredictable manual drivers on the roadway, the driver must be fully aware of the driving process; that is, he or she must (1) be alert for drivers that operate their vehicle dangerously or for other hazardous situations; and (2) be prepared to immediately assume control to avoid these dangerous situations. This is because the level of sophistication needed for sensors and vehicle controls needed in this unpredictable environment is beyond the current state-of-the-art. For example, if a reckless driver cuts off a vehicle under automated control, the vehicle may try to actuate the brakes hard to avoid a collision. It was felt that research in this area is needed.

Operation of a fully automated vehicles on a dedicated roadway is different in that the system assumes control of the vehicle and is responsible for the vehicle movement while on the AHS The system retains control until it is convinced that the driver is prepared to resume control, and the control is transferred. This is possible because the dedicated lane provides a more controlled environment in which full vehicle control by the system can be safely provided. Several researchers believed that this was a much simpler technical problem than mixed traffic. It was pointed out that on those exceptional occasions when a manually-operated vehicle enters the dedicated AHS lane, the system will know and can isolate the AHS traffic from the intruder until the intruded is expelled.

3.6.2 Relative Benefits

The researchers found that in an urban setting, the major AHS advantage of greater throughput could not be realized; the manual drivers would set the pace and tenor of the traffic flow. It was postulated that this would also be true when a non-automated vehicle enters the dedicated AHS lane; that is, the normally-smooth flow of the AHS lane would be disrupted until the intruder is expelled.

Regarding safety, it was felt that there would be some safety benefits from use of the AHS features on a non-AHS road. For example, in rural settings, the lane-keeping aspect of the AHS vehicle should be able to prevent most, if not all, of the run-off-the-road crashes. In an urban area in congested conditions, the safety value of the partial use of AHS features was not as obvious, although some rear-end or side-swipe crashes should be eliminated. Raytheon projected a reduction in crashes of up to 20 percent; the Calspan and Battelle numbers implied crash reductions of up to 30 percent for equipped vehicles.

User comfort in an urban area would probably come primarily from increased peace of mind that the trip is somewhat safer. The driver would not be able to relax because he or she must remain fully aware of the driving situation. In rural areas, the user comfort could be quite high as drivers on long trips are able to relax knowing that a safe distance will be maintained from the vehicle in front, and the vehicle will remain in its lane; however, the driver will need to remain alert for problems such as roadway junk, farm machinery along the roadway that partially intrudes into the lane, vehicles in the on-coming lane that suddenly move into your lane of traffic, etc. A concern was that the driver might be lulled into not giving adequate attention to the roadway and that this, in fact, could cause some additional crashes.

Of particular concern was how to avoid confusing the driver as he or she moves from a dedicated roadway, where the system is responsible, to a non-dedicated roadway where he or she has the responsibility for ultimate control of the vehicle.

Most agreed that more study is needed in this area since it is likely that some form of partial automation will be available on the market before AHS, and the AHS vehicle owners may well want to use their AHS features--even partially--on non-dedicated roads.

3.7 NATIONAL STANDARDS

3.7.1 National Compatibility

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

This means the following:

- There will need to be national standards for the communications between vehicles, and between the vehicles and the roadway. There will need to be standards for the “command and control” language used in the communications. It also means that there will need to be national standards regarding vehicle identification and vehicle status-reporting.

- AHS standards could be defined for different “classes” of vehicle—for example, narrow, normal and heavy. Large trucks would only be able to use lanes designated for their use; normal vehicles could only use the normal and heavy lanes; and narrow vehicles could use any AHS lane. Standards would then be set for the different vehicle classes.

- All rural and inter-city AHS systems would have at least one lane in which heavy vehicles could operate--for one lane systems, this would be a shared lane with occasional passing lanes; however, within a city’s boundary, lanes could be restricted to, for example, narrow and/or alternate propulsion vehicles only.

3.7.2 National Certification and Regulation

As new AHS-compatible vehicles are designed, certification that the vehicles do meet AHS standards, as set by a standards organization and/or the U.S. DOT, will be needed.
It also means that there will need to be standards for AHS infrastructures. One way of enforcing those standards is that federal funds could only be used for AHS infrastructure that meets the standards.

3.7.3 National Inspection Standards

It was generally agreed that in addition to the on-vehicle self-checking and roadside verification at check-in, the AHS-capable vehicles should be inspected periodically to ensure their safe operation on the AHS This would be done by each state individually; however, a standards organization (SAE?) may want to address standards for these inspections.

3.7.4 National Drivers License Criteria

A few researchers suggested that special drivers licenses could be issued to those wishing to use the AHS; these could be issued at renewal time. The license could ensure, for example, that the driver understands the liability conditions as well as any special emergency procedures. Minimum national standards could be set for those operating licenses.

3.8 ENGINEERING IMPLEMENTATION IN A POLITICAL ENVIRONMENT

A major new system that will directly interact with the general public faces significant pressures from two sides.

First, the engineering of such a system in the general public eye increases the need for very thorough testing to ensure robustness and operability; virtually every possible way of causing system failure must be identified and designed around. The safety of the system must be demonstrated.

Second, these systems may be expensive and the public and political leaders may get impatient with the cost and the amount of time it takes to develop. Unfortunately, it is not unusual for political pressures to be brought to bear on a public-oriented technical effort. The results of this can be disastrous as has been seen in numerous systems. One of the PSA activities was to examine comparable systems for lessons learned; one system examined was the Bay Area Rapid Transit (BART) subway system in San Francisco (Delco/PATH). Political pressures forced its early opening over the advice of engineers. Its early operation was marred by accidents, injuries, and unreliable service. It took years for BART to overcome its early reputation of being unsafe and unreliable.

One approach for avoiding this with AHS includes evolving the system one step at a time, and viewing the system as an extension of the existing vehicle-highway system. Also, to the extent possible, publicity on the new system should be minimized until the system is well into testing and a solid schedule is determined.

SECTION 4

TRANSITION-RELATED FINDINGS

Most researchers agreed that the transition to AHS should be a planned (i.e., guided) evolution rather than a revolutionary one.

A major concern identified in transitioning is that there must be sufficient "market penetration"; that is, a given area must have sufficient vehicles that are instrumented, sufficient highways upon which the instrumented vehicles could operate, and sufficient number of drivers that desire to use the service. Also, the state's DOT must have evolved to the point that it can construct, operate and maintain a sophisticated, real time information system. The AHS researchers estimated that the levels of AHS vehicle penetration needed in a given travel corridor to justify a single AHS lane ranged from 5 to 15 percent, depending on many factors such as frequency of entry and exit lanes and average trip distance (Battelle, Delco, Calspan).

The purpose of this section is to address the findings that relate to how the present vehicle-highway system can or should evolve the full vehicle control of an AHS. Additional summary-level conclusions, issues, risks, and concerns relating to this area can be found in the appendices.

4.1 EVOLUTION FROM EARLY VEHICLE CONTROL SERVICES

There are several facets of the term "evolutionary transition." The one primarily discussed was that AHS must be a next step in the natural evolution of automated vehicle control services such as ACC, lane keeping, and collision avoidance, and that, in fact, the first AHS may consist of a highway lane dedicated to vehicles that are equipped with ACC, lane keeping and roadside communications to allow the basic operating parameters such as speed and safe spacing to be transmitted from the roadside to the vehicles (Rockwell, Raytheon). Vehicle penetration would build as part of the drivers' desire for ACC and lane keeping. Roadway operators would have the incentive to dedicate the lane since researchers agreed that major improvements in safety and throughput cannot be achieved if AHS-equipped vehicles are intermixed with manually-operated vehicles.

Several researchers (e.g., Delco, Calspan) cautioned that tying AHS to the ACC and lane keeping services might be risky because those services may not have a broad appeal to drivers—certainly not the level of appeal that an AHS would have. A second concern was that the major throughput and safety gains that come with a dedicated AHS lane directly benefit the community and society as a whole; the driver benefits indirectly with faster, more reliable trip time and greater user comfort. For these reasons as well as others, most researchers agreed that evolutionary transition might not happen without the role of the federal and state governments to: (1) set standards; (2) ensure that the necessary infrastructure support is implemented; and (3) encourage driver participation.

It is believed that once the AHS is in operation, then the user will be able to see the benefits of reduced and dependable travel time, and greater user comfort. Conversion to AHS should then be easier. But until the drivers can directly see these benefits, they may need encouragement to convert. Several researchers (Delco, Battelle, etc.) voiced the opinion that an incentive for drivers to initially upgrade their vehicles would speed conversion.

4.2 REGIONAL TRANSITION

Another facet of transition that more directly addressed the issue of penetration was the strategy of a region-by-region AHS transition. The approach, voiced by PATH, assumes that the state and federal governments would concentrate on one region at a time to prepare the infrastructure for AHS and to encourage driver participation. The theory is that through concentration of resources, the initiation of the AHS service could occur much more quickly because drivers would be able to see greater benefits (i.e., more AHS roadway options). This was confirmed when a Delco/DMJM study showed that two AHS lanes rather than one (one east-west, the other north-south) would quadruple the number of drivers that AHS could serve. The analysis examined the Phoenix area traffic patterns and predicted that two cross-cutting AHS lanes through the city would result in a four-fold increase in user demand compared to a single AHS lane crossing the city.

4.3 TRANSITION BY VEHICLE TYPE

Evolutionary transition can also occur by the type of vehicles and/or users on AHS. Several, including BDM/Coogan, felt that the first AHS system will be a bus transit system. One of the BDM views was based on current European systems in which buses with lateral control operate on dedicated bus lanes with very close tolerances in restricted urban areas. A recent AHS-controlled vehicle implementation is the maintenance vehicle system in the Channel Tunnel. They also described the flexibility of a system in which close tolerance guideways at an airport (e.g., Dallas airport) are used by AHS-equipped shuttle buses that use the AHS lanes to travel to downtown where the bus is than able to deliver the riders directly to their hotels or work.

Calspan/Princeton University specifically examined the bus lane in the Lincoln Tunnel and concluded that AHS technology could significantly increase the number of bus riders into Manhattan from New Jersey, and that this implementation could be achieved in a much shorter period of time than conversion of the general population to AHS.

Some felt that commercial trucking companies might be the first to instrument their vehicles for AHS (Calspan/Parsons-Brinckerhoff, Raytheon/Freightliner, PATH/California Polytechnic Institute). Their arguments are that the incremental cost to the trucking companies is small, and the benefits of shorter, dependable delivery times in urban areas would be very attractive. Also, trucking companies would find rural AHS attractive because it could greatly reduce two of the major causes of crashes—run-off-the-road and excessive exit speeds. The potential ability for drivers to travel greater distances was also considered a big advantage, and the Daimler-Benz study focused on the electronic convoying potential of AHS where the lead vehicle would have a driver and one or two following trucks would not. This idea is also being researched by the U.S. DOD at the Army Tank and Automotive Command.

The assumption is that once trucks and/or buses are successfully operating on AHS lanes, then the public demand for the system would grow much more quickly.

4.4 LEVEL OF SERVICE TRANSITION

One facet of evolutionary transition is by level of AHS service and how that will evolve (Calspan). The initial AHS systems may be one lane systems with no passing ability, and possibly limited to a single type of vehicle (e.g., heavy vehicles, transit buses, passenger vehicles). As the vehicle penetration grows and system use increases, systems may be expanded to have multiple lanes, including lanes dedicated to different types of vehicles, and include more sophisticated tie-in to traffic monitoring and traveler information systems. The AHS of the future may include AHS lanes capable of providing power to electric vehicles (Calspan), or driverless transit vehicles with dedicated lanes to commuter parking lots (BDM/Coogan), or driverless commercial vehicles with dedicated lanes between freight terminals and rail and/or sea cargo terminals (Raytheon/Freightliner).

Similarly, the driver role may also evolve. Early systems may require the driver to maintain an awareness of the trip progress (Raytheon/USC, Rockwell). This awareness may also involve the driver as a supplemental “sensor” to help detect objects in the roadway or developing situations (deer beside the road, load about to fall from the truck in front). As AHS systems become more mature, and as drivers and operators feel more comfortable with the system robustness and integrity, then drivers will be able to use the vehicle as an office or relaxation center while traveling.

4.5 SYSTEM ELEMENT TRANSITION

From a different perspective, transition of AHS must occur more-or-less simultaneously among the four major elements of a vehicle-highway system—the vehicles, roadways, drivers, and highway operators. Each of these is addressed below.

4.5.1 Vehicle Transition

It is envisioned that progressively automated collision avoidance and vehicle control services will be offered prior to AHS so that when the first instrumented highway is installed and the first fully automated service is offered, many of the vehicles will have instrumentation that will require little enhancement to be AHS-compliant (Calspan, Delco, Raytheon, Rockwell). For example, many vehicles may have instrumentation for services such as ACC, lane keeping, and integrated longitudinal and lateral collision avoidance. These services require sensors, processors, and electronic actuators that could be upward-compatible to AHS. The specifications and standards for these components should be defined as early as possible so that they can be, in fact, upward-compatible and be used as integrated components of the AHS. And as described above, these services will continue to have value on non-instrumented roadways. For example, as a vehicle leaves an urban AHS system, it could move onto a rural non-instrumented roadway where the ACC and lane keeping services resume control.

As described above, having sufficient penetration of the vehicle population in a given area to justify an AHS in a given corridor may be a problem. Congress recognized this when they included language in the ISTEA stating that AHS vehicle instrumentation must allow retrofitting on existing vehicles. Within reason, by the year 2020 this should be possible. Once the AHS performance specifications are developed, three AHS classes of vehicles could be manufactured:

- AHS-Certified Vehicles - The vehicle fully meets the AHS specifications; these specifications will include sensor and electronics instrumentation as well as the basic vehicle construction such as acceleration, automatic transmission, steering tolerances, and electronically-actuated braking, steering, lights, and throttle.

- AHS-Capable Vehicles - The vehicle is capable of being upgraded to fully meet the AHS performance specification; electronics packages and sensors could be added, but the basic vehicle would be AHS-compliant; a goal would be to require little if any upgrade of vehicles that are equipped with collision avoidance, ACC, and lane-keeping.

- Non-AHS Vehicles - The basic vehicle is not reasonably capable of being upgraded to meet the AHS specifications without replacing engines, transmissions, etc.

During transition, "pallets" could theoretically be used to allow non-instrumented vehicles access to the AHS lanes (Battelle). These pallets would essentially be specially designed, fully AHS-instrumented trucks upon which non-instrumented vehicles would ride. As instrumented roadway segments are opened, the pallets could be moved to the area until the instrumented vehicle population became sufficient. Then they could be moved to another transition area.

The Battelle investigation concluded that the pallet system requires significant infrastructure investment, so it may not be cost-justified by itself, particularly as a transition aid. A pallet system is more likely to be cost-justified if it is more broadly based and includes feasible variations. For example, some of these pallet chassis could have transit vehicle bodies placed on them; this would allow them to carry transit passengers from one AHS entry point to another. The vehicle loading and unloading areas would need to be modified to accommodate pallets and/or passengers. Similarly, the pallet chassis could be designed to carry light, unitized containers so that cargo could be moved through the system and between intermodal terminals. Special AHS-specific docks would need to be developed for this variation.

Instrumented rental cars would also offer increased use of AHS. These could be offered by the rental car companies as well as the owner/operator of the AHS system.

If system ownership is through a public utility structure, conceivably the vehicle’s on-board equipment could be owned by the utility and leased on a long-term basis to the vehicle owners.

4.5.2 Highway Transition

The AHS will evolve as part of our nation's highway transportation system. Initial AHS deployments are likely to be on heavily traveled urban highway segments. The automated lanes may be separately accessed as are the HOV lanes on some of today's highways, and it is possible that special heavy truck/transit lanes could be established as an early step in transition.

Instrumentation of lanes will probably proceed a few segments at a time. At some point, after the AHS performance specifications are established, the highway community will develop standards in coordination with the U.S. DOT and standards bodies for AHS instrumentation of highways. Some of these standards could be applied to new, federally-funded highway construction occurring after the standards are set. For example, accommodations for passive or active lane markers for lane keeping, and space for roadside electronics and beacons could be provided. Provisions for future AHS entry and exit ramps could also be considered. This preplanning would reduce future AHS transition costs.

Some highway lanes could be time-shared between vehicle types; for example, rush hour traffic would be light vehicles only, while during off-peak hours, commercial vehicles would use the lanes (Calspan/Princeton). The AHS lanes could also be reversible.

4.5.3 Driver Transition

Driver transition must include acceptance of the service, training and cost justification. By the time AHS becomes operational, many drivers will be used to other AHS-related vehicle control services. The next step to AHS should not seem so large to those drivers. The few human factors studies by Honeywell regarding driver acceptance of AHS have shown that drivers seem to easily accommodate to full vehicle control; however, those are preliminary results and do not cover a full spectrum of operating conditions. Many of the researchers felt that the system should not scare the users, particularly during initial AHS operations (Raytheon, Honeywell). This means that very close spacing may not be a part of the initial AHS installations. Since close spacings are a strategy for increasing the number of vehicles per lane per hour, the initial installations that are not yet up to capacity would not need the increased capacity. Calspan calculated that throughput of a manual lane could be doubled by conversion to AHS without resorting to closely-spaced platooning.

Most of the researchers agreed that AHS should be viewed as a consumer product; thus, it must be very robust and easy to use—i.e., intuitive; special training should not be required for normal operation. The indicator showing that the vehicle is AHS-ready should be straight forward (a green light?) and pulling into an AHS access lane to request entry should be as straight-forward as pulling onto an HOV lane. Movement of the vehicle into the AHS lane after it has been accepted will be done by the system; if the vehicle is rejected, the driver's responsibility should be to simply continue driving straight; that is, the straight-ahead lane will return the rejected vehicle back to the manual lanes (Raytheon/Georgia Tech.). This means that the accepted vehicle will be pulled out of the main stream by the system. Assumption of control by the system should be similar to the assumption of the throttle control by today's cruise control systems. The design should strongly discourage drivers in rejected vehicles from attempting to manually negotiate the AHS system's movement (through design or signing or both).

Most agreed that leaving the AHS will be the more complex problem (Calspan, Delco, Honeywell). The system will need to ensure that the driver is prepared to resume control and that the control is successfully transferred. Many researchers felt that this is an area requiring more study.

Some of the researchers argued that AHS users should have special drivers licenses. This would allow the state or county to ensure that the driver understands the system and his or her responsibilities in using it; for example:

- Notifying the system of potentially dangerous situations
- Handling the vehicle in a total system shutdown in which all the vehicles are stopped and control is returned to the driver for system exiting (a postulated situation)
- Ensuring the safety and operability of the vehicle when entering AHS
- Meeting restrictions regarding trailers or rooftop carriers, following the entry procedures
- Agreeing to system liability conditions

The cost of the AHS may be a major concern. If drivers must pay for the service either in purchasing an instrumented vehicle, or in tolls for the special roadway, then the driver must be convinced that the AHS service is cost-effective, safer, and more convenient. The initial investment in the vehicle instrumentation will need to be reasonable enough that the driver can see a rapid return on the investment or feel good about the cost of the extra service. For example, if the AHS is in fact collision-free except when there is an AHS malfunction, then insurance rates for the AHS drivers should be substantially less, and the driver will feel safer and more comfortable in highway travel.

4.5.4 Facility Operator Transition

Today's state and local transportation departments are not organized to handle the construction, operation and maintenance of sophisticated, real time information and communications systems. These organizations must evolve to be able to manage an AHS. This could be done through training and expansion of the existing organizations and/or through contracts with private operating organizations. A few of the researchers also mentioned the possibility of a utility-type of organization to not only manage the system, but to provide a base for capital funding as well. This is addressed in more detail in section 6.

SECTION 5

VEHICLE-RELATED FINDINGS

The purpose of this section is to highlight the major vehicle-related issues based upon the accumulation of the AHS research findings. The vehicle-related issues presented in this section address such topics as lateral and longitudinal control requirements, reliability, maintainability, retrofitability, driver role, vehicle trends, AHS check-in, and AHS check-out. Additional summary-level conclusions, issues, risks, and concerns relating to this area can be found in the appendices.

5.1 LATERAL AND LONGITUDINAL CONTROL REQUIREMENTS

The PSA study of lateral and longitudinal control was perhaps the most technically detailed of the analyses. This topic focuses on the automated control of vehicles while on the AHS lane. It includes AHS system control of the vehicle's throttle and drive-train, brakes, and steering so that the vehicle maintains a safe speed and distance within the lane of travel. Specific maneuvers accomplished in lateral and longitudinal control include lane keeping (keeping the vehicle in its lane), lane change, following acceleration and/or deceleration profiles without braking, maintenance of speed, and following a braking profile, including bring the vehicle to a stop. AHS entry, operation, and exit use a combination of these basic maneuvers.

The level of development of vehicle control algorithms for these maneuvers varies. Reasonable advancements have been made in control algorithms for headway maintenance, including platooning. Also, there has been significant work on lane keeping algorithms that produce acceptable performance levels. However, robust lane changing and platoon/vehicle merging algorithms that will provide ride comfort while meeting AHS requirements are still needed (Delco). With regard to these algorithms, Rockwell felt that maneuver coordination is “best performed on the vehicle due to the high communications requirements.”

5.1.1 Lateral Control

Lateral control keeps the vehicle in its lane; it is also involved in maneuvers to change lanes and exit the system. Lateral control involves automated steering, lane position sensing, and sensors to detect vehicles in adjacent lanes. Lane changing was thought to be the most difficult of the vehicle maneuvers because it requires integration of the lateral and longitudinal controls for its accomplishment. Reliable automatic lane changing puts heavy requirements on sensors, diagnostics and algorithms for lane change control (Raytheon).

Several sensing techniques are available for determining positioning of the vehicle within the lane including on-board sensing of magnetic nails embedded in roadway, sensing of a magnetic stripe, sensing a field generated by an "active" embedded wire in the roadway, sensing of barriers, on-board vision-based lane marker sensing, sensing of fixed position infrastructure beacons, and GPS based sensing. Some of the PSA researchers felt that "passive" infrastructure markers, such as the magnetic nail-based system, was the most promising approach identified to date (Calspan, Martin Marietta). A primary reason for this was the expected low installation and maintenance costs because they “require no power, are extremely durable, provide control in all weather conditions, and component failure will occur gracefully (i.e., if a given magnet should fail, vehicle operation can continue because one missing magnet will not affect performance.)” (Calspan). Calspan identified that lateral control based upon overhead wires that radiate signals, while more costly to install, also operates in all weather and can be used to provide a moving reference for point-follower type longitudinal control (Calspan).

Despite the overall favorable outlook toward lateral control, one researcher (Raytheon). cautioned that sensor requirements for reliable lane keeping may not be met with today's affordable technology—reliable sensing at an affordable cost is the issue.

SRI took an in-depth look at the use of carrier-phase integrated GPS for vehicle control. They found that this new form of GPS data use could potentially satisfy lateral and longitudinal control sensor requirements for AHS. SRI suggested that in geographic areas where GPS signals cannot be received (e.g., tunnels), the GPS signals could be augmented with an in-vehicle inertial reference unit and infrastructure-based GPS "pseudolites" (SRI)..

Many researchers indicated that electrically actuated steering systems might be necessary for AHS lateral control. That is, the steering wheel is not mechanically linked to the steering mechanism; rather, a computer translates steering wheel movement and commands the steering mechanism. Although prototypes of these steering systems exist, concerns were raised as to whether there could be mechanical backup to the system. Researchers felt that there are many design issues to be resolved related to electronically actuated steering including reliability and user acceptability.

5.1.2 Longitudinal Control

Automated control of the vehicle's brake and throttle will allow it to follow at a safe distance behind the vehicle ahead, maintain a pre-determined speed, follow a given acceleration or deceleration profile, brake to avoid a collision, and come to a controlled stop. Automated longitudinal control of vehicles was seen as less difficult than lateral control; ACC systems that perform some of these functions are nearing introduction to the market.

Two of the major concerns in the area of longitudinal control are determination of safe following distance and obstacle detection; sensor technologies that may be used for these uses include radar, laser radar, and vision-based systems (Martin Marietta).

Assuming a radar-based longitudinal sensor, Calspan determined that longitudinal radars will be required to provide high azimuth angle resolution. “Longitudinal radars used on an autonomous vehicle will measure and locate the position of vehicles to determine the driving lane they occupy over ranges of approximately a few meters (feet) to 60 or 90 m (200 or 300 feet). Azimuth look or scan angles of ±45_ are likely to be required to confirm slots for lane change or merge/demerge. Because of the need to locate the vehicle in the azimuth plane, the headway radar will be required to have a beam width of one to two degrees, thus the radar sensor beam will need to scan in azimuth, either mechanically or electronically" (Calspan).

Raytheon cautioned that sensor requirements for full authority longitudinal control may not be met by the sensors that are currently planned for use by ACC applications. Regarding object detection, Raytheon also pointed out that sensors and signal interpretation algorithms that are capable of emulating human senses need to be developed.

Calspan determined that “...an AHS system configuration which is based on the use of infrastructure-mounted sensors to obtain vehicle longitudinal position and to provide a portion of the longitudinal guidance signals and vehicle malfunction detection functions may have cost advantages over a system containing vehicle-based sensors which perform these functions.” It was postulated that

“...component reliability of the infrastructure equipment could be made sufficiently high through redundancy so that component failure does not contribute significantly to the reliability of the overall system" (Calspan).

5.1.3 Platooning Versus Other Concepts

Platooning is the concept of several AHS vehicles traveling at the same speed together in a cluster to provide increased roadway throughput benefits. Depending on the concept, gaps between vehicles could be as small as one meter. Part of the platoon theory is that under emergency braking conditions the entire platoon would come to a stop with no collisions or only minor collisions among vehicles. This would be possible because all the vehicles are initially traveling at the same speed and inter-vehicle communications would allow following vehicles in the platoon to begin braking just slightly after the lead vehicle. Any impacts would involve small speed differentials.

The feasibility of this approach was discussed frequently among PSA researchers. Some of the researchers felt that collisions among vehicles traveling at high speeds (even with small speed differentials among vehicles) would not be safe (Calspan). The argument is that there will always be a chance of lateral disturbances possibly due to slightly off-center collisions, anomalies in the road surface, or the curvature of the roadway. These lateral disturbances could translate into multi-vehicle collisions. Another potential conflict with this concept is user acceptance of multi-vehicle low impact collisions as a possibility in an incident response.

As described by Delco, close inter-vehicle spacing increases throughput (i.e., triple the number of vehicles per lane per hour possible on today's highways). In cases of collision, the close spacing reduces the momentum transfer for any impact, thus enhancing safety. The close spacing will also mean less drag because of the vehicle aerodynamics; this should result in lower overall emissions and fuel consumption. However, close spacing adversely affects driver acceptance, increases the frequency of minor incidents, and challenges current technological capabilities (Delco).

Other operational concepts would have vehicles traveling at headways where during an emergency braking maneuver, all vehicles would come to a stop with no collisions among vehicles. Some researchers felt that this would increase inter-vehicle spacing up to 15 meters for normal highway speeds (Rockwell). Throughput could be double the throughput possible on today's highways. This longitudinal control strategy would become more efficient with communication of braking initiation and capability among the vehicles. For example, headway could be based upon real-time knowledge of the vehicles' maximum braking capability. This would allow "coordinated braking" where each vehicle adjusts its braking rate and coordinates the time its braking is initiated based on this real-time knowledge of the other vehicles' capabilities (Delco). Some concerns with this coordinated braking approach involves the accuracy of real-time braking data, the ability to synchronize the onset of braking, the ability to follow a braking profile, and the communications requirements (Rockwell).

Conversely, Calspan determined that “...communication between vehicles may not be required for vehicles following at gaps of 0.5 seconds, even during emergency maneuvers. Results of simulations showed that communication of the acceleration/deceleration of the lead vehicle(s) is not necessary for braking maneuvers. Simulation also showed that no collisions occurred even with the lead vehicle braking up to 1 g. The conditions for the simulation were a 0.5 second plus 1.5 m (5 feet) nominal gap between vehicles, 97 km/h (60 mph) vehicle speed, up to 15 following vehicles with the capability of 1 g maximum braking. The acceleration of the preceding vehicle was estimated from the rate of change of the differential velocity. The minimum value for the gap to maintain safe braking was not explored, but it is expected to be less than 3 m (10 feet).” This finding is significant since many researchers felt that each vehicle would need to pass its acceleration/deceleration rates to following vehicles to prevent a collision during hard, emergency braking (Calspan).

5.1.4 Obstacle Detection

Detection of obstacles in the lane of travel is one of the more technically challenging of the requirements of automated control. Objects ranging from old tire carcasses, boxes, mufflers, and animals are common sights on today's highways. For AHS, there needs to be both a reduction in the frequency of occurrence for these potential obstacles, and some means for detecting the obstacles when they do appear. Two ways of reducing the occurrence of roadway obstacles are (1) visual inspection of vehicles at check-in stations (e.g., non-secured loads, worn tires, loose vehicle trim, etc.); and (2) security fences along the right of way. Techniques for obstacle detection sensing include on-board vision-based systems, roadside vision-based systems, on-board ranging sensors (radar, infrared, etc.), and using the driver as an active sensor. In addition to identifying obstacles within the roadway, "...overall collision avoidance systems have to distinguish between threatening and non-threatening situations in a reliable manner. In a dynamic environment such as heavy traffic, most of the vehicles in the vicinity might be considered threatening by many sensor systems" (Raytheon). Obstacle detection was identified by the PSA researchers as an area that needs more research.

5.2 VEHICLE RELIABILITY

Reliability will be a driving factor behind AHS vehicle system design. AHS must be very reliable so that the goals related to safety, efficiency, and trip quality can be met. Much of AHS reliability relates to the reliability of the individual vehicles traveling on the AHS. The AHS cannot have frequent incidents in which vehicle malfunctions either slow or inhibit smooth traffic flow. The AHS system design must:

- Ensure that failures that might cause a crash are minimized
- Ensure that failures that might cause the vehicle to stop are minimized

The two most important vehicle operating functions are steering and braking because of the consequences of the loss of either (Calspan). It is hoped that entire vehicles will not be specially designed for AHS; rather, AHS will probably be an optional package available at the time of purchase, like air conditioning. Thus, the vehicle's steering and braking systems may well be those of the production line vehicles of the 21st century. Fortunately, the braking and steering systems of today's vehicles are very reliable. Further, vehicle design, in general, is becoming more and more reliable and this trend may increase in the future.

The reliability of the added AHS equipment, particularly related to steering and braking, must be considered. In general, AHS equipment will consist of processing hardware, software, sensors and communications equipment. Redundant processors and safety-tested software will be required to ensure communications and control processing reliability. For longitudinal and lateral control, researchers concluded that of greatest concern is the robustness of the AHS lateral and longitudinal control sensors. Redundancy and fail-soft and/or fail-safe design must be part of the system development so that a single sensor failure does not cause an incident. In addition, the sensors must be capable of performing under severe adverse weather conditions such as very heavy rain, dense fog, and heavy falling snow. The AHS sensors must be able to very reliably detect these conditions on a time-relevant basis so that the traffic control system can slow the traffic flow and increase inter-vehicle spacing to a safe distance, or even close the system in extreme conditions.

Sensors for determining inter-vehicle spacing must continue to operate at some level of accuracy and reliability even though a sensor may fail and even though weather conditions may greatly limit the detection capability of the primary sensors. This means that the sensor system must be able to determine when its effectiveness is limited. The back-up sensors may need to operate differently than the primary inter-vehicle spacing sensors. For example, in case of multiple sensor failure or in severe weather conditions, roadway-based radio beacons, inertial guidance units with on-board map, and/or GPS with carrier phase integration could conceivably be used to maintain a reduced or minimal level of operation until the conditions clear or the vehicles reach a point where they are able to exit. The fail-safe condition, if all sensor systems begin to fail simultaneously, would be to bring the vehicles to a stop.

Lateral guidance must also be maintained in case of sensor failure or in case of adverse conditions. Again, the system operating parameters (speed, spacing) will be adjusted due to adverse conditions by the traffic control system. The lateral control sensors must be able to determine when their effectiveness is deteriorating, and the back-up sensors must use a different sensing method even though operating speed and/or effectiveness may drop significantly. The fail-safe condition would be to bring the vehicle to a stop when all lateral control sensor systems fail simultaneously. “Loss of lateral position information cannot be allowed to occur" (Calspan).

In order to assure highly reliable AHS vehicle operation, AHS vehicle systems must undergo a series of tests. These tests will occur prior to entry on the AHS, continuously during AHS operation, and periodically at inspection stations. On-board diagnostics and sensors that assess the health of the vehicle's systems have been developed and are being expanded independent of AHS. The addition of AHS components to the vehicles will bring with it the necessary addition of diagnostic equipment and the potential for added design complexity and cost of components. “The importance of testing components is highlighted by the fact that over time, the likelihood that untested components have failed approaches certainty" (Honeywell).

Reliability of a vehicle operating on an AHS can be increased by ensuring that its operation at time of entry is proper. All critical functions related to vehicle operation on the AHS will be tested at designated check-in points prior to AHS entry. Many of these tests will be performed through on-board diagnostic systems. Other tests may need to be performed using roadside equipment or by visual inspection (e.g., to detect an unsecured load or the potential loss of a muffler). If a vehicle's critical components do not pass the test, the vehicle is then not allowed onto the AHS. Relating reliability to check-in, Raytheon notes that “...every vehicle function that affects the motion and safety of the vehicle has to be protected with on-board diagnostics and redundancies.” As a result, elaborate on-site check-in tests may not be necessary. When a redundant path fails the system shall be considered unfit; this means that the vehicle will be denied AHS entry, or if it is already on the system, it will be forced to leave AHS at the next appropriate exit (Raytheon).

During AHS operation, the vehicle's critical components can be continuously monitored to ensure the vehicle's reliability remains high. If faults are detected, the vehicle may be instructed (depending on the type of failure) to:

- Complete the trip, but deny entry for the next trip
- Exit at the next appropriate exit
- Pull-over into the next breakdown lane
- If there is an immediate risk of a crash, come to an immediate stop.

Reliability of AHS vehicle operation can also be increased through periodic inspections. These more thorough inspections will be for vehicle systems or components that cannot be checked using on-board diagnostics, roadside equipment, or visual inspection. These inspections could be similar to today's safety and emissions inspections performed in some states. The need for frequent period inspections has been identified as a potential user acceptance problem.

5.3 MAINTAINABILITY

The current vehicle design trend is toward low maintenance vehicles. For example, "...current vehicle electronics are designed to be maintenance-free for ten years or 150,000 miles and this trend is expected to continue with AHS vehicles" (Raytheon).

Maintainability refers to the ease, frequency, and cost of maintenance. Owners dislike the inconvenience of having their vehicles serviced. New car owners, in particular, have come to expect very few visits to the mechanic (even for regularly scheduled maintenance). The need for frequent and/or costly AHS maintenance might affect user acceptance, particularly if it is compulsory. For example, an AHS vehicle is not allowed on the system until the specified equipment has been serviced or replaced.

On the positive side, many components in future vehicles, and certainly many of the AHS-specific components, will be electronic and not subject to mechanical wear; they should require far less replacement or repair compared to the vehicle's mechanical and/or hydraulic parts (Raytheon). On the negative side, AHS will bring with it some additional maintenance requirements. For example, AHS vehicles may require alignment or cleaning of sensors. The AHS may also enforce appropriate replacement of the brake pads and tires; the driver may not be allowed to get extra miles out of them and still use the AHS (Raytheon).

To help lower maintenance costs, the AHS should be designed so that components are modular and easy to replace.

5.4 RETROFITABILITY

Retrofitability refers to the ability to add AHS capabilities to vehicles that are already owned by potential AHS users. Retrofitability was included in the ISTEA direction to the program, and was a topic for investigation in some of the PSA studies. Retrofitability will allow first generation AHS users to use AHS without having to purchase a new vehicle; instead, they could purchase upgrades to make their vehicles AHS capable.

It is believed that future vehicles will have many of the components necessary for AHS operation (e.g., electronic brake, throttle and steering actuators; sensors and processing for ACC and collision avoidance; and sensors and processing for lane keeping (Delco). Retrofitting vehicles equipped with some or all of these user services could be a matter of adding some AHS-specific communications and processing equipment and software, particularly if the vehicle was designed with retrofitability in mind (e.g., the AHS architecture is in place but the individual components were not purchased at the time of the vehicle sale). Future vehicles may be sold as AHS compatible, that is, designed for easy upgrading for AHS operation. Retrofitability will allow potential AHS users to purchase a less costly vehicle with the flexibility to someday upgrade to AHS.

The general consensus of PSA researchers was that retrofitting a vehicle not built with AHS in mind would be extremely expensive. Specifically, retrofitting of any component that affects the motion of the vehicle is going to be expensive (Raytheon). Raytheon/USC defined several potential stages of evolution from today to AHS, each stage representing an additional level of automated control. In analyzing these stages, they found that the requirements for redundancies and diagnostics for each incremental evolutionary stage was unique. This would make it difficult and costly to upgrade vehicles built for one stage to be used for a higher one. Therefore, for a vehicle to be retrofitable on a practical basis, it would need to have an architecture capable of accommodating the additional AHS components.

5.5 DRIVER ROLE

The role of the driver in AHS was a topic of much debate during the PSA studies. PSA researchers and others in the AHS community discussed various potential driver roles and responsibilities ranging from no role at all to constantly monitoring the AHS vehicle operations. The role of the driver has a major impact in the AHS design and on the legal aspects associated with AHS.

In the early stages of the PSA studies, many of the researchers felt that the driver should have no role in the operation of the vehicle while on the AHS. No role implies that inputs from the driver during AHS operation would be extremely limited (e.g., requests for destination changes or requests to exit the system.) As the PSA studies continued, most of the researchers felt that drivers should be allowed to have a panic button on-board the vehicle. This panic button would bring the vehicle to an immediate safe stop. The panic button concept could be further expanded to allow a driver to act as an additional vehicle sensor and be given a range of buttons for entry of this data; the AHS response could range from: (1) increasing the intensity of on-vehicle observation; (2) slowing down; or (3) stopping. For example, the driver may spot a deer along the shoulder of the road or he or she may see a load precariously balanced on a vehicle ahead. Some felt that a driver that activates the panic button feature or enters data that causes system slowdown, would need to justify the data or be subject to a fine.

Some PSA researchers felt that it would be beneficial to have an option to allow the driver to constantly monitor the AHS vehicle operation. This could make some drivers feel better about the system. Another option could require the driver's continued attention; the driver would be required to make inputs to the system throughout the AHS trip. Some of the researchers that studied the check-out function felt that this requirement would aid in keeping the driver alert for the transition back to manual control (see section on AHS check-out) (Calspan). Others felt that this constant input requirement would be viewed as an annoyance by many drivers.

All researchers were unanimous that control of a moving vehicle on AHS should never be given to the driver. For example, if an incident occurs with a platoon of ten vehicles, returning control to all ten drivers simultaneously while the vehicles are moving would very likely be disastrous. One alternative was that in case of a "full" system failure, all vehicles should, as a fail-safe design, automatically be brought to a full stop; only then (perhaps with official supervision) would drivers be allowed to assume control of their vehicles.

According to Delco, a driver “...cannot perform many control operations to the required standards of an automated highway. The driver can, however, identify potential hazards and notify the roadside infrastructure so that the other vehicles can be managed around the obstacle" (Delco).

Legal responsibility ties directly into the driver role. Although most felt that the driver would only have a minimal role in AHS vehicle operation, there was the opinion that the driver should have some legal responsibility for the operation of the vehicle. That is, by entering AHS, the driver is ensuring that the vehicle operates safely and soundly, and that he or she accepts responsibility for delays or crashes caused by his or her vehicle failure. This is modeled after today's vehicle highway system. This responsibility implies that the driver is the ultimate monitor of the system.

As the role of the driver increases, it is also possible that the stress on the driver increases and trip quality decreases. If the driver is required to be a system monitor, the concept of the in-vehicle mobile office or entertainment center may not be realized. But for some drivers, a monitoring role may in fact be less stressful; this, then, should be an option. In any case, the system should not be designed so that the driver is put in a situation that he or she cannot handle. The role of the driver has to be clear and meaningful (Raytheon).

5.6 VEHICLE TRENDS

As noted before, the current trend in vehicle design is increased reliability and maintainability. Additional trends include increased safety, security, performance, comfort, and emissions efficiency. All of these trends are consistent with the future needs of AHS, and trends upon which the AHS will build. A major element is the increased amount of electronics in the vehicle. Electronics are being incorporated in many vehicle systems and subsystems including engine control, braking, suspension, traction control, and on-board diagnostics. The increased level of electronics in vehicles is a factor in the trend of increased vehicle reliability and maintainability. Electronic parts are more reliable and serviceable (or replaceable) than mechanical parts. With the advent of ITS technologies (including collision avoidance products), the level and sophistication of the electronic equipment on board the vehicle will be further increased.

AHS will be using many of the systems that will be incorporated on future vehicles. In fact, “...much of the system monitoring capability required for AHS check-in will exist on the vehicle or be a straightforward extension of existing capabilities" (Northrop-Grumman). Many of the systems and sensors needed for ACC, collision warning and avoidance, and lane keeping will possibly be built upon by AHS for detecting vehicles, highway lanes, and potential foreign objects in the roadway. These services may also require electronic actuation of vehicle throttle, steering and brake systems. The AHS could also be designed so that its sensors, communications and processing capabilities could be used on non-AHS roadways as ACC, collision avoidance and/or lane keeping.

5.7 AUTOMATED HIGHWAY SYSTEM CHECK-IN

The AHS check-in function ensures that the necessary criteria for AHS entry are met by a vehicle and its driver. The criteria would ensure that the vehicle can operate reliably on the automated highway and that the necessary permits, licenses, or tolls are in order for the driver. Necessary information would be passed between the vehicle/driver and the AHS infrastructure system during check-in. Acceptance or rejection for AHS entry would be communicated to the vehicle as a result of the check-in process.

The first step for many of the PSA researchers studying check-in was to determine what items needed to be checked. A sample list of vehicle specific functions that should be checked during the AHS check-in process and an overall criticality score for the each function is shown in table 5-1 (Delco).

Table 5-1. Vehicle Specific Check-in Items (Delco)

Function	Criticality Scale (1 - 10)
Vehicle Specifications (Type, Speed, Size, etc.)	4
Brakes	10
Tires/Wheels	8
Engine	7
Vehicle/Body Condition	7
Transmission	6
Steering	10
Visibility Enhancement (Headlights, Wipers)	3
Wheel Speed Sensor	6
Vehicle Speed Sensor	6
Fuel/Gasoline (Quantity)	4
ABS	6
Vehicle System Processors/Computers	10
Communications	10
Automatic Brakes and Controller	10
Automatic Drive train Controller	10
Automatic Steering and Controller	10
Vehicle Longitudinal Position/Distance Sensor	10
Vehicle Lateral Position/Distance Sensor	10

In addition to the vehicle specific functions that must be examined at the time of check-in, other items related to the driver such as licensing and tolls could be checked. A sample list of some of these driver related items that could be examined during the AHS check-in process and an overall system value score for the each item is shown in table 5-2 (Delco).

Table 5-2. Driver Related Check-In Items (Delco)

Function	System Value Scale (1 - 10)
Name or Identification Number	10
Legal Status of Driver	5
Driver's License	10
Driver's License Validity	10
Vehicle Registration	6
Vehicle Registration Validity	6

Table 5-2. Concluded

Driver's Medical Record	8
Driver's AHS Certification	10
Vehicle's AHS Certification	10
Warrant for Vehicle	2
Toll Account Status	4
Toll Card Number	4
Insurance	5
Smog Check Certificate	7
Business Licenses	4
Commercial Cargo Information	8
Driver Sobriety	6
Driver Alertness	5

The physical allocation (e.g., vehicle-based versus infrastructure-based) of performing the check-in function was studied. In general, it was thought that much of the diagnostics and processing for the check-in function could be done on-board the vehicle. However, some tests such as structural integrity (e.g., a dangling muffler) or over-sized vehicle dimensions (e.g., loads tied on top of a vehicle) might best be detected from the roadside using sensors and/or visual inspections by a human inspector. Many of the PSA researchers believed that the check-in function could and should be performed "on the fly"; that is, the vehicle does not need to come to a stop or slow significantly for check-in.

One of the challenges is how to verify that the AHS equipment is operating properly. One researcher, Honeywell, suggested an "obstacle course" type of test at check-in to do this. This test would require the vehicle to maneuver through a predetermined path, communicate with mock vehicles, and identify mock obstacles to avoid. Calspan found that actuators for steering, throttle, and brakes will require testing in a series of dynamic tests. In order to test for the proper operation of the various actuators, it is necessary to command the actuator to move and measure its response to the test command. These dynamic tests, which will cause a steering maneuver and changes in the vehicle's longitudinal acceleration, need not be a large or long-duration displacement; in fact, the vehicle passengers may not be aware of them. For example, steering tests could be a series of short pulses that result in displacing the vehicle only a few inches. These tasks could be made on an entry ramp (Calspan).

Northrop-Grumman found that certain technologies might increase the cost of an AHS check-in concept considerably but might have efficiency and safety benefits (e.g., audio input, physical condition sensor, unique physical signature sensor). Other technologies increased the capability of the AHS check-in concept but with minimal cost (e.g., on-board data storage, built-in-test [BIT]). Many systems applicable to check-in will already be required for the vehicle to physically operate on the AHS; therefore, check-in requirements may not add significantly to the vehicle cost.

The Raytheon team had a vision of a vehicle-oriented check-in procedure where on-board diagnostics and self tests are performed continuously whenever the vehicle is operating under manual or automated control. These tests start at ignition, and are performed as long as the vehicle is operating. Part of this concept revolves around the actuators for braking, throttle, and steering being integrated into the manual control loops. The same actuators used under automated control would be continually exercised during manual driving and would continually undergo diagnostic tests. Under this concept, other electronic vehicle components (e.g., sensors) would use BIT for diagnostic purposes. With many of the check-in tests being performed on-board the vehicle, the time and processing required at the AHS entry should be drastically reduced.

Regardless of whether the majority of the processing for the check-in function is performed on the vehicle or on the infrastructure, AHS may require check-in stations located near AHS entry points. The PSA researchers looked into the issues surrounding different check-in station configurations. Results from these studies indicated that the more the vehicles need to slow down or stop for the check-in function, then more vehicle check-in stations would be needed to handle a given volume of vehicles if queue build-up and delay is to be avoided (Northrop-Grumman).

5.8 AUTOMATED HIGHWAY SYSTEM CHECK-OUT

The AHS check-out function ensures that the driver and vehicle are capable of operating in a manual mode before exiting from the AHS. The PSA researchers were instructed to focus primarily on the issues associated with ensuring that the driver is capable of assuming control while giving with less emphasis on the issues surrounding the vehicle's capability to resume manual control. In addition, the PSA researchers were also instructed not to address human factors issues in great detail because of the separate and concurrent FHWA study on AHS Human Factors issues.

The transition from automated control to manual driving must follow a progression of steps that ensures the safety of the driver and surrounding vehicles in the AHS and non-AHS lanes. Potential check-out protocols must be capable of maintaining safety in a cost effective manner while considering the technical feasibility and user appeal of the procedure.

5.8.1 Driver Readiness

The driver readiness portion of the check-out process can be fine-tuned to perform in the most optimal fashion. Human monitoring performance and associated vigilance decrement problems (reduction in level of alertness) have also been extensively studied. This research base can also be applied to design of level-of-alertness and monitoring performance features. For example, knowledge of task duration has been found to affect the vigilance decrement. On longer trips, one approach to ensure that the driver remains vigilant and alert is to test the driver periodically throughout the trip. However, these tests should be meaningful and related to the trip on the AHS. People generally do not respond well to meaningless tasks, and may perform poorly if they do not believe the test is important. On shorter trips, drivers will not tolerate a system that requires a battery of tests each time the AHS is exited. A check-out "test" that is flexible with respect to the trip duration seems to be a logical option (Calspan).

It is important that the driver readiness testing process not fail in determining that the driver is controlling the vehicle when automated control is relinquished (Calspan). For this reason, the driver response test must require him or her to initiate some kind of positive action, perhaps using the vehicle's manual controls, before the driver is judged as "in control". Only then can driver control be reasonably ensured, and only then can the control transfer process be completed (Calspan, Honeywell).

5.8.2 Vehicle Readiness

The integrity and proper functioning of the critical manual vehicle control mechanisms must also be ensured as part of the control transfer process. Most vehicle control functions operate under both automated and manual driving conditions, and, therefore can be assumed to be working. However, the manual links to safety-critical actuators must be verified. These include actuators for steering, braking, and throttle (Calspan). As a minimum, the manual braking and steering functions should be exercised prior to return to manual control since these two functions are critical to safe manual operation of the vehicle (Delco).

5.8.3 Transfer of Control

"It would be most advantageous if the driver assessment procedure is accomplished within the process of transferring control from the automated driving system to manual driving. That is, the control transfer procedure should be designed to include steps that accomplish both transferring control to the driver, and assessing the driver's readiness to accept control" (Calspan).

The Raytheon team suggested a combined driver readiness and transfer of control using a hybrid, automatic/manual controller. "After the driver has requested an exit from the AHS and the vehicle is under proper automated control (e.g., speed and spacing), the driver is instructed to resume manual control of the vehicle. In this procedure, the authority of the automatic controller is gradually decreased, while the manual control authority is gradually increased. This gradual control continues as long as the driver is capable of performing the manual control part of the controller. The system monitors the driver's progress, and accelerates or slows down the transfer of control from automatic to manual, so that a skillful, alert, and fast responding driver could resume control within a couple of seconds" (Raytheon).

5.8.4 Privacy and Liability Issues

Researchers discussed various approaches for determining the readiness of a driver to resume control. This range included tests involving sensors to detect the presence of substances in the driver's blood, prompts to gauge reaction times, or scanning of eye movement to evaluate alertness. It was pointed out that some of the more invasive tests may raise concerns among privacy advocates and have an adverse effect on user acceptance (Delco).

The return of the vehicle control to the driver has important liability implications. Assignment of liability in the event of an incident following the transition to manual control must be considered. Extensive testing prior to return of control to the driver may create the impression that the AHS is responsible for ensuring that no impaired drivers are allowed to have manual control.

Delco recommended that the driver check-out consist of a simplified routine that places the responsibility for assuming manual control completely with the driver. Eliminating complex operator verification tests and placing responsibility with the driver for accepting the manual driving task is one way to simplify the issue and reduce the risk of AHS being held liable for accidents caused by improper driving immediately following travel in the automated lanes. This approach is based on the premise that the AHS is not responsible for verifying driver readiness to safely operate the car prior to entering the AHS, and returning control to the driver following automated travel should not carry a burden beyond that of ensuring that the vehicle is functioning properly. The check-out process might follow a screening of manual brake and steering functionality with a prompt to the driver. The driver would then respond with a positive action such as pressing a push-button to indicate readiness to assume control. Delco also felt that legislation may be required to clearly delineate the responsibility for crashes following transition from the automated lanes.

SECTION 6

ROADWAY-RELATED FINDINGS

The major force that caused the Nation’s roadway system to evolve from the wagon trails of 1905 to the Interstate Highway System of today was the dramatic change in vehicles using the roadway. The automobile, with its speed and flexibility, placed significant demands on the roadway. As automobiles and trucks have evolved, so have the Nation’s roadways, so that today, the U.S. vehicle-highway system represents a highly robust and efficient system for personal transportation and the movement of the Nation’s goods. This evolution will continue; as automated vehicle control technology enables major increases in travel efficiency and safety in the 21st century, the U.S. highway network will evolve to meet the demands of automated control. That is, roadway system design that has been highly influenced by drivers’ performance, will now be challenged to meet the new demands of automated vehicle control. Highway designers of the (near) future will need to become familiar with sensors, communications, processors, and software for vehicle and traffic control.

This section addresses the PSA research in four activity areas—AHS Roadway Deployment, AHS Impact on Non-AHS Roadways, AHS Entry/Exit, and AHS Roadway Operations. Due to the mixed background of researchers, current as well as innovative concepts were investigated concerning all roadway aspects and how they may relate to AHS.

Many of the PSA researchers combined activity area analyses due to the complementary or supplementary nature of the areas of research; for example the AHS Impact on Non-AHS Roadways activity overlapped and interacted with the AHS Entry/Exit analysis. The research activities of these two areas benefited from the exchange of findings that enabled more thorough analyses.

Many of the critical PSA conclusions, concerns, and or issues were similar across various roadway research activities. In this section, they are summarized and overarching analyses are applied to identify the more important AHS roadway considerations. As the various findings were collated, they were categorized according to AHS infrastructure, infrastructure maintenance and operation, and deployment as described below.

6.1 AUTOMATED HIGHWAY SYSTEMS INFRASTRUCTURE

The roadway infrastructure can be broken down into various components that correspond to different aspects of a roadway system. Breaking down these components helped the researchers pinpoint specific aspects of the infrastructure that will directly influence an AHS. The components have been broken down according to standard highway engineering methodology. Many of the findings address certain aspects of the component categories, e.g., barriers are an aspect of a roadway's cross-section. The findings also contrast the envisioned needs of an AHS against current infrastructure standards. An overriding issue concerning infrastructure is to what extent can the existing infrastructure support or complement an AHS system?

6.1.1 Cross-section

The cross-section of a roadway illustrates aspects such as the width of lanes, the presence and size of shoulders, and the use of a medians or barriers between traffic in different directions. The relationship of these attributes to each other, and, the collective relationship to the surrounding environment are also shown. The cross-section of a roadway is very site-specific; it can change in relatively short distances. At the detailed level of design, a cross-section for a roadway may be illustrated every 15 meters.

Lane width is one cross-section component that may be affected by AHS. Researchers have suggested that AHS lane width could be narrowed, depending on the constraints of vehicle width, to a minimum of 2.5 meters (Battelle). A customized AHS system with special narrow vehicles could have lane widths of as little as 1.85 meters—two lanes could be installed where today there is one 3.7 meter-wide lane. Inclusion of heavy vehicles, however, would necessitate a lane width closer to (but still narrower than) the standard size (Delco). One suggestion was that during rush hour, the 3.7 meter lane could be used as two narrow vehicle commuter lanes; then in off-hours, the lane could be used as a commercial vehicle lane.

If heavy vehicles were separated into separate lanes, the AHS roadway cross-section could include two lane widths—one narrow and one closer to standard (Battelle). Some researchers expressed concern that changing the narrow lanes might exclude some retrofitted vehicles (e.g., sports utility vehicles with mirrors for trailing). If vehicles of different sizes use the same lane, then the lane width would default to the widest vehicle using the lane. Complications of having lanes of varying widths include lack of flexibility in rerouting traffic (cannot use a narrow lane for heavy vehicles), and the possible need for specialized lane construction, maintenance and snow removal equipment.

Many of today's roadways include shoulders. Shoulders provide an area for disabled vehicles, storage for plowed snow, access by emergency vehicles to incident locations, and space for occupants to egress from a stopped vehicle. The researchers debated the need for shoulders on an AHS, and generally agreed that space is required for them in the roadway cross-section, albeit not necessarily for continuous shoulders. Multiple uses were projected for AHS shoulders including stopping space for disabled vehicles, snow storage, and—since the AHS shoulder would need to be instrumented to allow disabled vehicles to pull into it, and if the shoulders are continuous—as an HOV lane in rush hours (Delco). The HOV use would be curtailed by disabled vehicles and/or snow storage. Calspan concluded that emergency pull-offs (or intermittent shoulders), as used on today's urban freeways, could be used on an AHS; these would need to be instrumented for AHS. This solution does not necessarily address the issue of snow storage. One researcher proposed that in heavily congested urban areas where highway right-of-way is at a premium, an alternative to shoulders may be a rapid incidence response system that can quickly clear a stalled vehicle. Specifically, the “flying crane” helicopter could theoretically be used (PATH). Other, similar means would need to be developed for incidents in which there is personal injury.

Researchers debated whether a vehicle occupant should be allowed egress from their vehicle on an AHS. The issue is, should occupants be held in their vehicle until emergency personnel are present? The concern is that people exiting from an AHS vehicle would create a major safety hazard; at the least, the system would perceive the person as an obstacle and bring traffic to a stop. Most safety people believed that the occupants would be safer if they remained in the vehicle, even though the occupants might be concerned. One problem raised was that if the inside of the vehicle was on fire, then the occupant could not be held in the burning vehicle; some type of escape would be necessary.

The issue of snow storage and storage of “roadside junk” was discussed. The issue is, if shoulders are not provided, what alternatives are there to remove the snow and/or junk? There were suggested roadway designs that might accommodate the snow problem—both suggestions were based on the fact that the wheels of the AHS vehicles will follow the same track very accurately; therefore, the roadway could actually be designed as a guideway—that is, narrow concrete wheel paths for each tire track with, perhaps, metal grating between the concrete paths that is strong enough so that a vehicle could drive on it in an emergency. Beneath the grating could be a gutter deep enough for snow storage. The other suggestion was that these concrete wheel paths could be heated, particularly on hills, so that snow and ice would melt. If the AHS roadway were designed in this manner, it was pointed out that construction of an AHS roadway would be significantly different than construction of today's roadways; for example, pre-formed concrete sections could be constructed, perhaps instrumented, and shipped to the construction site. Maintenance and construction equipment would need to be developed for AHS (UC Davis).

At the Entry/Exit mini-conference, one issue concerned the use of barriers to increase safety between an AHS and conventional traffic operations. There are two primary reasons for these barriers: (1) if the AHS lanes are adjacent to the non-AHS freeway lanes, the barriers will discourage manual drivers from attempting unauthorized entry onto the AHS lanes; and (2) crashes on the non-AHS lanes will intrude into the AHS lanes if there are no barriers (PATH). Other researchers present at the meeting concurred with PATH's assessment; however, the researches had different options on how this may be accomplished. One alternative was to construct physical barriers, e.g., Jersey Wall. Others thought a less intrusive six inch curb may be adequate. Taking into account the need to stop an intruding vehicle, many researchers opted to support using substantial barriers between AHS and manual traffic operations.

6.1.2 Entry/Exit Configuration Impacts

One of the most complex aspects of an AHS will be the infrastructure that permits the entering and exiting of vehicles. The entry/exit infrastructure design will be dependent on: (1) how the AHS traffic is collected from or distributed to the non-AHS roadway system, including any spatial/right-of-way constraints of the intersection; and (2) how the check-in and check-out functions are to be performed.

There are many issues concerning how the check-in and check-out functions will be performed (see section 5.7 and 5.8), and how these functions will effect entry/exit configurations. Some research assumed that there might be the need to stop the vehicle for check-in. This translates into a tollbooth type of configuration (Delco). The tollbooth configuration requires a lot of space and infrastructure, and is not conducive to space-limited urban environments. An alternative is to perform check-in and check-out "on the fly"; that is, without stopping. Check-in and check-out on-the-fly, however, may limit the system checks that can be accomplished. Even slowing the vehicles down affects the infrastructure depending on the speed at which the vehicle is traveling; it could impact the length of the check-in lane (Calspan). Most researchers felt that on-the-fly check-in will be feasible, particularly if there are on-vehicle status systems and periodic off-line system checks. Others noted that in urban areas at rush-hour, ramp metering may require the vehicle to be stopped anyhow (Calspan/Dunn); therefore, the entry ramps will need to be designed to accommodate long queues regardless of AHS. Today, many rush-hour travelers encounter (and to some degree, accept) ramp metering.

There are basically two kinds of entry and exit configurations for an AHS-dedicated ramps and transition lanes. The dedicated ramps can come in any configuration that is normal for a freeway entry ramp except that the ramp is dedicated to entry to the AHS and has adequate room for the check-in function and any necessary queuing. Several different kinds of ramp configurations were explored by Raytheon, Calspan, Battelle, Delco and PATH. As with today's highways, it was found that the specifics of the entry and exit locations (expected amount of traffic, geographic constraints, etc.) would dictate the design at a given location.

6.1.3 Transition Lanes

The concept of a transition lane was explored by several researchers. A transition lane, as first conceived, would allow drivers to request access to the AHS by moving into a continuous lane between the normal freeway lanes and the AHS lanes. The system would assess the acceptability of the requesting vehicle, and if satisfactory, would pull the vehicle into the AHS lane. Those vehicles that are rejected would be expected to move out of the transition lane back into the normal freeway lane. Similarly, when a vehicle requests to exit the AHS, it would be moved into the transition lane where control would be returned to the driver after the system ensured that the driver was capable of assuming control. This creates a situation where both manual-controlled and system-controlled vehicles are operating together in the same lane; this causes some difficult problems. For example, manual drivers might be tempted to use the transition lane as a normal lane of travel, particularly if the manual freeway lanes are clogged. Since drivers would be moving from the (presumably clogged) manual lanes into the transition lane, the speed of vehicles in the transition lane could range from 100 to 5 Km/h—a dangerous situation. This causes particular problems for traffic being exited from the AHS lane, where presumably the traffic flow is a smooth even speed of, say, 100 Km/h. If the system moves a vehicle into the transition lane at 100 km/h at the same time that a manual driver moves out of the manual lane into the transition lane at 5 km/h, then a collision is likely. If the AHS system exits traffic at a very slow speed, then the effective travel speed of the AHS lanes would be slowed considerably.

At the entry/exit mini-conference, it was agreed that the concept of a continuous transition lane was not workable. It was agreed, however, that transition lanes can exist between the manual and AHS lanes, but: (1) they cannot be continuous (e.g., rejected vehicles would be forced to return to the manual lanes by barriers preventing continued travel in the lane); or (2) any given segment of the lane must be dedicated to either system entry or system exit. With these restrictions, the transition lane becomes, in effect, a series of dedicated entry and exit ramps that just happen to be located between the manual and AHS travel lanes. In short, they are another option to be considered by the highway designers for specific situations.

6.1.4 Impact on Surface Streets

One of the overriding issues concerning the AHS is its possible overwhelming impact on the surface street system due to the large volume of vehicles it can handle. Calspan and Battelle pointed out that in many high-density corridors, an AHS lane added to an existing freeway will attract traffic from several miles away as drivers seek to enjoy its benefits. This will mean that the existing freeway's entry and exit facilities (i.e., those designed for manual traffic flow) will fail without enhancement when an AHS lane is added to the freeway. This will also mean increased traffic flow on crossing non-AHS roadways, which may result in some redesign.

Delco research illustrated various alternative configurations that effectively mitigate the entry and exit of AHS vehicles onto a street network; these configurations are specific to the cases they investigated. Researchers concluded that the mitigation of AHS impacts at the entry and exit points will need to be analyzed on a case-specific basis.

6.1.5 Electronics

Various AHS concepts require different levels of infrastructure-related electronics. Many researches agreed that, regardless of the concept, there will be electronics added to the infrastructure to enable the AHS operation. These electronics will need to tolerate the wide range of climates, and should not be susceptible to vandalism or sabotage. The AHS requirements must address these and other infrastructure operational environment concerns.

6.2 INFRASTRUCTURE MAINTENANCE AND OPERATIONS

As with any highway facility, the AHS facility's maintenance and operations will need to be managed; however, because of its instrumentation, because of its automated operation, and because of the operator’s liability, the AHS roadway maintenance and operation will need to be thorough and responsive. Traditional as well as new functions will need to be supported. New operational policies will need to be established. Resources to support the facility will need to be acquired and administered.

An AHS facility can build upon some of the knowledge of administering current toll facilities and freeway management centers. However, researchers do have concerns about the nuances of an AHS and the new capabilities that AHS operators will need to support them. Traditional administrative and managerial structures may not be sufficient, new and innovative arrangements may be necessary (Calspan, Delco). If these new arrangements are necessary, revolution to them will take time.

6.2.1 Administrative Options

The administrative options that can be instituted to manage an AHS are dependent on various factors. These factors can vary for each AHS depending on the location and governing bodies associated with that location. The various options to consider include a state-managed AHS, a public/private partnership, and a privately administered AHS (Calspan). These high level arrangements could take on may shapes according to the levels of the jurisdictions involved. In one location the AHS could be administered by a public/private partnership between the state and a private entity. Another location may find it more conducive for the local jurisdiction to privately contract out the administration of the AHS facility. Other communities or regions may find that a public utility type of organization may best ensure the AHS construction and operation.

“From the examples above one conclusion can be drawn—the need for flexibility” (Calspan). But underlying that flexibility there is the need to accomplish some similar functions. Some of the functions require a high level of coordination. The management structure chosen must be compatible with the community environment and the structuring of the local jurisdictions. It must meet the operational needs of the AHS as well as the conventional roadway facilities.

6.2.2 Support of Operation and Maintenance

On of the more resource-intensive activities an AHS facility will have to administer is the operation and maintenance of the facility. Investigations have identified that a major concern among current freeway management administrators is the need for a steady, reliable operations and maintenance funding source (Delco). An AHS cannot be allowed to fall to the state of disrepair of some of our current roadways and bridges; a lapse in funding of AHS operations and maintenance would cause system shut-down. Some system operators cautioned that if there is no reliable funding source to maintain AHS, funds for improvements to the system might be diverted to cover the maintenance shortfalls.

“Even with a reliable funding mechanism in place, there will still be a need to acquire the appropriate personnel to operate and maintain the system” (Delco). Transportation engineers, the traditional personnel of many state and local transportation authorities, will need to be complemented with new personnel with training such as software engineering and communications. Many administrators feel that current salary constraints may limit their ability to obtain and retain quality personnel. Also, many organizations might need to modify their promotion practices and develop new career paths to attract these new disciplines. Many state DOTs are already implementing these new career paths, but many do not have resources to compete with current market salaries for certain disciplines.

To reduce the burden of operation and maintenance on resources, researchers investigated if an AHS could share the resources of freeway management centers. It was concluded that many of the operational and maintenance functions could be accomplished by the same staff (Battelle). There would still need to be some independent staff for certain functions such as daily operation, monitoring and control. However, other functions such as sensor maintenance could be conducted by the same maintenance personnel. The freeway and AHS operations could be housed in the same building (Battelle). Sharing and the optimization of personnel is one option that should be considered to effectively and efficiently administer an AHS facility; however, the extent to which that could effectively be done needs research.

6.2.3 Key Functions

During the analysis of AHS operations, many of the researchers identified key functions needed to support the operations of an AHS facility. Many of these functions are similar to current or advanced freeway management functions; however, in an AHS environment they become critical (Calspan).

Many of the functions of today's freeways will also be a part of an AHS; the AHS operation will be interdependent with the freeway operation. However, researchers have identified the following areas where AHS functionality may be unique:

- Surveillance
- Security
- Incident detection and response
- Obstacle detection
- Vehicle and information coordination
- Adverse weather condition response

Surveillance for an AHS must support all the functions required for a freeway and more. For example, surveillance can assist in providing a deterrence and notification if AHS equipment is being tampered with or vandalized. There is also the need to increase surveillance capabilities to assist in the detection of AHS incidents and obstacles. Having the information needed to instantly detect and react to an AHS situation is very important.

Besides surveillance to provide security, other measures may have to be taken to protect critical equipment (Delco). Many believe that if there is a system, someone will try to tamper with it. In AHS, tampering could have catastrophic results. Access to the AHS roadway must be protected, and sensors may need to be specially housed to protect against vandalism. Actual or perceived barriers will be needed to prevent non-automated vehicles from entering the system; even so, the assumption is that occasional unauthorized vehicles will enter AHS. When this happens, the system must be able to identify the intruder and operate to protect the safety of the automated vehicles; for example, wide separations could be maintained from the intruder. Methods for retrieving and ejecting these vehicles—as well as apprehending the individuals involved—will need to be developed.

The next key function identified is incident detection and response. Even though incidents on an AHS are not as likely, an infrastructure that can detect and respond to an incident must be in place. The AHS incident response time should be less than current response times on conventional roadways (Calspan). Fast detection and response is needed due to the nature of an AHS operation. Any reduction in capacity caused by an incident (crash or stalled vehicle) can reduce the operation efficiency of an AHS facility and cause significant delays. The quicker the response, the easier it is to mitigate the effects on the flow of traffic. One approach for reducing an incident's impact would be to slow or divert all traffic flowing toward the incident; this could be onto a second AHS lane, the AHS shoulder, or onto a non-AHS roadway.

A related function to incident detection is obstacle detection, a proactive effort to reduce the occurrence of incidents. Obstacles could range from a deer intruding onto the AHS facility to a small piece of debris in one of the travel lanes. The concept is to identify the obstacle, determine how it might be detrimental to traffic operations, and take any appropriate actions. The most formidable problem concerning obstacles is detecting small objects that could affect system safety. Some ideas have been investigated such as devices to scan the travel lanes of the facility from the shoulder or mounted on Jersey wall (UC Davis); however, more research is needed. Another approach is the use of CCD video camera systems that are capable of instantly detecting objects in the roadway that are not either infrastructure or moving vehicles.

One of the more complex functions is the coordination of vehicles and information. This can be illustrated thought the explanation of the processes involved in successfully entering a vehicle onto the AHS (PATH). Information needed includes the entering vehicle's performance characteristics, the location and speed of vehicles traveling on the AHS lane, and the characteristics of the roadway at the location the interaction is to take place. This information must be associated with each specific vehicle, processed, and commands formulated for each vehicle to coordinate with the entering vehicle. Other instances of vehicle/information coordination include the transfer of vehicle travel information from one AHS to another, the coordination of vehicles in lane assignment and lane changing, and vehicle exiting, particularly from a platoon. Further research is need regarding how these functions can be safely accomplished.

The climate of an AHS facility will determine the system's operational environmental conditions. Some researchers and stakeholders felt that an AHS should be able to operate, at some level, under adverse weather conditions. The preferred strategy was to develop a system that can work as well as, or better than, the conventional system during adverse weather conditions; this means that the AHS could conceivably be shut down during extreme weather conditions. To accomplish this goal, issues concerning the functioning capabilities of sensors during adverse conditions, such as dense fog, must be determined. Also, what actions must the operator take to ensure safe operation during adverse conditions? Will the facility personnel need special equipment to deal with these conditions? How frequently will different conditions occur? Further research is need to determine how the different adverse conditions will affect AHS in general, and what options the facility operator has at his/her disposal to mitigate the effects of adverse weather conditions.

6.3 DEPLOYMENT

The initial emphasis of the deployment investigation was to identify the characteristic differences between an AHS and a conventional freeway and the impacts to the infrastructure that may occur. However, researchers discovered that the impacts to existing infrastructure were minor compare to other issues that may impede deployment of AHS (PATH). During research, issues surfaced pertaining to the relationship market penetration will have on deployment. Others pointed out that if AHS is to be deployed in the next 20 years, the planning and analysis of the deployment would need to start now. Another major resulting issue of the research was AHS impact on surface streets (see section 6.1.4). Many believe the impact of AHS on surface streets can be mitigated, however, there are issues concerning who will be responsible for mitigating these impacts.

Below the four issue areas identified above are discussed.

6.3.1 Impact to Existing Infrastructure

As stated previously, researchers concluded that any impacts to infrastructure associated with the deployment of AHS would be similar to impacts associated with deploying a conventional freeway. This conclusion is the culmination of two detailed case studies conducted by PATH and Parsons Brinckerhoff, a member of the Calspan team.
PATH's study was conducted in two phases. The first phase identified the most challenging California corridor to deploy AHS. In the second phase, a detailed analysis of infrastructure impacts was conducted. PATH's findings concluded that "The specific issues affecting the feasibility and cost of AHS roadway deployment are highly localized and dependent on a variety of physical constraints." This indicates that no two deployments will be exactly the same. Each deployment may encounter similar infrastructure impacts, however, the extent and various types of impacts will vary. Also, due to the specific nature of the existing infrastructure, unique impacts may be encountered.

PATH's case study involved the deployment of an AHS along Highway 101 (Hollywood Freeway) in Los Angeles. Various AHS roadway and entry/exit configurations were analyzed. For each configuration the study cites specific infrastructure alternatives that would mitigate the impact of AHS to the existing infrastructure. It should be noted that the most difficult impacts to mitigate were those associated with freeway-to-freeway interchanges. A general conclusion PATH cited is, "Even in the most challenging case study corridor that could be identified in California, there were only moderate infrastructure constraints to the deployment of new AHS lanes. This means that in the large majority of California freeway settings it should be relatively easy and inexpensive to add AHS lanes."

Calspan's (Parsons Brinckerhoff's) approach was similar to the PATH approach; however, their analysis was based on plans already completed regarding the addition of an HOV lane to the Long Island Expressway (LIE.). In this analysis, Calspan assumed that the addition of an HOV lane was similar to the addition of an AHS lane. The majority of the differences between an AHS and an HOV lane were based on the AHS entry/exit locations and configurations assumed.

The AHS deployment analysis assumed two areas based on general characteristics. The first area was sectioned according to the detailed characteristics of the existing infrastructure. For each section and/or area, an AHS cross-section conducive to each section's characteristics was selected. This first area of the LIE is characterized as an urban freeway with no median and little to no room to expand the width of the freeway. In contrast, the second area is a suburban area and the freeway's cross-section includes a 38 foot median.

The end result of the analysis was a comparison between the cost of deploying an HOV lane or an AHS. Two AHS configurations were analyzed, the results cited here correspond to the least costly alternative. Each section's costs were identified for major roadway components. These component costs were combined and divided by each section's length to calculate the cost per mile. For the very heavily congested section, section 1A, the addition of 0.8 miles of HOV lanes was estimated to cost $39.7 million per mile. In comparison for the same section deploying an AHS was estimated to cost $62.7 million per mile, a 58 percent increase. Cost in the suburban area were estimated to increase from $8.9 million per mile to $13.9 million per mile, a 56 percent increase. Again, most of the increase was related to the assumed addition of entry and exit points.

6.3.2 Market Penetration

Different analyses were conducted on various regional transportation networks (Battelle, Calspan, Delco). Each of the research efforts produced various results pertaining to the relationships between AHS and the market penetration needed to support an AHS, and the market penetration at which the AHS reached capacity. Actual results were specific to each of the analyses. It was concluded that the level of market penetration that would affect an AHS operation had direct relationships to region transportation characteristics. The minimum levels of market penetration needed to open a single AHS lane ranged from five percent in the Minneapolis analysis, to ten percent for the Long Island Expressway. Further analysis also identified relationships to trip length, time savings, and placement of access and egress.

Many of the researches ran "what if" analyses to determine relationships between trip length, time savings, and placement of access and egress. Many found that travelers with short trips did not benefit by taking the AHS; there was no significant time savings given time to get to the AHS. Even if entry/exit facilities were place close together to serve the short distance trips, drivers would not be inclined to use the facility.

One relationship that could not be significantly evaluated was how the extra cost of an AHS-equipped vehicle would affect market penetration. Many researchers could not quantify this due to lack of information on what may be the actual cost differential and also lack of confidence in determining the consumer threshold for this differential cost (Battelle). More definitive research is still necessary to determine the cost relationship of AHS-equipped vehicles to market penetration. This research should also include an investigation to quantify the relationship of cost of owning an AHS vehicle to the proximity of an AHS facility. All these investigations would further the ability of transportation professionals to analyze the relative benefits an AHS could have on a regional transportation system, and enable decisions makers to view AHS as a viable option to solve an area's transportation problems.

6.3.3 Construction Prerequisites

For any project to be funded it must meet certain requirements and be eligible for funding. Projects start out as a transportation problem someone has identified. The next series of studies, Location, Feasibility, and Environmental Impact Statement (EIS), are conducted in order to determine what is the most appropriate solution to the identified transportation problem. As stated before, AHS is a possible solution to various transportation problems; therefore, AHS must be able to compete with all the other possible solutions. Once a solution is chosen, it proceeds through detailed design. For the solution to be funded it has to be accepted as part of the region's and/or state's 20 year plan. Each year, projects from the 20 year plan are proposed for inclusion into the region's and/or state's implementation plans. The implementation plan presented by the regions and states must conform to the Clean Air Act and the projects in the plan must be priority items according to funding preferences. Once the implementation plan is accepted, projects are funded according to their priority. If funding is granted, the project is entered into the short term plan of funded projects, however, the actual funding that is guaranteed is that specified for the current year. Even though funding is only guaranteed for the current year, construction of the project commences.

The path to construction of any project is complicated and long. As a rule of thumb for most major projects, the time that elapses from identification of a problem to actual construction of the solution can range from 10 to 20 years. The issues that have been expressed concerning AHS associated with this process are: (1) How will AHS be incorporated into this process? (2) Will conventional funding sources be adequate for AHS? (3) Can AHS make it on an individual project basis or is an initiative similar to that which created the Interstate Highway System necessary?

Of lesser importance, but precursor to construction, is the need to identify and develop the processes and procedures that will be used to construct an AHS. To increase efficiency, there will be a need for new construction equipment that conforms to the construction processes and procedures identified. Research has been conducted into the possible use of robotics in an effort to identify how the AHS tolerances can best be met (UC Davis). Further research still needs to be conducted to identify the tolerances and how these tolerances can be achieved in an efficient, cost effective manner.

6.3.4 Traffic Operations

Many of the precursor studies showed that modifications will need to be implemented on the roadway facilities adjacent to an AHS. The volume of AHS traffic could congest surface street intersections, or if traffic is entering and exiting via the conventional freeway lanes, major congestion could be caused due to weaving, and over-saturated ramps. In the Entry/Exit discussion, some of these issues were addressed. Results suggested that if analyzed on a case-by-case basis, different configurations and operational approaches could mitigate the impacts of the AHS traffic.

These impacts can be rectified; however, the issue is whether these improvements are part of the deployment of an AHS system, or are they a part of, and the responsibility of, the affected jurisdiction’s transportation improvement plan? That is, should the non-AHS upgrades be considered a normal cost of improving service in the affected jurisdiction? A major factor affecting this issue is the placement of the entry/exit facilities. Research showed that closely spaced AHS intersections distribute the impact on non-AHS roadways, while widely spaced intersections concentrate the impact (Battelle, Calspan, Delco). However, no matter how the AHS interchanges are spaced, these interchanges will stress the adjacent roadway system. Some felt that AHS should define these modifications; they indicated that AHS should take a systems approach to traffic operations and not only be concerned solely for the AHS facility itself, but also for the surrounding facilities it affects. Some felt that AHS funding should provide for all improvements. Others felt that this is an extensive burden to place solely on AHS, and that it may make the AHS solution less capable of competing with comparable solutions. One suggestion was that an AHS should be viewed in the same perspective as the addition of a new, non-AHS solution; for example, if an alternative solution is light rail, then the approach for costing the impact on surrounding roadways because of access to the light rail system should also be used in evaluating AHS.

The AHS researchers felt that AHS is a viable solution to the increasing demand on many existing roadway networks. Research conducted by PATH has illustrated the operational capacity of an AHS. At the theoretical maximum, an AHS operating 15 car platoons with intra-platoon spacing of two meters and inter-platoon spacing at 60 meters traveling at 90 km/h could theoretically service 8250 vehicles per hour per lane. However, the PATH researchers caution that this theoretical maximum is for "steady state" flow conditions; that is, no entries or exits. Vehicles traveling on AHS will be maneuvered in and out of platoons, across lanes, etc.; this will disrupt the steady state flow and reduce the capacity of the facility. PATH has analyzed various AHS operational configurations in order to determine a operational estimate of AHS capacity. This estimate has many facets including the issue of whether to platoon or not. In the platoon case, PATH calculated capacities ranging from 4600 to 7200 vehicles per hour per lane (vphpl) depending on frequency of entries and exits, and depending on the entry and exit strategies.

Instead of investigating the possible capacity of an AHS, other researchers concentrated on identifying the operational characteristics of an AHS. Besides the issues concerning the volumes of vehicles entering an exiting an AHS, researches also identified AHS relationships to facility speed, travel time, and delay. Dunn Engineering, part of the Calspan team, modeled various scenarios in their investigation of operational aspects of AHS. The scenarios studied included the Long Island expressway, Maryland I-495 Capital Beltway, Boston I-93, and the New York State Thruway. The results of these investigations indicated an overall benefit in traffic operations when AHS is introduced into an area. Dunn's research indicated that as much as a 38 percent reduction of a driver’s travel time could be obtained. In the area serviced by the AHS, findings also indicate that average operating speeds increased and total vehicle hours decreased for both AHS and non-AHS vehicles. All of Dunn's results were based on an AHS lane capacity of 5000 vehicles per hour (vph). Dunn's findings are confirmed by investigations conducted by DMJM, of the Delco team, on a hypothetical freeway based on I-17 near Phoenix, Arizona. Their investigation of an AHS and surrounding operations also indicated that, "..an AHS lane increases the overall travel speed within a corridor." and "The total number of vehicle-hours in a corridor is reduced by the implementation of an AHS lane." DMJM's results are based on an AHS lane capacity of 6000 vph.

SECTION 7

INSTITUTIONAL AND SOCIETAL FINDINGS

This section describes some of the institutional and societal concerns that surfaced during the PSA. The opinions of a wide range of interested parties were sought and recognized. These included professionals in many transportation related skills and others, some of who were specialist or experts in their own fields, some who were claiming no particular relevant perspective other than to be potential users/customers, and some whose profession is to represent the interests of others. Many researchers feel that institutional and societal issues will be more difficult to resolve than technical issues, and that the nature and form of these resolutions will have a critical influence on the overall success of AHS deployment projects.

The concerns are grouped here in six areas; Legal and Legislative, User/Market Acceptance, Environmental, Drivers' Roles, Equity, and Governmental. Interactions between and among the areas often exist. The referenced PSA reports treat both the areas and their interactions in considerable detail.

7.1 LEGAL AND LEGISLATIVE

Society's desires are, to some extent, codified in the institutions that have been established. The legislative context facing AHS and the nature of legal activities that may be associated with the introduction and operation of an AHS, combine to suggest a series of issues that AHS project designers must consider. None are simple, but none appear to be show stoppers.

7.1.1 Tort Liability

Because an AHS takes total control of all the vehicles on its dedicated highway lanes, "the system" must assume some level of liability for the consequences of any malfunction. An AHS will be made up of the instrumented AHS highway lanes (including the system-wide traffic management operations), and the AHS instrumentation of the vehicles traveling on the AHS lanes.

When an AHS malfunction occurs and there are losses, the owner and/or operator of the AHS lane may be responsible (i.e., government, utility, toll road operator, etc.). If a failure occurs on a vehicle, determining the responsible party may not be a simple process. The liability could be deemed to lie with the vehicle assembler, the component manufacturer, the vehicle owner (who is responsible for maintaining the equipment), the driver/passenger, the state and/or Federal government who establishes guidelines and procedures to ensure each vehicle's safe operation, or some, or all of the above. Appropriate/acceptable models for risk sharing among vehicles, infrastructure, and operators will need to be established.
Tort liability is also not seen as a '"show stopper" if costs are controlled and safety is secure (SAIC). The ongoing ITS program will provide some basis for predetermining the conditions for AHS. But these questions remain:

- Should Federal legislative protection be sought to limit liability per transaction and the amount of punitive damages that can be awarded?

- Should the user be expected to accept limited liability through a "user agreement" format? Are there driver and vehicle performance indicators that would serve as probable cause for police intervention?

- Can or should a mediation process be established to avoid nuisance lawsuits?

The existence of a variety of possible approaches through changes to state/federal law, creative regulatory approaches, insurance industry involvement and efforts at tort reform are already underway unrelated to ITS/AHS (Calspan). The higher the level of command and control exercised and accepted, the more complex the resolution may need to become. Legal opinion (SAIC) noted that the positive control of AHS should reduce the potential for serious crashes, thus reducing the total liability cost per vehicle mile of travel. The savings in total liability cost can be used to help compensate stakeholders who must assume shifts in liability. Reforms that limit damage awards shift the cost of product caused injuries to the injured party. The most effective (and proactive) method to control costs related to liability is through careful product design and careful system operation. This is best accomplished by a fair and open regulatory framework.

7.1.2 Privacy/Enforcement Issues

The potential for invasion of personal privacy is part of a broad societal concern for impacts linked to living in the information era. The research to date suggests that appropriate conditions can be designed into an AHS. Ultimately, the technical issues around privacy, as legislated to date, can be resolved. However, AHS may introduce a level of complexity over current ITS technologies which will require specific design attention (SAIC).

7.1.3 Compliance with Current Legislative/Prohibitive Regulations

An AHS system will probably evolve to become one of many tools for improving our highway system. This will subject it to all of the legislation that currently affects more traditional highway projects. Furthermore, it is possible that the AHS will be heavily affected by regulations and legislation in other areas, such as Federal Communications Commission (FCC) mandates, which do not always affect traditional transportation improvement projects. These could be regulations that have already been or will be enacted for other reasons, such as protecting the public right-of-way, before the requirements of an AHS are determined. As the AHS program progresses, it will be necessary to keep current on the impacts of pending legislation as well as help identify necessary legislation for deployment (Calspan).

7.1.4 Multiple Objectives

Surface transportation policy can offer a mechanism through which several objectives can be implemented. There are many different stakeholders in the transportation arena that have different objectives to satisfy. This includes a range of things from demand strategies such as the use of HOV facilities and transit-only lanes to move more people with less vehicles, to reducing congestion and vehicle miles traveled (VMT), to better regulation and operations of commercial vehicles and hazardous materials. An AHS could offer an opportunity to implement one or more of these objectives. Furthermore, an AHS may only be acceptable if it is used in a manner by which multiple policy objectives are incorporated (Battelle).

7.1.5 Special Licensing

The complexity of an AHS system could conceivably make standard licensing procedures inadequate to ensure driver capability. If separate AHS licensing were necessary or desirable, it might require the federal government to take a role in the licensing and regulation to ensure consistency among the states. The SAIC research suggests that the FAA regulatory model may supply an insight for important aspects of implementing a federal inspection program. However, this model has some drawbacks and would probably need modifications to make it appropriate and attainable (SAIC).

7.2 USER/MARKET ACCEPTANCE

Questions of acceptance by individual users, and by "the market", turn on matters of benefits (those that are visible and perceived as credible), complex issues of society's desires for economic growth using environmentally positive and sustainable technology (green mobility), and a rate of introduction that reflects acceptable rates of change. To begin to get a sense for the public’s appreciation for the attributes, costs, and benefits expected for AHS, four citizen focus groups were conducted (BDM). There were positive interests expressed regarding system performance and economic development. The groups were enthusiastic in their discussions; the “techno-phobia” level was low. The focus groups indicated that public acceptance has both user and community aspects; potential users became creative in their personal responses to AHS attributes, while guardians of the community good raised environmental and land-use concerns.

7.2.1 Demonstrable Benefits

The success that an AHS will have depends largely on the benefits that it demonstrates. The benefits must be desirable to many different stakeholders: it is competing for funds with transportation and other projects. In addition, benefits should be visible as well as quantified; documented benefits are desirable, but may be less persuasive than what the public/ consumers can see for themselves (Calspan). Another researcher suggests that an important element is winning public acceptance even in the face of ideologically based opposition for the new technology to present such clear and widespread benefits that the public judgment of benefits vs. costs and risks is positive (Battelle).

The type of benefits that are desired may vary by stakeholder. For instance, the transportation community may demand a cost effective, sustainable system that improves efficiency while the environmental community will insist that the AHS demonstrate an overall net benefit in environmental measures like carbon monoxide (CO) and nitrogen oxide (NO_2). Furthermore, the user may demand that the system is safe and convenient before opting to make a transition. It rapidly becomes clear that the desired benefits of these communities must be established either prior to or concurrently with design to ensure a system that will be acceptable. Focus groups conducted with participants who had no prior knowledge of AHS concluded that the benefits should be clearly seen in order to gain public acceptance (BDM). This will make it critical to involve these groups during the life-cycle and use the insight they offer as goals and objectives for the AHS. The benefits expressed by the focus groups included reduced travel times and spare time for work or leisure while traveling.

7.2.2 Perceptions

The role that public perceptions will play in AHS development is a subject that must be understood sufficiently well for an appropriate strategy to be formed and acted upon. Risk perceptions cannot be ignored, and equally, should not be allowed to control the debate for lack of perspective, or misrepresentation, or being misunderstood. Battelle noted that the political viability of AHS will be affected by the way it is perceived by the public--will its perceived benefits outweigh its perceived costs and risks? Review of comparable transportation and other new technology implementations suggests that the safety of AHS will be the subject of intense public scrutiny and media attention, and that, regardless of the prospective actual (real) merits of AHS, people will act largely on their perceptions. To the individual, perception is fact. For example, activities over which we exercise personal control are generally perceived as less risky and thus more acceptable. This may or may not be supported by statistical analysis; people are not consistently rational. AHS can win public acceptance if it presents the clear benefits that overwhelm risk concerns.

Informal interviews and literature reviews suggest that AHS technology, at this early stage, is not well known by the public. It is perceived by some to have potentially fatal or catastrophic consequences. The perception of safety may be an important public acceptance/marketing tool for a new vehicle-related technology (Calspan). However, experience also supports the fact that most people hold a positive attitude toward advanced technology and automated systems, particularly when human control is possible as a back-up. The public has learned that human error is ubiquitous, that automation can mitigate the effects of some types of human error. On this basis, knowledge about and familiarity with the "new" technology can help reduce the level of concern.

7.2.3 Sustainable Transportation

Politically influential stakeholders (e.g., environmental organizations), as well as federal agencies, are pressing for greater attention to be paid to sustainability (Battelle, BDM). AHS can support improved sustainability when transportation planning takes a proactive approach to mitigating adverse impacts on human communities and settlement patterns, and reducing pollution and the use of non-renewable energy resources.

Transportation and mobility are critical to economic sustainability. Those with concerns for the nature of economic growth and the "culture of speed and mobility" (UC Davis), look to reductions in urban trips because the equation between VMT and environmental impact is assumed. AHS offers a technological alternative that can restructure this equation.

7.3 ENVIRONMENTAL

The following sections describe the environmental issues that an AHS will face. This section does not include the weather related aspects of the environmental domain as those are addressed in other sections dealing with design issues. These issues are not comprehensive but are considered to be some of the most important. It is crucial that AHS designers (as well as transportation entities) embrace the concerns of the environmental communities and work towards mutually satisfactory solutions. Environmental groups are looking for good research evidence based on solid modeling that AHS will work as advertised without causing the “same old set of problems” for which they have been criticizing transportation systems in the past (Battelle).

7.3.1 Increased Vehicle-Miles-Traveled

Society is concerned about the quality of the nation’s air and the increased consumption of the world’s liquid fuel resources; VMT has been identified as a control parameter. The concern is that an AHS might encourage/induce more internal combustion engine vehicle-miles-traveled; if so, then overall emissions and fuel consumption may increase even though emissions are reduced on a per-vehicle-mile basis. Research suggests (Calspan) that AHS might help lower emissions by smoothing out traffic flow. Other studies have shown that travelers appear to increase their VMT until they use up a given amount of travel time (BDM). MPOs may be able to take advantage of these characteristics as they incorporate AHS into their transportation plans. In non-attainment areas, AHS may be used in conjunction with transit, HOV traffic, congestion pricing and the introduction of alternative propulsion (low and zero mobile source emission) vehicles. One consideration is whether addenda or changes to the ISTEA would recognize these opportunities and revisit the use of VMT as the sole surrogate parameter representing environmental impact.

7.3.2 Land Use Impacts

Land, in many places, is becoming a scarce and valued commodity. Transportation is an integral part of land-use planning, which is very much a local political issue. It could be argued that AHS could have profound effects on urban sprawl due to its potential to increase throughput and reduce travel time. Research from Princeton University (Calspan) states that by reducing the time cost of travel, an AHS has the potential to significantly alter the current land use pattern. By reducing the travel time for a given trip, AHS will decrease the demand for proximity; in general, such changes tend to decentralize the residential and business areas. Therefore, it is necessary to research the impacts and build the necessary tools so that land-use planners can explore the net effects of deploying an AHS. This can then be coupled with other objectives, such as demand management strategies, to enhance the desirability of an AHS. On the other hand, the lack of accurate projections could become a major stumbling block and adverse effects may result.

7.3.3 Emissions/Air Quality

A critical aspect of any transportation project is its net effect on the environment. AHS-related air quality issues are of particular importance because of the mandatory nature and strict standards of the Clean Air Act as amended (Calspan). AHS research and development will take account of technological advances in emissions control, cleaner fuels and alternative propulsion systems which could aid in reducing emissions on a per kilometer basis (Delco). Such advances in vehicle technology are already improving emissions compliance. Coupling these improvements with research that suggests that AHS might help lower emissions by smoothing out traffic flow (Calspan, PATH). This could lead to a very desirable system. This reinforces the need for accurate and conclusive research to demonstrate the net effect on the environment.

7.4 DRIVER RESPONSIBILITY

One challenge of particular concern is understanding and managing the human aspects of full vehicle control. More detailed research findings with respect to driver role are contained in section 5.5. The system must be designed so that the role of the driver through various phases of transition to the AHS is accommodated. The transfer of control to the system, and then back again to the human will need to be carefully researched. Also, reactions to the closer operating headway possible with an AHS need to be carefully studied. The system cannot scare its users.

Concerns identified by the PSA research include:

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

7.5 EQUITY

One issue is whether the system should be available to the entire public or only those who can afford tolls and options on their vehicles. This is an issue generic to public services in general, and to the broad ITS program of transportation improvements. A restrictive deployment might be subject to criticism even though AHS is expected to reduce congestion on both AHS and non-AHS roads. Each region will need to consider the demographic and economic impacts of its AHS installations and pricing to avoid this mistake.

- Should the state and/or Federal government provide incentives and/or help to individuals to equip their vehicles with AHS instrumentation?
- If a totally toll-financed system reduces equity concerns (no tax subsidies), will everyone be able to afford access, or will it raise concerns about discrimination for people with lower incomes? Would the public utility type of AHS management and ownership reduce this concern?

7.6 STATE, LOCAL, AND REGIONAL CONCERNS

Improvements to the highway system have traditionally been handled by state and local transportation agencies. At some point, these same agencies will be considering AHS. It may be that little will be required of them if AHS relies on a strongly vehicle-based system or they could be facing major infrastructure improvements if AHS requires a smart roadway design. The following sections highlight some of the major concerns that will face this group of stakeholders.

7.6.1 Changing Responsibilities and Environments

The AHS will introduce a new, high-technology level of complexity to those organizations which are responsible for highway functions and services. The AHS lane instrumentation could include advanced electronic sensors, on-line computers and software, and multi-element integrated communications systems. Installation and maintenance of these systems may present a significant challenge to the operators. Currently, state and local transportation authorities lack the manpower and technical expertise to operate and maintain an advanced AHS system with a lot of control in the infrastructure (Battelle). For example, maintenance of roadside electronics may involve relatively frequent circuit and/or software testing, component replacement, and system integration testing, as the replacement components are brought on-line. An advanced AHS will employ traffic management functions which may involve real time system monitoring; the operators for such a system will need special training.

7.6.2 Funding Challenges

Planning organizations that recommend AHS must realize that the funds for the systems' operations and maintenance must be adequate and must be included in the state's operating budget as a non-negotiable item (Battelle).

Approaches to meeting these challenges include the following:

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

- Facilities management firms can be hired. Full service management of the AHS infrastructure could be privately provided. However, this could introduce questions regarding the liability of these firms when incidents occur.

- Facility ownership could be private, such as a private toll road.

- A separate public utility type of organization could be established to fund, build, and maintain AHS. Would an AHS commission need to be established?

- Insurance companies and insurance regulators will need to assess the impact of AHS operation on rates.

- Programs for inspection of AHS vehicles will need to be established.

7.6.3 Interagency Cooperation

Transportation agencies are beginning to realize that coordination and cooperation are essential to succeeding with current and future transportation improvements. However, many agencies experience a variety of organizational fragmentation both internally and across jurisdictions, especially with the transportation system growing out of a role that was strictly building and maintaining roadways to an expanded role that includes installing and upgrading electronic equipment. Many of the problems currently facing state and local DOT's have solutions that possess a regional foundation to obtain optimal results.

Recently there has been a gradual shift to deal with transportation issues on a regional basis erasing traditional local boundaries. Furthermore, transportation agencies and urban planning organizations are beginning to recognize the value of cooperative efforts for major transportation endeavors. Regional transportation authorities such as TRANSCOM are forming to work ever increasingly difficult transportation problems and deal with a changing transportation paradigm that includes more technology driven applications. Although this is occurring, an AHS is likely to require an even higher level of coordination due to the complexity of the operations.

7.6.4 Planning Process

A critical AHS Program goal is for AHS to be recognized for what it can contribute to the total spectrum of regional surface transportation needs in traditional transit, commercial, rural and urban, private and evolving public para-transit environments--that it should be viewed as a set of flexible tools for transportation planners and decision makers, not as an inflexible construct.

An AHS project will face the same challenges that traditional highway projects encounter in the planning process as well as additional ones that are unique to an AHS. For example, conforming to legislation (e.g., the Clean Air Act as amended), allocating environmental and land use impacts, developing cooperation among local and regional jurisdictions, and securing funding sources. Such institutional and societal issues are typically more challenging and difficult to bound than technical issues. Technology is not a guaranteed "fix" for social problems, and in some cases, new technologies may create more problems than they solve. But, in his presentation to the Transportation Research Board in January of 1994, Secretary Pena commented that "...we can meet these challenges by providing 'sustainable transportation'—transportation that meets the needs of this generation without compromising the ability of future generations to meet their needs." (Volpe).

SECTION 8

BENEFITS AND COSTS

The goal of the PSA research in this area was to identify the major benefits and costs of an AHS, and to attempt to define metrics for some of the elements. This section describes the results of these PSA research efforts...a high-level attempt to: (1) define a model for structuring AHS costs and benefits; (2) quantify the potential impacts of a conceptual automated highway system; and (3) define how an AHS might be financed.

The research was conducted by three teams using very different strategies and assumptions; the results provide a good sense for the problems that face those who would answer the questions: "How much will AHS cost, and, How should we represent the benefits?" Table 8-1 compares the three approaches. The combined output provides the following:

- A national perspective from a survey of AHS project initiatives (PATH)
- A generic cost/benefit analysis (CBA) based on an existing urban freeway (PATH)
- A review of the uncertainties in applying a CBA to AHS (PATH)
- A traditional transportation project parametric CBA model (Delco)
- A CBA reflecting the introduction of AHS as a new product, designed for extrapolation to the national level (Delco)
- A traditional U.S. DOT-type MOE analysis treating four highways (Calspan)
- A framework for organizing AHS CBA efforts (Calspan)

8.1 BENEFITS

The AHS should provide benefits in all of the stakeholder categories; that is, those who will design, build, deploy, operate, and use the AHS. Benefits should accrue to users, communities, State and regional transportation agencies, U.S. industry, and society as a whole. The following is a qualitative description of the types of benefits that have been identified to date. As with any new capability which offers a step-change in system performance, efficiency, and accessibility, we can expect as yet undefined applications with benefits (and costs) to stakeholders not yet imagined. It is critical that efforts to identify, measure, and evaluate all these benefits continue, building on the PSA findings. The PSA

Table 8-1. Comparison of the Characteristics of the Three Cost/Benefit Analyses

	PATH Team	Delco Team	Calspan Team
Approach	Life-cycle CBA of three evolutionary stages of AHS to be introduced into a defined existing urban corridor; assumptions guided by intent to develop "representative " results leading to a range of generic insights.	Traditional highway construction project CBA for development in an existing corridor. Baseline plus two options plus AHS highway (four scenarios) for typical MPO comparative decision support. Demand data and assumptions guided by recent studies (DMJM for infrastructure, Hughes Electronics for vehicle equipment), and intent to develop ROI type answers for federal executive/legislative decision makers.	A framework for identifying and accumulating AHS system element costs (vehicle and infrastructure) that is inclusive/comprehensive, and reflects the costs and benefits for an incremental/evolutionary approach to AHS implementation. Assumptions are guided by an operations perspective and the intent to develop a tool for exploring C/B threshholds, for addressing a comprehensive list of costs and benefits, for evaluating these lists, and for ranking them.
Vehicles	Mixed with defined equipment.	Mixed with defined equipment	Mixed
Infrastructure	California Route 101 (Hollywood Freeway) from Hollywood to central Los Angeles.	Route I17 in the Phoenix non-attainment region	Long Island Expressway, Boston Artery project, the National Beltway (I495), NY State thruway sections.
Scenarios	1. AHS Ready (e.g., ICC +automated steering) 2. No lane chg, 3500-4000 vplph 3. Full AHS: 7000 v/hr/lane	1. Base case 2. Converted HOV lane 3. Additional general purpose lane 4. Converted AHS lane	The framework will be populated with detailed infrastructure cost data and parametric vehicle cost data.

Product:	Illustrative benefits (qualitative) and associated costs ($) for a range of site difficulties (e.g., lane additions, elevated sections present in an existing corridor) presented in the context of a survey of AHS-like project study findings, and an assessment of the uncertainties in developing CBAs for AHS.	Parametric model suitable for continued research (into alternate scenarios), with particular sensitivity to the distribution of stakeholders' benefits and the relationship between AHS vehicle costs and AHS market penetration & demand. Costs and benefits rolled up into relative dollar measures for 2010 and 2017.	A tool for organizing/developing CBA inputs and studies. A basis on which to assemble subsystem costs (for elements and increments); a catalyst for common data dictionary; and, using the available practical cost data, a basis for exploring the relative outcomes (e.g., benefits and costs against service levels) of high level AHS program initiatives.

evaluations relied on traditional measures such as trip time and accident rates; what follows is, therefore, an agenda for the areas needing expansion and improvement.

8.1.1 User Benefits

The AHS will provide travel services to a full range of today's highway users. The prime urban market for AHS is made up of commuters, HOV lane users, transit operators, and truckers. All will benefit from reduced congestion and reliable travel times (Calspan). Rural users will benefit from faster trip times (from higher speeds) and greater safety as run-off-the-road crashes are virtually eliminated. Benefits will accrue to all users; however, the relative level of the benefit may vary. For example, trucking operations may benefit more from the dependable travel times and greater safety than from user comfort.

- Reduced congestion - Conversion of an existing freeway lane to AHS increases the capacity of the freeway; if the addition is coupled with demand management policies, such as HOV and transit lanes and/or parking management, then congestion will be relieved. This will reduced travel times for both those traveling on the AHS as well as those that continue to travel on the manual freeway lanes (Calspan, Delco). Calspan suggested that a target trip time savings of one minute per travel mile on the AHS is probably achievable with a dedicated AHS lane and proper entry and exit provisions. Their modeling of the LIE projected travel time reductions of 38 percent; reductions of 48 percent were projected for the Washington Capital Beltway (I-495). In Calspan's study, all traffic in the corridor experienced reduced travel times.

- Trip time reliability - Travel times should be much more dependable because of the consistent AHS traffic flow due to automated traffic management. However, congestion at AHS entry and exit points could off-set this advantage. The AHS, as a supplement to the existing roadways, must be integrated with the existing highway system. Measures for the interaction of the AHS flow and the existing road system must be developed.

- Greater travel safety - Estimated improvements ranged from a minimal 30 percent better assuming automated traffic mixed with manual traffic (Calspan and Battelle) to 80 percent better (Calspan). This is based on analysis of causal factors in crashes, and of automated reactions that would help avoid inadequate and inconsistent human responses that often result in crashes. However, the reliability of the automated response and the human reaction to this assistance requires further research. In general, it would appear that fewer crashes should translate into reduced insurance rates. The specific impact on system safety from deploying an AHS must be explored.

- User comfort and access - Focus groups anticipate far less stress and worry in highway travel for those using AHS. For many travelers (commuters) the AHS may translate into increased work time (the office in the car); on long trips under AHS control, this may mean increased leisure time (e.g., read a book). These benefits will be real, but translating them into a dollar value will be difficult. Even though all travelers enjoy the benefits of reduced congestion, only those on the AHS will enjoy the increased safety and comfort. This could raise an issue about who benefits and who pays. Comfort and convenience are marketing realities for many commodities; they are examples of new measures of benefit in transportation services that require study and quantification.

- Mobility - A national AHS network would enhance the Nation's mobility for all users including shippers, transit companies, senior citizens and the handicapped. Smooth transition through several stages of driver assist systems on the way to fully automated vehicle control must accommodate all categories of users. Defining a highly reliable and safe system which is also affordable and provides nationwide compatibility with local/regional tailoring will be a major challenge. To help with the decisions along the way, we need an expanded understanding of, and measures for, these system mobility aspects.

8.1.2 Community Benefits

The AHS will represent a powerful supplement to a community's transportation system as it is augmented to meet growing needs and/or problems. It will provide communities with several specific benefits:

- Air quality - There are indications that per-mile tailpipe emissions of individual vehicles will be reduced on AHS due to smoother travel and less congestion. However, the increased capacity from AHS may attract additional vehicular traffic. Approaches and policies for ensuring that this added capacity results in reduced congestion and increased passengers-per-vehicle--such as car pooling, demand pricing and transit-only lanes--must be defined and correlated to AHS.

- Need for right-of-way - Relative to construction of new highway lanes to add capacity, there will be less land needed for highway rights-of-way by allowing increases in traffic flow to be handled on existing rights-of-way. In many cases this will mean that the costs (both direct and indirect) of building a new highway can be avoided.

- Transit support - Bus transit systems will benefit from AHS services through faster, more reliable service. In addition, bus-only lanes and integration with local transit operations can extend this benefit; for example, transit terminals that connect to local routes and/or rail services could be provided.
- Integration with ITS services - In many ways, the AHS is a logical extension of other ITS services and integrates nicely with them. As discussed above, the AHS is the next logical step for the partial vehicle control services such as ACC and collision avoidance. AHS also will integrate into an existing traffic information service where it will be viewed as yet another transportation asset upon which travel planning and information can be provided. AHS will also integrate nicely with existing traffic management centers; again, it will be another highway resource to be monitored and to be integrated into the other community roadways. The level of weather and congestion monitoring required for AHS is greater than for other ITS services, so AHS can enhance travel management for the entire region by feeding these enhanced monitoring results to the regional transportation management center. Finally, AHS could integrate nicely with commercial vehicle operations improvements such as automated vehicle identification, electronic permits and registration and weigh-in-motion.

- Less demand for emergency services - Because of the reduced crash rate on the AHS, demand on a community's support services--such as fire, rescue and emergency room--should be less. AHS should allow better response times from these services when they are needed in the community.

8.1.3 State and Regional Transportation Agency Benefits

The State and regional transportation planning agencies are key stakeholders in the AHS. They will need to integrate AHS into their planning activities, including statewide State Implementation Plans (SIP) and regional or local Transportation Implementation Plans (TIP). They must view the AHS as a desirable, cost-effective investment alternative that can be tailored to meet their community's transportation needs. As a platform for local transportation policy initiatives, the AHS will provide the following benefits:

- Peak efficiency - Estimates are that an AHS will allow two to three times as many vehicles per peak-hour of travel compared to today's manual highways, often using existing highway rights-of-way. This will come from increased traffic density and speed per lane because of the tighter operating tolerances possible with full automated control. It also comes from providing a more uniform driving performance by eliminating variances caused by human distractions and by reducing acceleration, deceleration, and unnecessary lane changing. And it also comes from the possibility of narrower lanes allowed because of the more accurate AHS steering. However, this increased capacity must be integrated with the local roadways to obtain an overall increase in transport efficiency.

- Gradual transition - The AHS can be built one segment at a time. This will allow a long-term upgrade for major highways and a smoother transition from today's vehicles, highways, and drivers. A smooth installation and practical operation for AHS are also achievable using automated design, deployment and maintenance approaches (UC Davis).

- Investment return - Early cost/benefit analyses indicate that an AHS may be able to provide a favorable return on investment when compared with other transportation options in many potential deployment environments.

- Emissions conformance - Because of its increased efficiency, AHS offers state and MPO-planners a tool for both increasing capacity and meeting the Clean Air Act (Amended) requirements in non-attainment areas. AHS will also increase the efficiency of other programs aimed at reducing total VMT through transit, HOV lanes, and demand pricing

8.1.4 United States Industry Benefits

The AHS will also offer major benefits to industry:

- AHS Market - Vehicle manufacturers, highway construction firms, and vehicle electronics companies will enjoy substantial, long-range market opportunities as AHS is deployed nationally. These opportunities will be available to all because of interoperability standards and regulations. International market opportunities should also be available since the U.S. AHS effort is at the forefront of AHS development worldwide. For vehicle manufacturers, near term automated vehicle control products (e.g., ACC, collision avoidance) will benefit from the technology research efforts of the AHS program.

- Trucking - Trucking firms will benefit from safer highways and more efficient roadway operations, particularly more reliable point-to-point travel times which will translate into lower operating costs and support for realistic just-in-time inventory control for its customers. A more advanced AHS may offer potentially substantial labor savings because a single driver may be able to operate a vehicle longer, or because the requirement for operators of some vehicles on special systems may be reduced or eliminated.

- Market access - Industry in general will benefit from increased transportation reliability, mobility, and flexibility.

8.1.5 Societal Interests

Some of the Nation's broader societal needs will be addressed by the AHS. These include:

- National Highway System supplement - As a supplement to the National Highway System, the AHS will help meet the goal for an inexpensive, reliable national network of highways that will increase our Nation's mobility. This will increase the Nation's robustness and vitality.

- Increased mobility for disabled and disadvantaged - People who are disadvantaged in some way tend to be cautious in planning travel because of accessibility and the ordeals of highway travel. The AHS may offer increased mobility for these people by assuming many of the more arduous driving tasks.

- Reduced fossil fuel consumption and emissions - The AHS can reduce both fossil fuel consumption and emissions per vehicle mile traveled. And when coupled with other programs and policies aimed at demand management, this should have a national impact as AHS implementation increases.

- Defense conversion - During AHS development, defense and aerospace firms can employ their expertise in this "civilian" application. In the long run, these firms will have opportunities to compete as the AHS implementation results in the creation of opportunities nationwide.

- Tort liability - Fewer crashes should result in substantially fewer tort liability cases. However, in those cases where there are crashes on the AHS, it is not clear at this point who would be responsible. A definitive set of rules and/or legislation that clearly pre-defines this area would be helpful; they might help reduce the painfulness of initial tort liability claims in a new AHS.

- Emergency response - An AHS, with its system-wide management, should be highly responsive to local and regional emergencies and evacuations.

8.2 COSTS

It is difficult to recognize and quantify the costs of a system that is still in the conceptual stages and where many unknowns concerning design performance and operational concepts (such as the distribution of liability) still exist. Nevertheless, the PSA studies were able to use available cost information, coupled with engineering judgments on the unknown elements, to develop scenarios that were quantified. The PSA research used traditional methodologies to develop the profiles of various AHS configurations as well as to define baseline cases (otherwise called the 'do nothing' approach) on which they performed the reported cost analyses. Although the specific approach each team took is different, the results--taken as a whole--provide preliminary evidence for the economic feasibility of AHS; and under favorable assumptions, several approaches anticipated a strong economic rate of return.

The PATH research team studied an evolutionary approach using the catalyst of AHS0-ready vehicles, and installation of low-cost infrastructure to support automatic steering on inter-city highways. Elemental roadway costs were based on a specific implementation along the U.S. 101 freeway in Los Angeles. For the year 2020, high capacity AHS appears to be most viable in a select group of cities, reasonably amounting to 7,500 lane-kilometers, supporting 25 to 40 million vehicles. Associated annual cost savings would amount to $2.3 billion per year. This represents a five percent annual return on a $11 billion investment, deferred twenty-five years.

From a cost based perspective, PSA researchers determined the minimum viable peak hour AHS market penetration of vehicles to be nine percent, depending on the number of manual lanes parallel to the AHS lane. Below this level, AHS operations actually reduced the overall highway capacity. The penetration needed for viable operation of a single AHS lane in a corridor was judged as 5 to 15 percent (Delco, Battelle, Calspan); at this level, the number of vehicles that should be attracted to an AHS lane were sufficient to justify its operation as a dedicated facility. However, one cost analysis (Delco) estimated the peak-hour threshold at 33 percent; this assumed that only vehicles traveling in the highway adjacent to the AHS lane would use AHS.

There are uncertainties associated with the vehicle costs for AHS. Much of the equipment needed for an AHS may well be part of the standard vehicle by the early part of the 21st century. Electronic actuators, communications antennae for roadside communications, and on-board health-monitoring systems may be common by then. If a vehicle is designed with a potential AHS-upgrade in mind, then much of the increment needed for an AHS capability in a vehicle may be electronics and software (Delco). “Software costs on a per-vehicle basis will be modest due to the large number of vehicles. At a 70 percent market penetration (70 million vehicles), a cost of $5 per vehicle would amount to $350 million dollars of software development.” (Calspan).

Another viewpoint is what the consumer will be willing to pay. One conservative estimate puts the owner tolerance for increased vehicle cost at $500 per year. A second comparison was with the typical price curves for introduction of new options to vehicle owners. As an example, initial units may cost over $2,500, and market penetration will be very low--only among those with higher disposable income. As prices drop to $1,500, the number of units sold may increase ten-fold. Then as the price drops to under $1,000, the option becomes more-or-less a standard offering. The price of in-vehicle navigation units in Japan is following a similar price/penetration curve.

Many of the conventional cost categories that are associated with traditional roadway projects are also applicable to an AHS. How these may change is significant in absolute terms, and, as it may affectthe AHS-specific elements of an integrated regional system. It is possible that the magnitude of the cost may be greatly reduced due to the configuration of an AHS. For instance, the AHS could use existing right-of-way alleviating the high costs associated with obtaining previously undedicated right-of-way or require less than adding conventional lanes or transit. Furthermore, with increased capacity of these lanes, the demand for additional lanes could turn out to be lower, possibly allowing for conversion of under utilized lanes to other uses such as bicycle rights-of-way. These are just a couple of infrastructure related aspects that would have significant cost impacts.

Working with the three PSA reports would lead to many other differentiators (between AHS and conventional highway projects). There will also be “Added Costs.” Currently, the interstate infrastructure does not rely heavily on electronic equipment for normal operations. Preliminary designs of an AHS all have strong emphasis on electronic infrastructure necessary to operate the system. These types of costs for highway projects are not traditionally built into conventional cost equations in this environment. Therefore it will be necessary to incorporate this into future planning and costing models. Also, the upgrade of a region's traffic management center and/or its traveler information services to accommodate AHS will also need to be considered.

How future AHS concepts evolve with regard to the balance of development between the vehicles and the infrastructure, and the scope of system wide (regional) traffic management plans, will all play into the actual deployment costs. Practical projections of the value of benefits and the system costs must be made as the program continues.

8.3 FINANCING

The PSA researchers explored financing alternatives in a general way to see whether they would affect the benefit/cost analysis work. The results were inconclusive because of the lack of definition—the business of ”what and where” needs to be decided before funding strategies can be selected.

The general findings were that potential revenue sources include public tax, subsidies, tolls, fee for use (including priority), special tax districts including those structured similar to public utilities, private development, governmental funding, and public/private partnerships. These correlate in many ways with funding approaches identified for other ITS services.

Since the private sector could potentially build an AHS facility faster and more cost-effectively than the government, rates of return defined by contracts between state and developer could be used and once the investment is recovered and the agreed profit is realized, the road could be turned back to the state.

Some likely methods to obtain revenue for system deployment and operation include user fees, private investments, equipment fees, and involvement of the insurance industry. The question arises concerning which part of an AHS should come first—the roadway infrastructure or the intelligent AHS-equipped vehicle? This clearly has great impact on the funding strategy. The more vehicle-based the system is, the greater the cost is to the individual owner and the less operating costs for the infrastructure. A test track will not be satisfactory to demonstrate the financial success of an AHS. Real-world operational testing will be necessary before major financing decisions can be made.

Market research is needed to help understand the public's willingness to accept various financing approaches such as congestion pricing over other alternatives. A complicated taxing system could be detrimental to the success of an AHS system. On the other hand, a totally toll-financed system could reduce equity concerns (no tax subsidies); however, perhaps not everyone could afford access. In the final analysis, the potential user must perceive enough benefit to be willing to accept the costs.

And, after the system is built, the (perhaps more challenging) concern will be for funding the system's operation and maintenance. The issues associated with a fee-for-use or congestion pricing with an AHS system focus on whether vehicle cost is a bigger concern than fee for use of infrastructure. Clearly, financing is an AHS cost, and, the method of financing will influence the AHS net benefits.

LIST OF REFERENCES

References in this report refer to the Precursor Systems Analysis teams selected to study the sixteen activity areas. Below, the manager of each team is given, the members of the teams are listed, and the Final Reports that were produced are given.

BATTELLE

Team Manager: Jerry Pittenger, Battelle Institute, Columbus, Ohio

The Battelle team consisted of the following entities:

Battelle Institute
BRW
Massachusetts Institute of Technology
Ohio State University
Transportation Research Center
University of Minnesota

Nine Final Reports were delivered in December, 1994:

Contract Overview	
Task A	Urban and Rural AHS Analysis
Task E	Malfunction Management and Analysis
Task H	AHS Roadway Deployment
Task I	Impact of AHS on Surrounding Non AHS Roadways
Task J	AHS Entry/Exit Implementation
Task K	AHS Roadway Operational Analysis
Task N	AHS Safety Issues
Task O	Institutional and Societal Aspects

BDM

Team Manager: Mike Martin, BDM, McLean, Virginia

The BDM team consisted of the following entities:

BDM
Cambridge Systematics, Inc.
George Mason University
SNV
Sverdrup Civil, Inc.

Three Final Reports were delivered in December, 1994:

Contract Overview	
Task F	Commercial and Transit Aspects
Task O	Institutional and Societal Issues

CALSPAN

Team Manager: Joe Elias, Calspan Corp., Buffalo, New York

The Calspan team consisted of the following entities:

Calspan
BMW
Dunn Engineering
Farradyne Systems, Inc.
Parsons Brinckerhoff
Princeton University
TRANSCOM
Connecticut Department of Transportation
Massachusetts Department of Transportation
New Jersey Department of Transportation
New York State Department of Transportation
NY State Thruway Authority

Calspan addressed all of the activity areas; their findings were produced as eight Final Reports delivered in December, 1994:

Volume I	Overview Report
Volume II	AHS Comparable Systems Analyses
Volume III	AHS Roadway Analysis
Volume IV	AHS Systems Analysis
Volume V	AHS Malfunction Management and Safety Analyses
Volume VI	AHS Alternative Propulsion System Impact
Volume VII	Commercial and Transit AHS Analysis
Volume VIII	AHS Institutional, Societal and Cost Benefit Analysis

DELCO

Team Manager: Herb Hall, Delco Systems Operations, Goleta, California

The Battelle team consisted of the following entities:

Delco Systems Operations
DMJM
Hughes Aircraft Company
University of California (PATH)
General Motors Corporation

Delco addressed all of the activity areas; their findings were produced as seventeen Final Reports delivered in December, 1994:

Overview Report

Task A	Urban and Rural AHS Comparison
Task B	Automated Check-In

Task C	Automated Check-Out
Task D	Lateral and Longitudinal Control Analysis
Task E	Malfunction Management and Analysis
Task F	Commercial and Transit AHS Analysis
Task G	Comparable Systems Analysis
Task H	AHS Roadway Deployment Analysis
Task I	Impact of AHS on Surrounding Non-AHS Roadways
Task J	AHS Entry/Exit Implementation
Task K	AHS Roadway Operational Analysis
Task L	Vehicle Operational Analysis
Task M	Alternative Propulsion Systems Impact
Task N	AHS Safety Issues
Task O	Institutional and Societal Aspects
Task P	Preliminary Cost/Benefit Factors Analysis

HONEYWELL

Team Manager: Mahesh Jearage, Honeywell Navigation and Systems Architecture, Minneapolis, Minnesota

The Honeywell team consisted of the following entities:

Honeywell Technology Center
Purdue University

University of California (PATH)
University of Minnesota

Two Final Reports were delivered in December, 1994:

Malfunction Management Activity Area Report for AHS Health Management Comparable Systems Analysis

MARTIN MARIETTA

Manager: Rich Luhrs, Martin Marietta Corp., Littleton, Colorado

One Final Report was delivered in December, 1994; it contained:

Volume I	Executive Summary
Volume II	Maneuver Definition and Functional Requirements
Volume III	AHS System Concept Definition
Volume IV	AHS System Concept Evaluation

NORTHROP-GRUMMAN

Team Manager: David Blancett, Northrop Corp., Pico Ravera, California

The Northrop team consisted of the following entities:

Northrop
PATH

One Final Report was delivered in December, 1994:

AHS Check-In Activity

PATH

Team Manager: Steve Shladover, University of California, Richmond Field Station, Richmond, California

The PATH team consisted of the following entities:

PATH
Bechtel
California Department of Transportation
California Polytechnic State University
Lawrence Livermore National Laboratory
Rockwell International
University of Southern California

Five Final Reports were delivered in December, 1994:

Overview	
Task A	Urban and Rural AHS Comparisons
Task H	Roadway Deployment Analysis
Task J	Entry/Exit Implementation
Task P	Preliminary Cost/Benefit Factors Analyses:

- Vol. I — Cost/Benefit Analysis of Automated Highway Systems
- Vol. II — System Configurations: Evolutionary Deployment Considerations
- Vol. III — Electronics Cost Analysis
- Vol. IV — Roadway Costs
- Vol. V — Analysis of Automated Highway System Risks and Uncertainties
- Vol. VI — Review of Studies on AHS Benefits and Impacts

RAYTHEON

Team Manager: Mike Shannon, Raytheon Corp., Tewksbury, Massachusetts

The Raytheon team consisted of the following entities:

Raytheon Company
Daimler Benz
Ford Motor Company
Georgia Institute of Technology
Tufts University
University of Southern California
VHB

Ten Final Reports were delivered in December, 1994:

Volume I	Executive Summary
Volume II	Automated Check-In
Volume III	Automated Check-Out
Volume IV	Lateral and Longitudinal Control
Volume V	Malfunction Management and Analysis
Volume VI	Commercial Vehicle and Transit AHS Analyses
Volume VII	Entry/Exit Implementation
Volume VIII	Vehicle Operational Analysis
Volume IX	AHS Safety Issues
Volume X	Knowledge Based Systems and Learning Methods for AHS

ROCKWELL

Team Manager: Richard Barber, Rockwell AESD, Anaheim, California

The Rockwell team consisted of the following entities:

Rockwell International Corp.
University of California (PATH)
Systems Technology, Inc.

Five Final Reports were delivered in December, 1994:

Overview
Vehicle Operations Analysis
Malfunction Management and Analysis
Lateral and Longitudinal Control Analysis
Vehicle Evolution Analysis

SAIC

Manager: Cary Vick, SAIC, McLean, Virginia

One Final Report was delivered in December, 1994:

Legal, Institutional and Societal Issues Related to the Deployment and Operation of an Automated Highway System

SRI

Manager: Randal Galijan, SRI International, Menlo Park, California

One Final Report was delivered in July, 1995:

Use of Global Positioning Satellite (GPS) Carrier-Phase Integration for AHS Vehicle Control

TASC

Manager: David Whitney, TASC, Reading, Massachusetts

One Final Report was delivered in December, 1994:

HiVal: A Simulation and Decision Support System for AHS Concepts Analysis

TRW

Team Manager: R.L. Pickel, TRW LBC-1, Redondo Beach, California

The TRW team consisted of the following entities:

TRW
California Polytechnic State University

One Final Report was delivered in December, 1994:

Alternative Propulsion Systems Impact

UC-DAVIS

Team Manager: Bahram Ravani, University of California, Davis, California

The UC-Davis team consisted of the following entities:

University of California, Davis
California Department of Transportation

One Final Report was delivered in December, 1994:

Automated Construction, Maintenance and Operational Requirements for AHS

APPENDIX A

HIGHLIGHTS OF DELCO OVERVIEW REPORT

This appendix contains highlights extracted from the Delco Contract Overview report. The material is included as a convenience to the reader; the full Contract Overview report, as well as the reports on each of the 16 study areas, is available through NTIS.

The material, which contains all of the major Delco findings, is organized into four parts:

A.1 Cross-Cutting Conclusions/Observations
A.2 Focus of the Individual Activity Area Analyses
A.3 Highlights of the Activity Area Analyses
A.4 Summary of the Delco PSA Database Items

A.1 CROSS-CUTTING CONCLUSIONS/OBSERVATIONS

Towards the end of this PSA program, all members of the research team met and identified a common list of cross-cutting conclusions and observations. The following team vision of AHS is a synthesis of those cross-cutting conclusions and observations.

One of the fundamental aspects of AHS design is the division of instrumentation between the infrastructure and the vehicle. Certain system design elements, namely sensing and control, should be principally based in the vehicle. By so doing, the overall cost per user, assuming comparable performance, would be less. A failure in an AHS vehicle, especially on a multi-lane highway, would have less impact than the failure of an AHS infrastructure component. Vehicle components may be tested earlier in the AHS development cycle, before final system integration, and this is another reason for favoring the vehicle control and sensing systems. Overall control of the relationship between vehicle cells or platoons, response to most malfunctions, and high level vehicle guidance are features which should be managed by the wayside infrastructure.

A platoon is a group of indeterminate size of cooperative, coordinated, non-autonomous vehicles. The coordination among vehicles within the platoon is primarily determined by individual vehicle controls (merging and splitting is cooperative with the wayside), whereas coordination among platoons is completely determined by the wayside command structure. Close inter-vehicle spacing reduces momentum transfer at impact, thus enhancing safety, derives certain aerodynamic benefits causing lower overall emissions and fuel consumption, and is more efficient, thus reducing travel time and enhancing capacity. Close spacing adversely impacts driver acceptance, increases the frequency of minor incidents, and challenges current technological capabilities. The spacing can be increased to a distance which lacks the disadvantages of close spacing without risking high momentum transfer impacts if braking control can be coordinated through vehicle-to-vehicle communications. This spacing can be chosen to provide almost the same efficient operation that close spacing allows.

Several conclusions were reached regarding roadway system design. Check-in and check-out stations are required, however these operations should create little or no time delay and should be associated with special AHS ramps, isolated from the regular ramps, except for the special case described as RSC 3. Continuous in-vehicle self-testing, with the results communicated to simple, automated check-in validation stations will minimize check-in delay. Automated vehicle check-out, with a minimal driver test, will produce the lowest possible check-out delay, but does increase the responsibility of the driver.

Some provision must be made in automated highway design for potential breakdowns and for the passage of emergency vehicles to handle malfunctions. It is recommended that the solution be a second, breakdown lane large enough to serve as a second AHS lane if necessary. An intermittent shoulder of sufficient width may be adequate, but this concept requires further study. If the automated highway consists of one or more lanes side-by-side with a non-automated road (RSC 3) then a barrier between the two adjacent dissimilar lanes is required except where transition is allowed to occur.

The operation and maintenance of the AHS should be the responsibility of the present highway operational agencies; the state DOT's, the toll road authorities, and the local highway agencies. An alteration in the attitudes of these agencies towards operations must occur, however, because of the system complexity and the need for pro-active maintenance. For example, specially trained operations personnel will be required and they will probably be needed for round-the-clock operation. It may be that private organizations will be contracted to operate these facilities.

The driver may play a role in the automated system. The desire of many stakeholder and focus groups, made up of agency personnel and the public, would be to generate significant driver involvement. However, many control operations cannot be performed to the required standards of an automated highway by the driver. The driver can, however, identify potential hazards such as road debris and large animals running onto the road and notify the roadside infrastructure so that the other vehicles can be managed around the obstacle. Thus the driver input would initiate a controlled response, but not directly control the vehicle. The driver could also be utilized to control the vehicle in the event that the entire system shut down and manual vehicle operation was the only method of clearing traffic.

A general rule for AHS design should be that the system must be safer than an equivalent non-AHS highway. Specific, quantifiable, and measurable safety goals are needed in order to demonstrate that this rule has been satisfied. There is a safety tradeoff: automation will avoid driver errors, which are responsible for most of the freeway incidents, but the system malfunctions and the impact of external forces can degrade safety. Safety concerns mandate that special consideration be given to the requirements for reliability and maintainability of the AHS.

The establishment of national standards for the automated highway system will be one method for improving system safety. The existence of clear standards will insure compatibility between the vehicle and the highway and common vehicle design standards will reduce vehicle inspection and check-in costs. Care should be taken to avoid the establishment of overly restrictive standards which would limit creativity, competitiveness, and efficiency.

The national transportation system is multi-modal. The automated highway must be integrated with the other transportation technologies and be a key, integral part of the transportation taxonomy. Certainly the automated system must provide for commercial vehicles, public transit vehicles, and public safety vehicles and should offer unique benefits to these vehicles. Exit ramp queuing is one barrier to the integration of the AHS into the transportation system. If the issue cannot be mitigated or avoided with careful design techniques, then special solutions such as direct parking terminals at the exits or an entrance reservation system which guarantees that exit will be to an unblocked road must be resorted to.

Deployment of the automated highway system is difficult because any AHS will require major funding and benefits will accrue only to those who own special vehicles. At issue is total functionality with the first implementation versus staged levels of functionality, probably with mixed flow in a separate lane as a first stage. It is recommended that, for the near term, the evolutionary approach should be adopted, however it is not possible to predict at this time what the final deployment methodology will be. The required subsystems and an open architecture can be developed within the evolutionary framework without a major expenditure for an entire system. There is nothing lost if a switch is made to attempt a fully developed AHS at the first deployment. Automotive product functionality increases incrementally, in step with highway evolution. Early results are obtained from a federal program based on an evolutionary strategy, thus reducing the risk that the program will be canceled because of cost or a major error. However, the evolutionary approach may provide only a small safety benefit initially and the driver comfort benefit that is essential means that driver-in-the-loop evolution would be counterproductive. Also, the revolutionary approach offers significant immediate safety, driver comfort, travel time, and capacity benefits.

It was concluded early in the program that user benefits must be provided at all stages of AHS functionality. Besides safety, reduced travel time, driver comfort, potential reduction in fuel consumption and vehicle emissions derived from highway agency vehicle management, and reductions in traffic congestion, other significant benefits derived from AHS would be the improved traffic flow at peak hours and the improvement to the urban environment derived from increased mobility. Induced demand could be mitigated by using a pricing strategy that penalized single occupancy vehicles and those, in general, who exceeded a certain number of kilometers per week on the AHS, The automated system must be compatible with and contribute to the special interests of the stakeholder groups. In early stages of evolutionary deployment the AHS may be synergistic with transit systems and the HOV program. A study is needed to determine the AHS impact on VMT, vehicle emissions, and fuel consumption, as these are vital current topics.

One key benefit of AHS that should be achieved wherever the automated system is deployed is a strong economic rate of return. Certainly, sustained industrial participation in the program could not be achieved without a projected positive rate of return. On the other hand, development and infrastructure deployment will require strong federal funding that demonstrates federal commitment. There must be an assured source of funding for AHS operations and maintenance. This could be the federal government, state or local sources, or a source distinct from the usual funding sources for highway and transit projects.

An automated highway system offers major benefits to the national system of transportation. This study was intended, however, to find the potential flaws in the system, rather than to characterize its many attributes. No problems were identified during this study that are insurmountable. However the large number of issues and risks that were found certainly is a challenge to those charged with developing an automated highway system.

A.2 FOCUS OF THE INDIVIDUAL ACTIVITY AREA ANALYSES

The analyses performed within each of the activity areas are addressed in terms of four primary factors: vehicle, roadway, operator, and infrastructure electronics. The vehicle perspective encompasses subsystem functions associated with automated lateral and longitudinal control, ranging from sensor and actuation requirements to communication of control information. The roadway issues include the physical configuration of AHS sections from all aspects of design, implementation, and operation. Operator related concerns involve public acceptance of AHS technology and alleviation of privacy issues, as well as human factors design of the user interface. The infrastructure electronics perspective encompasses the instrumentation required along the roadway, including sensors, communications, and traffic operations centers. The specific development, deployment, and operational issues and risks are discussed with respect to vehicle, roadway, operator, and electronics implications as appropriate in the individual activity areas.

A.3 HIGHLIGHTS OF THE ACTIVITY AREA TECHNICAL ANALYSES

The highlights of each of the 16 activity areas examined will be discussed in this section. The highlights will contain a summary of each activity, including key findings, conclusions and recommendations.

A.3.1 Activity A - Urban And Rural AHS Comparison

The Urban and Rural AHS Comparison identifies and analyzes, at a high level, the technical and operational requirements of an AHS in urban and in rural environments. The characteristics of urban freeways and the needs of commuters and work-day truck and transit traffic are compared with the profile of rural highways supporting relatively long trips with typically low traffic volume. The RSCs are used to evaluate the compatibility of specific configurations to typical urban and rural environments.

The primary results of the urban rural analysis indicate that the goals of urban and rural AHS are not compatible. The impetus towards increased automation in the urban setting is to improve traffic flow and reliability of travel times, while in rural areas the main advantage of automation is reduced travel times and ease of travel. The challenge of the AHS design will be to develop a configuration which addresses both environments.

The division of instrumentation between the infrastructure and the vehicle must be determined by systems level design considerations which take into account the complexity, testability, reliability, and maintainability of the system. The design complexity and testability of the control loop system is directly affected by the placement of the equipment. Implementation of the vehicle control loop within the vehicle simplifies the timing of inputs to the processor, allows testing prior to system integration, and improves reliability in the sense that a failure affects a single vehicle only. Alternative infrastructure based configurations which reduce the individual processor load will increase the quantity of roadside processors and increase the complexity of coordination among processors. Infrastructure placement is not considered practical for the vehicle control loop function.

Functions which operate over a wide area are candidates for implementation in the infrastructure. Examples include route guidance planning, which can be handled at a regional traffic operations center, and zone or regional flow control, which may be communicated along the infrastructure most efficiently. The feasibility of AHS is dependent on evaluation of each subsystem element individually to determine the appropriate division of content. The system architecture must first be developed to determine the functional decomposition, at which point the most effective configuration can be established.

Instrumentation specifically required to support very tight headway tolerances in close vehicle following modes may not be necessary in areas with low traffic densities. A certain amount of AHS specific equipment will be required in the vehicle to support any proposed system configuration. The urban AHS may require highly accurate, rapidly updated vehicle position information to support platooning or tightly spaced vehicles. This will place stringent requirements on the capability of AHS instrumentation in the urban environment. It is possible to improve long distance travel times and user convenience without increased throughput merely by implementing intelligent cruise control and lane keeping instrumentation. This may lead to a situation where vehicles which operate strictly in a rural area are over-equipped. Excess equipment affects both purchase price and maintenance costs. An AHS design which requires the same vehicle equipment for urban and rural operation would be ideal from a design standpoint, but may not be practical from an implementation perspective.

There is a risk of creating a system in which user costs are not in balance with benefits in the early deployment stages, especially in areas with low traffic volumes. The cost of operating an AHS may be financed through fees collected from users of the AHS. The large number of vehicles and existing congestion in most urban areas is expected to generate a demand for the AHS, even if user fees are charged. There will be significantly fewer vehicles in rural areas from which fees can be collected. Drivers may choose to save money by not using the AHS in the absence of congestion on rural highways. Financing alternatives to usage fees, or methods of distributing fees collected over all areas may be considered.

The goals of evolutionary deployment of AHS functions are different in urban and rural scenarios. ACC combined with lane keeping instrumentation are candidates for early AHS deployment which can provide safety benefits for travelers and trucks making long distance trips. This capability is compatible with a rural environment, but may not provide throughput benefits in an urban environment in which rush hour traffic densities prevent effective use of automated headway control. Similarly, a subset which addresses the congestion problem by providing higher vehicle densities in AHS lanes, but does not address heavy trucks would be effective in an urban environment, but would not be well suited to a rural environment.

The results of the urban and rural analysis indicate that a system configuration which places responsibility for the vehicle control loop dynamics in the vehicle is the most feasible. The conclusion is drawn that the evolutionary deployment of incremental AHS capabilities may provide limited safety and convenience benefits to some users, considerable throughput improvements can not be achieved with out full automation of vehicle control functions. It is recommended that the initial proof of concept be targeted to specific user requirements in a congested urban environment, with funding designed to include usage based fees to establish operational capabilities prior to wide scale deployment in connecting rural areas.

A.3.2 Activity B - Automated Check-In

The AHS is quite sensitive to vehicle malfunctions of a type which are common on a non-automated highway. Furthermore, the AHS vehicle has a variety of specialized equipment which is not required on a typical roadway and is also likely to fail occasionally. The notion of a system which inspects and approves vehicle entry, a check-in system, makes sense for an AHS.

The check-in operation is central to a successful AHS. A sensible check-in system will easily pay for itself due to the reduction of AHS malfunctions. The number of vehicle functions which might fail on the AHS is indicative of the fact that the check-in system must be comprehensive and reliable. A critical analysis of system functions and the development of methods for validating those functions have been the two principal means of describing the automated highway check-in system.

Among the standard vehicle functions that require inspection are engine, brake, and steering operations. These are critical functions, as are the specific AHS control functions, which include lateral and longitudinal sensors, automatic controllers for brakes, engine and steering, and the communications and data processing system which supports automated operations and relays instructions between vehicles and between vehicles and the roadside.

Windshield wipers, headlights, and other equipment which assist a driver but which would provide little benefit to an automated system are considered less critical. Vehicles that are carrying external loads, vehicles with loose or damaged equipment, and the current energy supply and available range of the vehicle are functions which are considered to be in an intermediate critical range.

Public service vehicle entry to an automated highway often requires different service that a private vehicle entry. This service is provided at the check-in station. During routine operation, the public vehicle should be inspected in the same manner as any other vehicle, however, for example, public safety vehicles should not be deterred from entering the AHS when there is an emergency.

Validation of vehicle functions is performed either at a special check-in station, during routine inspection or while the vehicle is under manual control (continuous in-vehicle test). Special inspection stations were categorized according to their functionality. At a validation station, information is communicated from the vehicle to the station and the vehicle is notified that it has either passed or failed the check-in evaluation. No delay is involved with this test. The data communicated from the vehicle includes all information from the built-in-testing equipment and from the last routine inspection.

At a remote special check-in facility, the vehicle undergoes several minutes of rigorous inspection and is then certified to enter the automated highway. This type of station is associated principally with a highway which is divided into automated and non-automated lanes. Since both equipped and unequipped vehicles can enter the highway, testing must be done before the automated vehicle enters the roadway and the results would be transmitted to a verification station before the transition to the automated lane took place.

The check-in station that is located at the on-ramp to a dedicated automated highway and is designed to evaluate vehicle functionality while the vehicle is at rest is similar to the remote facility except that the inspection must be of shorter duration in order to prevent the buildup of queues. Visual inspection is routine at such a station.

The final type of facility is a dynamic test area which compares vehicle performance after control has been transferred to the automated system with a standard for acceptable automated vehicle performance. The test is done while the vehicle is gaining speed to enter the automated highway and includes some on ramp curvature to demonstrate automated steering. If the vehicle fails the test, it is automatically steered off the ramp and into a lot for rejected vehicles.

A special analysis of communications and data loading feasibility determined that, for a properly equipped vehicle compatible with the automated highway, the communications and data requirements of a check-in facility would be met. Concerns about falsifying data in the vehicle computer or adjusting a critical piece of electronic equipment may be met by encrypting the information in the vehicle computer to prevent tampering.

Driver functional validation may be required because of health considerations or because of a concern that the same driver, when released into the non-automated traffic stream, may cause an accident for which the automated system would be liable. Privacy is a major concern, although equivalent privacy is yielded in everyday life. Liability and privacy remain major unresolved issues.

Many additional issues and risks were identified but were not addressed in detail. There are many issues related to non-standard equipment or multiple versions of the same hardware or software. Another general area of concern is the control and interception of vehicles which fail check-in but attempt to enter the automated highway illegally.

After reviewing the available literature regarding vehicle systems failure it was concluded that a survey of vehicle system failure modes and frequency of failures was needed. This survey would relate only to loss of functionality which could be associated directly to failure on an automated highway. The result of this survey would be a comprehensive list of component details which fail and the likelihood that they would fail if they were not detected at check-in.

A.3.3 Activity C - Automated Check-Out

The goal of the check-out analysis is to evaluate potential automated-to-manual transition scenarios in terms of relative feasibility, safety, cost, and social implications. The check-out alternatives range from minimal testing of the operator and the vehicle to extensive testing of the operator and vehicle.

The transition from automated control to manual driving must follow a progression of steps that ensures the safety of the driver and surrounding vehicles in the AHS and non-AHS lanes. Potential check-out protocols must be capable of maintaining safety in a cost effective manner while considering the technical feasibility and user appeal of the procedure. The check-in process used to validate the transition from manual to automated control has often been considered to be a vehicle-intensive task, while the check-out process used to validate the transition to manual from automatic has been considered as operator intensive. This assumption focuses on the functionality of the automated control systems as the vehicle enters the AHS, and the qualifications of the driver to regain manual control as the vehicle exits the automated lanes. This study has determined that vehicle functional verification is also required to ensure a safe transition to manual control. It is recommended that the manual braking and steering functions be exercised prior to termination of automated control as a minimum. These two functions are critical to safe operation at the time that control of the vehicle is given to the driver.

The impact of a specific check-out procedure on the system configuration can be viewed from the perspective of coordinating decision-making tasks among the vehicle system, infrastructure, driver, and exit facility. The dedicated lanes protocol places most of the burden for decision-making and coordination on the vehicle and infrastructure. In contrast, the driver is assigned more decision-making tasks under the mixed flow lanes protocol. The level of coordination required among the vehicle system, infrastructure, and driver is greater in the mixed flow lanes protocol than for the dedicated lanes protocol. The complexity of the check-out decision rules and the rate at which these rules must be executed should be consistent with the abilities of the decision maker. The vehicle system and infrastructure are typically more efficient than humans at processing sensor data and complex decision rules, transmitting the results of processing, and performing multiple decision-making tasks currently.

The check-out protocols proposed for dedicated and non-dedicated exit scenarios assume that the exit maneuver is aborted if a fault is detected, regardless of whether the fault detection represents a false alarm. A conservative check-out policy may ensure safety at the risk of introducing liability issues, and will increase costs associated with handling detained vehicles and closed segments of the infrastructure. The potential for loss of goodwill resulting from user dissatisfaction with the AHS must also be considered.

The topic of storing vehicles which fail vehicle or operator validation procedures has extensive implications in terms of roadway deployment. There are multiple design issues associated with the use of depots or shoulders to temporarily store vehicles. The storage system design is based on the expected number of users and the duration of use. Construction and operational costs and land use issues are primary considerations in determining the effectiveness of storage areas. Vehicle diversion to centralized storage facilities is an option which may alleviate design issues concerning land usage, occupancy levels, and operating costs at the risk of causing poor user acceptance. The disposition of vehicles disqualified from manual operation will be a key consideration in the design of the check-out procedure.

The issue of driver readiness to resume manual control is related to issues of privacy and liability. There is a broad range of tests available to verify driver capabilities, including sensors to detect the presence of substances in the driver's blood, prompts to gauge reaction times, or scanning of eye movement to evaluate alertness. The invasiveness of certain tests may cause concerns among privacy advocates and have an adverse effect on user acceptance. The assignment of liability in the event of an incident following the transition to manual control is a concern as well. Extensive tests may create the impression that the AHS is responsible for ensuring that no impaired drivers are allowed to have manual control. It is recommended that the driver check-out consist of a simplified routine that places the responsibility for assuming manual control completely with the driver. The check-out process might follow a screening of manual brake and steering functionality with a prompt to the driver. The driver will then respond with a positive action such as pressing a push-button to indicate readiness to assume control. Legislation may be required to clearly delineate the responsibility for accidents following transition from the automated lanes.

Eliminating complex operator verification tests and placing responsibility with the driver for accepting the manual driving task is one way to simplify the issue and reduce the risk of AHS being held liable for accidents caused by improper driving immediately following travel in the automated lanes. This approach is based on the premise that the AHS is not responsible for verifying driver readiness to safely operate the car prior to entering the AHS, and returning control to the driver following automated travel should not carry a burden beyond that of ensuring that the vehicle is functioning properly.

A.3.4 Activity D - Lateral And Longitudinal Control Analysis

The AHS will be designed to reduce travel times, increase highway safety, reduce congestion, decrease the economic, physiological and psychological costs associated with accidents, lessen the negative environmental impact of highway vehicles, and increase lane capacity. Lateral and longitudinal control system development will play an important role in this effort. Hardware and software performance capabilities will directly affect the achievement of each of the stated AHS goals.

The emphasis of the lateral and longitudinal control analysis work is on defining significant issues and risks associated with vehicle control. Reference is made to numerous research results that described the state-of-the-art in vehicle control technology. These concepts are applied to representative system configurations which formed a basis for system comparison and critique.

Vehicle platooning is a very feasible concept for an AHS. The choice of the intra-platoon spacing parameter presents a challenge as there is a perceived tradeoff between capacity and safety. Close vehicle spacing (1 m) may result in many low velocity collisions, while larger spacing (5 m – 20 m) may result in fewer collisions (possibly none under reasonable assumptions) with relatively high collision velocities. An adaptive control system in conjunction with accurate and timely vehicle-vehicle communication should be able maintain intra-platoon vehicle spacing under a variety of maneuver conditions. One significant question that remains is the likelihood of non-predictable vehicle/roadway malfunctions that could cause a vehicle in a platoon to decelerate at a relatively high level. The coordinated braking scheme would potentially have difficulty responding to this malfunction in a manner that maintained all intra-platoon spacing.

In the event of a serious vehicle malfunction, a loss of lane control, or an intentional maximum braking maneuver, intra-platoon collisions in a closely-spaced platoon may result. In this case, it is important to understand the nature of the resulting collision dynamics. These dynamics are the physical interactions and resulting body motions between vehicles. Based on the results of this study, lateral and longitudinal controllers can be tested to ensure that they are able to maintain vehicle attitude control while the platoon brakes. Note that the front and rear ends of vehicles may not generally align well with other vehicles. At the time of a collision, the platoon may also be undergoing a turning maneuver which would slightly misalign each vehicle with respect to surrounding vehicles. Individual vehicles would probably also brake before any collision. This would result in a vehicle that is pitched forward with respect to the previous vehicle, which if braking, is also pitched forward.

In the area of vehicle control algorithms, reasonable advancements in headway maintenance control systems for platooning vehicles have been made. Also, good lane keeping algorithms which produce acceptable performance levels have been developed. However, robust lane changing and platoon/vehicle merging algorithms that will provide ride comfort while meeting AHS requirements are still needed.

In order to develop, test, and analyze vehicle control algorithms, communication systems, and vehicle maneuvers, a comprehensive AHS simulation encompassing basic vehicle dynamics, vehicle interactions with other vehicles and with the roadway, multiple lanes (possibly mixed traffic), entry/exit lanes, various roadway configurations, and environmental effects (wind, rain, icy roads, etc.) must be developed. The simulation will serve as a testbed to develop flow/maneuver optimization, platoon control, merge/separate, lane change, entry/exit algorithms and understand the effects of various vehicle maneuvers. It will also help to determine the best mix of infrastructure and vehicle-based functionality.

The ability of communication systems to be able to guarantee error-free transmissions in the presence of electromagnetic interference from such sources as AHS vehicle-roadside communication systems, AHS vehicle-vehicle (intra and inter-platoon) communication systems, and non-AHS signals is critical to the success of communication-based control systems. It is also important from a data transmission viewpoint as well. Various methods have been described to counteract the effects of interference, such as the use of spread spectrum techniques, the proper choice of overall communication bandwidth, and the use of specific transmission frequencies and message coding methods.

Sensor, communication and control design needs to be as flexible as possible in a given roadway operational environment since it is difficult to predict the transportation needs of the country in 5 to 10 years after a design is completed. To achieve this goal, system software should be carefully developed in a well documented, object-oriented manner to allow for various operational conditions, and hardware should meet performance requirements.

A.3.5 Activity E - Malfunction Management And Analysis

This activity is devoted to an investigation of the necessary reactions of the AHS sub-systems to failures or degraded performance of the AHS functions. Pro-active measures to prevent malfunctions are often included in the traditional definition of malfunction management, but for the purposes of this investigation these pro-active measures have been declared as the province of Activity N - AHS Safety Issues and are addressed only incidentally. The following are the key findings, conclusions and recommendations of this activity.

There is not a large number of malfunctions. A count of the items on the malfunction lists reveals approximately 70 malfunctions distributed as follows:

- General vehicle malfunctions - 19.
- AHS specific vehicle malfunctions - 28.
- Wayside electronics malfunctions - 15.
- Roadway malfunctions - 9.

There were no operator malfunctions identified for the RSCs defined other than the operator not being prepared to assume manual control on check-out.

Methods and technologies have been identified which enable detection of each of the identified malfunctions. A survey of current research found that a considerable amount of research is being conducted in industry and in universities with the aim of improving malfunction detection capabilities.

Analysis needs to be done to determine which of the identified detection methods are practical and cost-effective for use on AHS. Some of the methods and technologies identified are commonly used for malfunction detection in military and space applications, but may be too costly for AHS application. An example would be triple redundant processors with data sharing and majority voting.

Methods for automating the detection of roadway malfunctions, which are presently detected by manual inspection, were identified. Further analysis should be performed to determine which malfunctions require automated detection to meet safety and performance goals and which malfunctions are detected more cost-effectively by automated detection than by manual inspection.

The management strategy for each malfunction can be divided into two parts: a set of immediate actions to contain the malfunction and a set of actions to restore AHS operation. Five sets of immediate actions were defined that cover all of the malfunctions and five sets of actions to recover from the effects of these immediate actions were also defined.

In RSCs where access to the AHS lanes is from parallel manual lanes via a transition lane (RSC 3) it was assumed that the AHS lanes is continuous and therefore to not interfere with access to the AHS lanes the breakdown lane was placed as the farthest AHS lane from the transition lane. In the other RSCs, since access is intermittent, it is assumed that the breakdown lane is the lane adjacent to the exits so as to facilitate self-clearing of malfunctioning vehicles when possible and to simplify extraction of malfunctioning vehicles by service vehicles when required. This should be a topic for further investigation by roadway operations analysts.

The evaluation of management strategies shows that most malfunctions can be managed effectively by the strategies defined. In the evaluation of malfunction management strategies for malfunctions which result in loss of lateral control, the scoring of safety critical items show that these malfunctions are difficult to manage. This results from having no identified adequate backup for lateral control. The RSC most affected by malfunctions resulting in loss of lateral control is RSC 1. In this RSC a large part of the control function resides with the wayside. A failure in this function affects multiple vehicles. Collision avoidance systems are assumed to be an adequate backup for longitudinal control. An investigation of what is required to provide backup for lateral control should be undertaken. Perhaps side-collision warning systems can be adapted.

From a safety critical standpoint the next most difficult malfunctions to manage are those associated with brake failures, tire failures, and failures of roadway pavements, barriers, and bridges.

Malfunctions that are difficult to manage for safe operation also are difficult to manage for maintenance of performance. Malfunctions that can be managed for safe operation but that require closing of AHS lanes, or even entire AHS sections, also have a large impact on performance

On the non-automated highway the operator is presently the major detector of malfunctions and implementation of malfunction management. Intuitively, it seems that the operator could continue to play some role in the detection of malfunctions, that there are some malfunctions that the operator could detect better than, or at least as well as, the automated detection system, and therefore serve as a backup or alternative detector. One item that continually is brought up in discussions of the subject is that of animals on the roadside that may jump in front of the vehicles and how the operator may be better able to anticipate the animals movements than the automated detection system. Some further investigation of the operators role in malfunction detection should be carried out, as well as a determination of how the operator can indicate the perceived malfunction and desired management actions to the AHS.

Results from studies of operator reaction capabilities suggest that virtually no operator participation in malfunction management be allowed in the mature AHS RSCs assumed in this activity report. The discussion found in the fifth task of Activity D - Lateral and Longitudinal Control Analysis reviews studies of driver reaction time and the possibilities of driver intervention in case of automatic control failure. The long reaction times shown in that task and accounts of accidents due to improper operator reaction or over-reaction to malfunctions (blow-outs, drifting out of lane) when the driver has had continual control seems to preclude sudden resumption of lateral control after a long period of no driver involvement with vehicle control. The analysis of this activity assumes that the operator will not have a role in any management strategies except in those cases where control can be assumed at the operator’s leisure. The operator is allowed a role only in those cases where the vehicle can be brought to a complete stop before the operator assumes control, or where the vehicle can continue to operate in a near-normal fashion until the operator can assume control. If it could be shown that under some benign set of conditions, short of coming to a complete stop, the operator could safely assume control, this may mitigate some of the difficulty with managing loss of lateral control.

A.3.6 Activity F - Commercial And Transit AHS Analysis

The physical and operational characteristic of commercial and transit vehicles differ significantly for passenger vehicles. As a result the implication of these differences must be accounted for in the design and operation of AHS facilities that accommodate such vehicles. Generally physical characteristics relate to the infrastructure while the operational characteristic refer to the operations on the AHS facility. Physical characteristics of heavy vehicles require additional infrastructure compared to a passenger vehicle only facility. These additions include; wider lanes, increased vertical clearance and increased pavement thickness. In addition to the physical differences between heavy and light vehicles, operational parameters of heavy vehicles including; acceleration, deceleration, effect of grades, capacity, comfort and safety, off tracking, trailer sway, load shifting, and use of automatic transmissions; may affect overall operation of a mixed use AHS lane (presumably passenger vehicles).

Although provision of separate AHS lanes for heavy and light vehicles may alleviate many of the issues associated with the physical and operational differences between these two types of vehicles, the costs associated with this may be prohibitive. However by comparing the demand and the overall operation of the lane, a combination of separate and shared lanes may provide the most cost effective solution of providing access to heavy vehicles without adversely affecting overall operations. In rural areas capacity is not a concern and the nature of the rural AHS is such that each vehicle is adequately spaced so inclusion of heavy vehicles would not hinder operations. In areas where terrain severely hinders heavy vehicles operations a separate lane could be provided in order for overall operations not to degrade. In urban areas where high capacities are expected with AHS, public concerns may exist for inclusion of heavy vehicles on the AHS lane . However it is felt that transit vehicles could share the same lane as passenger vehicle as their operational characteristics are not as adverse as trucks. Inclusion of transit on a AHS lane will take away some passenger vehicle capacity, however depending on demand of buses overall passenger throughput could be increased four times.

In order for heavy vehicles to be included on AHS without separate lanes, a policy regarding gaps between vehicles needs to be developed. This policy should address the following issues; multiple vehicle operation modes, exclusive passenger vehicles headway policy, actual and perceived risks associated with headway spacing, variations in vehicles performance, human factors, relationships to AHS subsection, interface to ITS, and institutional factors.

All the issues associated with inclusion of commercial and transit vehicles on AHS are only valid if demand for these vehicles to use an AHS facility exists. There are, in general, different issues relating to demand for both rural and urban situations. In urban areas, trip characteristics of transit vehicles match well with the expected operations of AHS hence a potential for high demand exists. Trip characteristics of local trucks whether large or small, are such that it is doubtful that AHS will provide any benefits and as a result demand from these types of vehicles is generally expected to be low. Certain types of inter-city/interstate trucks will find urban AHS beneficial especially in intermodal type cities. In rural areas issues affecting demand for trucks include; travel time savings, safety, fuel consumption, maintenance cost, comfort and convenience, arrival predictability, initial equipment cost and usage costs. In order for demand of heavy vehicles to exist in rural areas, the benefits associated with these issues must far out weigh and negative aspects of these issues. The issues presented here are general in nature and may not apply to all areas. Therefore, demand issues should be done on a site specific basis.

Although the costs associated with inclusion of heavy vehicles on AHS are high, the benefits of inclusion of certain types of heavy vehicles, especially transit, are enormous. The most important benefit associated with transit use is the comfort and convenience for passengers leading to increased ridership potentially reducing congestion. Other potential benefits include lower operating costs, fuel efficiency and decreased air pollution.

Interface requirements for heavy vehicles at AHS facilities must include check-in procedures that limit delay in order for full benefits of AHS to be realized. However, due to the difference in components between light and heavy vehicles light vehicle testing procedures must be modified to address the following heavy vehicle issues; safety implication associated with testing of load security, frequency of tests, and verification of truck and trailer compatibility. In addition to the additional testing required between heavy and light vehicles, infrastructure requirements at interface points are much different. The acceleration of heavy vehicles requires acceleration lengths corresponding to urban interchange spacing (1600m) in order to avoid degradation of the mainline AHS traffic. Solutions developed for this problem include; limited access for transit an commercial vehicles, access at only terminus points and exclusion of certain types of heavy vehicles in urban areas.

The same methods and issues associated with urban testing of heavy vehicles apply to rural testing also. However, the availability of offset testing is a concern as situations may arise that require testing in rural locations where the cost of providing this type of service may not be cost effective. Infrastructure requirements for rural areas differ significantly as it is assumed that access to AHS will be via existing freeway lanes and ramps, hence eliminating the need for an acceleration lane.

A.3.7 Activity G - Comparable Systems Analysis

Twelve complex systems were identified that correlated at least partially with AHS requirements. These systems included automated teller machine systems, military communications systems, nuclear power systems, air traffic control systems, rapid transit systems, airport ground transportation systems, automated aircraft landing systems, space program systems, automobile air bag systems, ship command and control systems, automobile navigation systems and air defense systems. Of these twelve, three systems were selected for further analysis. The three systems selected are: the BART system, the Supplemental Inflatable Restraint (SIR) system, commonly called air bags, and the TravTek navigation system.

The goal of the analysis of these three systems: BART, SIR and TravTek, was to present issues which have been addressed in the design and deployment of comparable systems in order to derive lessons learned and provide insight into design considerations relevant to AHS. Specific recommendations have been included in the Conclusions section.

The experience gained from the three representative comparable systems, BART, SIR and TravTek offer a number of important insights into the application of new technologies to the field of passenger transportation. These lessons reflect the process of technology development and management that may also be experienced in the development of an automated highway system.

On the technical side, these systems offered additional insight into appropriate techniques for technical systems specification, verification of system performance, and initial pre-deployment testing and quality assurance. Given the potentially high complexity of the many systems involved in AHS, successful deployment depends critically on the ability to specify and test a highly reliable system. A related issue is the treatment of both system safety and reliability in the technical development and in system operation. In addition, the level of effort required to maintain the automatic systems is an important consideration. Specific recommendations from the technical side include the following:

Technical systems specifications:

- A complete AHS system requirements specification is necessary at the beginning of the development process. This specification should be the focus of strong scrutiny in order to avoid creating an unnecessarily complex system. Clear, comprehensive, documented and testable requirements should be established at the beginning of the program and then subject them to a controlled review and change process for the life of the program.

- Trained human factors specialists should be utilized in the design of the driver interface. Personnel with the proper background know and can apply the basics of human/computer interaction research. It should also be ensured that the design is suitable to the wide range of people who drive. For instance, nomenclature testing was done on TravTek to avoid the use of computer terminology with which many people are not familiar. In addition, the tasks must be designed to be almost intuitive to minimize driver training requirements. The entire driver task load during check-in and check-out must be considered. The addition of any task which may distract the driver from safely driving the vehicle must be carefully considered. That task must be designed to create the minimum distraction from primary driving tasks. In general, guidelines must be developed and applied which restrict the use of displays and controls during driving, reducing the density of visually presented information, and use of auditory tones to augment the visual displays. One of the most difficult, and therefore most often ignored, design tasks is to design acceptable response times into a system. These need to be established at the beginning of the design process and then rigorously enforced as the design is implemented.

- Importance should be placed on defining and documenting subsystem interfaces, especially those between different suppliers. Various features of an AHS are the same as features for other IVHS areas. Communications and the driver interface are just two. Standards for AHS must be compatible with those for IVHS in general. Since the division of responsibilities on TravTek followed natural system boundaries, this made the preparation of a detailed and complete interface specification relatively easy. The fact that this detail was documented and available to both responsible partners certainly contributed to the interoperability of the system components. Division of the work among the participants should be such that simple and easy to define interfaces exist between their efforts.

Verification of system performance:

- A comprehensive set of performance parameters along with reasonable evaluation methods must be established. In some aspect, it proved very difficult to establish measurable performance parameters for parts of TravTek. For instance, a measurable parameter was never established for the quality of traffic data from the Traffic Management Center. It turned out that the poor quality of this traffic data was the most serious performance flaw in TravTek. Local users, familiar with Orlando traffic, preferred not to receive the TMC data. The lesson here is that performance parameters must be established and tested for all parts of the system

- In the development and procurement of AHS technologies, a competent and independent technical review team should be retained in each phase of the technical development and testing of the system.

Initial pre-deployment testing:

- Functional testing should be sufficiently funded to be complete and rigorous. On TravTek this activity was under-funded and skipped because of schedule constraints. The evaluation effort could only assume the underlying system was working. Because of funding problems, different completion dates of the system components, and schedule pressure to begin the evaluation phase, a rigorous functions testing of the completed TravTek system was never accomplished. Although subsystem testing by the responsible partners did uncover most problems, some critical issues only came to light after the evaluation started..

This led to more changes during the evaluation than were necessary and the loss of valuable time from the evaluation effort.

- The highest priority must be given to safety and reliability in pre-service testing. Safety issues should be given highest priority in determining the readiness of an AHS system before start of service. Systems which have an overriding impact on safety obviously require extensive testing. It should also be realized that the formulation of test procedures, standards, and specialized instrumentation requires long lead times which can be comparable to the system development time.

- Test and evaluation procedures must be a mix of actual testing and simulation to span all possible response scenarios.

Provide quality assurance:

Sufficient time in the AHS development process must be left for product testing and quality control. This involves allowing ample time for suppliers to debug new technical sub-systems, as well as time and resources to test and debug the fully-integrated AHS on site before beginning operation. Development of TravTek continued throughout the evaluation phase. Software fixes were installed, design deficiencies were corrected, and of course, errors in the map database were corrected. It was found necessary to implement strict configuration control procedures so the evaluation team knew the configuration and the characteristics of the system being tested. Even at that, it proved difficult in some instances to usefully compare data recorded at the beginning of the evaluation period with data recorded at the end.

System safety:

AHS development should include both safety and systems engineering functions from the earliest part of system planning, design and development. AHS specifications and standards must carefully balance the needs for technical innovation with the need for more specific design criteria to assure a safe and reliable system.

Reliability:

System requirements must include diagnostics to alert operators of failed components. AHS specifications should include a strong emphasis on the design issues associated with service degradation, including equipment malfunctions in the vehicle, at the wayside, and in the infrastructure. In addition, these systems must be sensitive to the information provided to drivers during automatic operation and especially during degraded service conditions. Human factors research should emphasize the driver's response to information especially in degraded service or emergency situations.

Maintenance:

Maintenance issues should also be included early in the planning stages for an AHS, focusing on long-term maintenance requirements. For both vehicle- and infrastructure-based components, these requirements include maintenance equipment to identify and repair failures, common information systems, and clearly-defined procedures for addressing scheduled and unscheduled maintenance needs.

Non-technical issues included such areas as the continued political pressure to bring the system such as BART into revenue service, coupled with the early loss of public confidence. Typically, new technologies in transportation come under intense political pressure, as elected officials press for early photo opportunities and quick benefits to improve their political standing. The high expectations already placed on AHS ensure that the political process will have much bearing on the development and deployment of these systems. Furthermore, in considering the early stages of AHS deployment, safeguards are necessary to avoid quick loss of public confidence. Close scrutiny of AHS operations is unavoidable, but lessons from the three comparable systems may help avoid the erosion of public trust that may seriously hamper planned AHS projects. Specific non-technical recommendations include the following.

To minimize political pressure:

- Technical personnel should maintain high visibility in AHS decision-making throughout the development process. Administrative and management boards should include staff with a high degree of technical competence in AHS.

- As much as system design will allow, AHS projects should take advantage of incremental deployment. This may imply that an automated highway be deployed in a small corridor initially, allowing for system expansion to other corridors in the near future. The selection of an initial corridor should be based at least in part on the ability of that corridor to demonstrate significant first user benefits. The development of AHS systems will likely follow the trends of automotive systems such as the air bag with respect to the driving developmental influences, which are:

  - First generation systems are driven by the need to provide features which are pleasing to the customer, incorporate desirable technical, diagnostic, and service functions, meet overall cost targets, and meet applicable legislative requirements.

  - Second generation systems continue to meet the first generation requirements while also placing increased emphasis of cost and packaging considerations (size, shape, weight, and location).

  - Third generation systems meet all earlier generation requirements while also meeting the need to integrate functions both within the system and with other systems and addressing concerns for the recycleability of system components.

To increase public confidence:

- The introduction of a pervasive consumer oriented system such as AHS needs the highest degree of coordination between government, manufacturers, consumer needs/wants, and technical state-of-the-art. The public perception of the use, benefits, and operation of a system is fundamental to market place acceptance.

- The public needs to be educated as to the programmed response of the AHS in both normal and abnormal situations as well as how to correctly interface with the AHS. This will increase the public's level of confidence in the system as well as prevent attempts to override correct system response.

Management/funding philosophy:

- TravTek operated under a "manage by consensus" style. Almost all important issues were discussed in open meetings with all project stakeholders present and able to express their concerns and position. After such open discussions, it was always possible to agree to a course of action which everyone agreed was the best possible under the circumstances. This approach was facilitated in three ways. First there was a very natural division of responsibility between the partners which greatly lessened the impact of one partner on the work of another. Second, the responsibilities of each partner were established in some detail at the very beginning of the effort. Third, and finally, the project held meetings every 6 weeks for the entire length of the effort at which all partners were present. In addition, careful minutes were kept in which all actions items were noted and assigned to a specific individual. This kept the dialogue between the partners going and insured that critical items were not forgotten but regularly discussed until they could satisfactorily be resolved. Program management must emphasize the building of consensus. Getting support from local agencies, either public or private, is difficult and requires careful, sensitive planning.

- AHS development should include an aggressive and honest public information effort. This should include open public forums to discuss system planning and development and, as much as politically feasible, candid discussion of problems with development and deployment.

- On TravTek, each major partner (General Motors, the American Automobile Association, and the Public Sector) funded their own effort. There was no prime contractor but three equal and independent partners. In addition, each partner had responsibility for clearly separate and relatively independent parts of the system. This made preparation of a Statement of Work easy and ensured that the funding responsibilities were usually obvious. This natural division of responsibilities greatly contributed to the smooth running of the project. A well thought-out Statement of Work for all participants and all activities, accompanied by adequate funding, should be the first order of business.

Privacy issue:

- TravTek overcame a potential problem with premature disclosure of some project data. Since the two private partners were funding their own effort, they wanted to keep test and evaluation data out of the hands of competitors. This concerned the raw evaluation data and not the carefully analyzed results of the evaluation contractor. The problem arose because various public agencies, and to some extent private contractors being funded with public money, had legal requirements that might have led to disclosure of the data. The problem was resolved by ensuring that the raw data stayed in the possession of the concerned private partner. Only carefully extracted subsets were provided to the evaluation contracts. Of course, the evaluation contractor had complete visibility as to the types of data available to ensure they received everything they needed.

- Ethical concerns about ensuring that test subjects understood the nature of the tests and their actions were being recorded for later analysis were overcome by having each subject sign an informed consent document.

- TravTek was implemented such that is was possible to identify specific vehicles and to track the route of any vehicle. To ensure the anonymity of the assigned driver of any vehicle, all information as to the specific identity of the driver was impounded by either the AAA or the rental car agency and not released to the other partners or to the evaluation contractor. For AHS, individual privacy must be considered in such areas as check-in/check-out, route planning and toll collection.

To mitigate liability concerns:

- Concern about potential product liability was the basis of many technical discussions of proposed design features for TravTek. It was, of course, an important issue in designing the driver interface. Product liability was also a concern to the AAA and led them to extraordinary efforts to improve the quality of the map database. But there also was a dark side to what sometimes was a preoccupation with product liability concerns. Occasionally, instead of stimulating the design of the highest quality product, it resulted in the fearful deletion of a desirable feature. Management must ensure that when a desirable feature is identified, product liability concerns can be met by building higher quality into the product.

- A liability budget should be firmly established early in the AHS development process. A manufacturer needs to clearly understand its liability exposure in able to properly budget the cost of liability into the AHS system's business case.

- An onboard recording device should be incorporated into the vehicle's AHS equipment in order to enhance diagnostics and discourage unfounded litigation.

In light of the preceding issues, the major risk for an AHS will be the public concern over price, benefit and safety. Drivers may like the features of the system and would utilize it if perceived as safe. An AHS demonstration project should be able to resolve the safety risk. However, people’s expectations of a reasonable cost must be consistent with the anticipated benefits. Finding a way to overcome the benefit risk will be an interesting challenge which will hopefully be aided by the lessons learned from comparable systems.

A.3.8 Activity H - AHS Roadway Deployment Analysis

This analysis covers the entire range of highway infrastructure topics that will be encountered when AHS is deployed. The research team approached the deployment analysis problem by considering several alternative highway configurations, then making various sets of assumptions and conducting what-if analyses. Hypothetical freeway sections, based on sections of Interstate Highway 17 (I-17) in and near Phoenix, Arizona, were used for the analyses. Various design years were used for the traffic volumes used in the analyses.

A fundamental requirement to the modeling of every operational measure of effectiveness of the AHS/non-AHS system is the capacity of the AHS system. This research effort made assumptions regarding AHS mainline throughput capacities and determined that, given the assumptions used, the platoon-oriented RSCs will have extremely high mainline capacities. It is recognized that these top level capacities must be degraded to provide for entry and exit operations. Even so, it seems reasonable to expect that AHS capacities double or triple those of conventional lanes should be achievable. These capacities (4,000 to 6,000 VPH) were therefore selected for modeling use throughout the report.

Capacity assumptions were also developed for non-platooning operations. If assumptions regarding inter-vehicle spacing are the same as those for inter-platoon spacing, much lower capacities result. In fact, in some cases the capacities are even lower than those of manually operated lanes. It is necessary to make assumptions that coordinated braking is achievable for non-platoon operation to have capacities similar to those of platoons. (It should be noted that coordinated braking or at least coordinated deceleration, is also a requirement for safe operation of platoons.)

While more difficult to quantify than capacity, repeatability of travel time is an important AHS advantage. By significantly reducing the number, severity, and duration of accidents and incidents, AHS will allow more dependable forecasting of travel times.

Various configurations of AHS lanes and shoulders for the AHS were considered. It was concluded that AHS shoulders are desirable for operational benefits they bring. With shoulders, broken down vehicles as well as snow debris or spilled loads can be stored while automated operations continue unimpeded. Without shoulders, these events would require the complete shutdown of the automated facility.

The width of the AHS lane need not be the same as present day manual lanes due to the superior lateral control AHS will bring. Lane widths of 2.5 m (passenger cars only) and 3.0 m (trucks and transit vehicles) are expected to be adequate if a deviation of plus or minus 200 mm from the desired path is achievable. Shoulder width requirements are essentially the same as travel lane width, although slightly greater widths may be considered due to the requirement for manual operation within the breakdown lane.

While improved lateral control results in a reduction in lane width, deployment of a dedicated lane AHS scenario still involves construction of new pavement if the number of non-AHS lanes is to remain the same. Even if an existing HOV or mixed traffic lane is taken over for AHS, the requirement for the AHS lane, its shoulders, and its barrier result in a new pavement widening. This can be mitigated by using narrower lanes and shoulders on the conventional freeway but generally not without compromises to safety and traffic operations.

A.3.9 Activity I - Impact Of AHS On Surrounding Non-AHS Roadways

This activity evaluated the impact of AHS lanes on the surrounding non-AHS roadways. The non-AHS roadways include the general purpose freeway lanes, freeway ramps, cross streets, and parallel arterials. For both urban and rural situations, the study evaluated key issues relating to non-AHS roadways including: 1) highway re/design issues; 2) the spatial requirements of AHS facilities and entry/exit facilities; 3) the traffic operations of both AHS facilities and the non-AHS surrounding roadways; and 4) the impacts of AHS facilities on land use

The analyses undertaken for this activity resulted in findings that AHS lanes potentially can generate significant travel time benefits compared to conventional freeway and arterial lanes. The travel time benefits result from the ability of AHS lanes to accommodate relatively high speeds at high vehicle capacities. The resulting benefits will attract significant volumes of AHS traffic from the freeway and arterial lanes. The AHS volume which can be attracted to an AHS lane is limited by the capacity of that AHS lane. For the corridor studied, the volume of AHS traffic which could be attracted to one directional AHS lane is equal to approximately 40 percent of the corridor traffic (or 40 percent of total vehicles with AHS equipment). An additional AHS lane might be a possibility to accommodate more AHS vehicles as the market penetration of AHS equipped vehicles increases. The study found that the urban freeway corridors used for analysis can generally accommodate the spatial requirements of an AHS lane.

The performance of the AHS lane is limited by the ability of the AHS on and off ramps to effectively accommodate traffic entering and exiting the AHS lane. The AHS ramp capacity is a function of the amount of traffic which can enter and exit the AHS platoons operating at maximum capacity. AHS ramp capacity is also a function of the traffic volumes which can be handled at the intersection of the AHS ramps with the adjacent street system.

The high traffic volumes which can be accommodated by an AHS lane can significantly impact the surrounding roadway system. The high entering and exiting AHS volumes will impact the cross streets carrying AHS traffic to and from the AHS ramps. The intersections of the cross streets with the parallel arterials will also be impacted. In addition, the overall traffic circulation patterns will be impacted by the changes in vehicle origins and destinations to enter and exit the AHS ramps. The high entering and exiting AHS volumes could generate significant vehicle delay within the corridor. This study found that as the AHS traffic volumes became high (generally greater than a 40 percent market penetration), the benefits of the AHS lane to accommodate more volume began to decrease as a result of the additional delay at the entry/exit locations.

The opinions of the transportation experts agreed with the findings of the technical analysis that increased AHS ramp volumes could adversely impact the surrounding roadway system. The experts also expressed concern that AHS lanes could attract additional single occupant vehicles (SOVs) and impact the overall vehicle occupancy within a freeway corridor. Future planning and research should investigate how demand management techniques can be used for AHS lanes to encourage higher vehicle occupancies.

The potential impacts on the surrounding roadway system have implications for planning and research. First, it is important that the planning of an AHS lane be carried out within a larger systems planning context to optimize the operations of the AHS lanes, cross streets and parallel arterials. This is desirable from a technical as well as an institutional perspective. Second, the AHS traffic control and the street system signalization control must be integrated and coordinated to accommodate the additional AHS traffic and to respond to changing traffic patterns of AHS entering and exiting traffic. Another element which must be considered in planning and research is the impact of AHS facilities on the surrounding land use.

A.3.10 Activity J - AHS Entry / Exit Implementation

This activity considers the infrastructure elements required for accessing an AHS lane or freeway. Infrastructure requirements are a function of the AHS entry/exit strategy utilized, the level of performance desired and the traffic demand on the facility. AHS check-in and check-out procedures have a profound effect on the entry and exit facility size.

Two main check-in and check-out procedures are possible with AHS; on-site testing and off-site testing. On-site testing, requiring a testing duration delay to users, results in entry and exit facility sizes that are extremely large and unfeasible to implement, especially in an urban environment.

Entry and exit to and from the AHS lane can occur under two scenarios; through dedicated facilities or non-dedicated facilities. Dedicated facilities provide direct ramp access to and from the AHS lane. Non-dedicated facility utilizes the existing conventional freeway interchange and enters or exits the AHS lane by weaving across conventional freeway lanes and entering from a transition lane. The focus of the work conducted for this report was on dedicated AHS entry/exit facilities in an urban setting.

The work performed resulted in identifying main issues associated with AHS entry and exit strategies. These main issues are:

- On-site check-in and check-out procedures should be limited to “on the fly” procedures that do not delay the AHS vehicles. Even with minor check-in or check-out duration, sizable queues of vehicles will form, large delays will be imposed to the entry and exit procedures, and the size of the facilities including the length of the ramps will exceed practical and realistic design parameters.

- For the corridor studied, market penetration rates of 40 percent will cause AHS ramp demands as high as 2,900 vehicles per lane (if unrestrained demand is assumed) which would cause the signalized ramp terminal to fail operationally. Current capacity of a ramp under urban settings is approximately 1,500 VPHPL. AHS ramp volumes of this magnitude will not only affect AHS operation, but will affect the local street network operation as well.

- At approximately forty percent AHS market penetration, ramp delay affects overall corridor performance and diminishes the benefits achievable by increasing through capacity on the freeway by the AHS lanes. Entry and exit facilities will determine how well AHS operates and dictate the benefits achievable by AHS implementation.

- Increasing the spacing between AHS entry and exit facilities causes ramp demand volumes to increase. Ramp delay increases significantly and overall corridor performance degrades significantly.

- Dedicated entry and exit capacities are governed by where and how they interconnect with the local street system. These capacities can be increased by separating AHS and conventional freeway interchange, separating AHS entry and exit procedures from the same location, and eliminating conflicting movements at the ramp terminals. Providing for free flow movement at these points could increase ramp capacities to 2,300 VPHPL.
- Entry and exit volumes must be collected and dispersed by the local street network. Operational and geometric changes to local streets will be required even at lower market penetration rates. Implementing one-way streets is one method that will limit physical widening of existing roadways locally.

- AHS design and implementation will require a collective effort between the FHWA, State and local governments to assure a balanced system results.

- The cost of providing dedicated AHS entry and exit facilities will most likely be considerably higher than non-dedicated facilities due to structure costs of the new interchanges. A slip ramp configuration would best suit dedicated AHS facilities. This would allow complete separation of the conventional and AHS freeway operations and minimize construction costs.

It is suggested that portions of the work conducted under this study be continued and investigated in the second phase of AHS development and prior to determining a preferred entry exit strategy.

The research conducted on interchange spacing of AHS facilities was limited 1.6 kilometer and 4.8 kilometer spacing. Longer spacing between facilities should be investigated that accounts for actual origin-destination of trips and how this affects market penetration and ramp volumes of AHS. The effects of eliminating short trips on AHS should be documented.

Modeling of the limited access AHS concept should be conducted with this modeling accounting for heavy vehicle and transit use.

The actual procedure for entering and exiting the AHS lane needs to be defined and quantified to ascertain the impacts on entry and exit design. Will vehicles enter and exit AHS as single units or mini platoons? Will cars be required to stop to wait for a gap in AHS mainline traffic prior to entry? This will have a profound effect on entry facility size, especially at higher market penetration rates.

The effects of reducing the conventional freeway capacity (through reduction in lanes converted to AHS) on non-dedicated entry and exit strategies needs to be quantified. In dense urban areas already experiencing congestion, the reduction in the number of lanes will add to the problems. Weaving, merging, and ramp operations should be quantified and compared to a dedicated entry/exit facility design.

A.3.11 Activity K - AHS Roadway Operational Analysis

This analysis considers the unique operational and maintenance aspects of AHS, as they are similar to and different from the operations and maintenance of a conventional highway system. The traditional operational measures of highway, freeway, and street networks, such as capacity and level of service, are covered in the AHS Roadway Deployment Analysis report. This activity report deals with the issues and concerns that an operating agency needs to deal with after AHS is deployed.

The security and surveillance needs of AHS, while more stringent than those required for an advanced traffic operations system, are nonetheless felt to be within the means of present technology. AHS brings elements of radio communication not present in present Traffic Operation Systems (TOSs), but maintaining security and avoiding deliberate interference should not present difficulties different from other areas where radio frequency communications security is important.

Maintenance activities present more of an impact to AHS than to today's highways, due to the requirement that automated operation be either terminated, or an automated path around the work site be provided. It is therefore a conclusion and recommendation of this report that maintenance activities be given careful consideration throughout every stage of infrastructure planning and design.

It is recommended that AHS planning be based on the premise that the AHS will provide a superior service to the motoring public compared to conventional freeways. This includes travel speed and occupant safety and comfort. To address this requirement, subsequent AHS planning and design should account for the combination of design life and maintenance requirements needed to provide this superior service.

The analysis of incident rates an existing freeways, and an estimate of achievable reductions to these incidents, led to the conclusion that incidents on AHS will still have to be dealt with. Incidents must be mitigated by designing an incident-tolerant system and by providing a service to respond to incidents quickly.

Without an AHS shoulder, the densities on which the research was based would quickly back up and halt AHS operations in the event of an AHS lane blockage. The alternative to shoulders would be a form of incident response that would require extremely short response times and the ability to mitigate the incident without using the AHS lane to reach the incident. Such scenarios are believed to be unrealistic and/or prohibitively expensive; therefore, the recommendation is made that shoulders should be included in AHS planning and design.

A good evolutionary scenario for AHS deployment requires stages which provide additional functionality and justify the required effort to overcome the associated difficulties. The categories of these difficulties are technology, infrastructure, human factors, vehicle manufacturing and maintenance, and public will.

A serious challenge to deployment is expected to be initial AHS market penetration. The evolutionary scenarios presented address this challenge. However, only two scenarios are defined in this report. A recommendation is made that more scenarios be developed, based on candidate sites for AHS deployment. A manageable number of these scenarios should be evaluated in detail and a small number of superior ones selected for possible deployment.

Interviews with operating agencies verified many concerns and findings of the researchers. Significant concern regarding sustainable funding, not only of construction but of operations and maintenance, was heard. Communications regarding AHS development within State DOTs was also a concern. It is a conclusion, based on these inputs, that funding be kept at the forefront during the System Definition Phase, to avoid successful completion of technical work but ending up with a product that will not be deployed due to lack of funding. To maintain communications between the consortium and the freeway operations community, it is recommended that the Transportation Research Board Committee on Freeways be given the opportunity to be a consortium member.

Early descriptions of AHS included the possibility of the driver reading, sleeping, or moving out of position during automated travel. It is the finding of this research effort that this brings many burdens, including increased tort liability exposure and even more severe incident detection requirements, to the system. It is therefore a recommendation that systems be developed which exploit, not ignore, the capabilities of the driver. This is not a recommendation that the driver be able to assume manual control at will, but that the system recognize the driver's ability to respond to certain emergencies that would be extremely difficult to design for.

A.3.12 Activity L - Vehicle Operational Analysis

The vehicle operational analysis addresses topics associated with the development, operation, and deployment of AHS vehicles. Each area of analysis presents a variety of aspects which affect the feasibility of the AHS from the vehicle perspective. Vehicle electronics are discussed in terms of recent trends in subsystem automation, existing state-of-the-art, and expected future developments. The impact of subsystem reliability on the process of bringing new technology to the consumer car market is another factor. The methodologies for providing safe system operation in the event of subsystem failures is an important consideration in the design of AHS specific vehicle components. This analysis is also concerned with the ability to optimize early market penetration by supporting reverse compatibility in vehicle models as advances in automation are achieved. The benefits of AHS-specific vehicle subsystems in terms of potential user services while traveling outside of the AHS are also estimated.

AHS will be reliant on dependable communications between vehicles and between the infrastructure and vehicles. A high degree of research and development must be dedicated to RF communications and it's role in AHS vehicles. Interference, power consumption, transmitting power limits, FCC regulations, RF congestion, frequency allocation, and communication protocol are some areas that should be researched.

The cost of electronics has been decreasing over time including electronics in today cars. The general trend appears to be that in the future the cost of automotive electronics will become less for production cars and light duty trucks. However, any AHS-specific item on that car will be more expensive because the initial quantity produced will be small. Furthermore, AHS electronics will need to incorporate more sophisticated components capable of operating at faster speeds than what is normally needed on non-AHS cars. History has proven that new electronic technology does not drive the automotive electronics market, but Federal mandates may, and profit always motivates the market. Automotive manufactures will not install more expensive or sophisticated electronics in their products unless they have to or have financial incentive to. Therefore, the general trend of cheaper electronics in the future may not affect AHS, especially in the beginning phase. Also, the software development and systems development efforts will be substantially more complex. In order to make the AHS vehicle affordable to the public, automotive manufacturers and or the infrastructure stakeholders must be willing to spend funding to initially deploy AHS.

Vehicles are becoming more electronic intensive. After market suppliers of vehicle electronics are finding it more challenging to find space inside of the passenger compartments of automobiles and light duty trucks for their products. In the future integration of electronics will become even more challenging. One current solution to decrease cost and to save space is to integrate two or three modules into one. This methodology will continue to be popular in the future. Research and development should continue in the packaging area, including wiring solutions and alternatives such as multiplexing and fiber optics.

The retrofit of AHS equipment into vehicles will be made much easier if proper hooks are put into the vehicle to accept the integration of actuators, control modules and wiring. To create the proper hooks in the vehicles, vehicle manufactures must work toward phasing in AHS equipment incrementally.

A.3.13 Activity M - Alternative Propulsion System Impact

This activity analyzes the impact of propulsion systems other than gasoline fueled spark ignition engine on the deployment and operation of AHS and identifies key design issues and enabling technologies for these alternative propulsion systems. At the direction of FHWA the analysis, as here reported, excludes roadway provided electric power since that technology is being addressed in depth by another contractor.

The spark ignition engine combines generally good characteristics, a long history of development and refinement, and an almost overwhelming infrastructure and production readiness advantage to present a propulsion system which is very unlikely to be significantly replaced without the exogenous market inputs such as legislative mandates within the time frame of this study.

None of the batteries currently under consideration can be said to be able to meet the mid-term goals set by USABC in actual vehicle operating conditions. Even when a battery that meets the mid-term goals is fully developed, it would still be disadvantaged in many respects relative to the current gasoline automobile. Limited range, long recharge time (measured in hours), high battery cost and short life, inferior acceleration performance, large size and weight, and performance deterioration in cold weather or as the battery reaches a low state of charge are among the problems faced. In addition, there is inadequate heat available for passenger comfort in cold climates, and air conditioning in hot climates significantly decreases range. However, analysis determines that they should fit into the continuum of performance capabilities for which AHS would be designed. The rational is based on the following observations:

- Fuel economy regulations and fuel taxes will exert pressures on standard propulsion vehicles to not extend their present performance.
- AHS must be compatible with light duty trucks and sport utility vehicles exhibiting performance lower than standard vehicles because they are a large part of the fleet.
- Consumer pressures will force alternative propulsion system vehicles to improve performance until they fall at least into the lower portion of the continuum which includes the above categories of vehicles.

Two unique operational attributes are identified for the alternative power/fuel systems. The first is the obvious, each requires a fuel which is unique to that system. This attribute is mitigated if the several alternative systems are available in bifuel form. The M85 fueled system is the most likely to be capable of bifuel operation since ordinary gasoline or RFG could be stored in the M85 fuel tank. CNG can be make in bifuel form but this required more modification and definitely a separate fuel tank. Battery-electric when combined with an internal combustion engine (a hybrid power plant) in effect then also becomes bifuel. Thus there is a likely possibility that each of the alternative power/fuel systems will appear as a unique fuel system even though some of their numbers may be bifuel.

The other unique operational attribute is associated only with the battery-electric system. All of the required motor, power management, and etc. controllers are very different from the engine and transmission controllers on other power trains. The sensors, actuators, diagnostics, and all aspects of the power trains are different. Thus the battery-electric system will have a unique check-in requirement as it addresses this aspect of vehicle operation and preparedness for operating on an AHS. The range of a battery-electric vehicle is very significantly impacted by the use of heating or air conditioning during the trip. Thus the range will vary with the ambient temperature at the time of the trip as well as the individual user's heating or air conditioning setting preference. These factors may need to be considered in real time at vehicle check-in setting the acceptable destination choice of a battery-electric vehicle. Uncertain environmental factors can also affect energy consumption during the trip period such as depth of snow fall and unexpected traffic delays due to natural disasters and traffic collisions.

As to the question-will AHS need to provide routine refueling capability for alternative propulsion system vehicles? We can conclude that routine refueling for alternative propulsion system vehicles is not needed as a part of the AHS infrastructure. The rationale is based on the assumption that alternative propulsion system vehicles and AHS must both be viable economic and consumer concepts independent of each other. A viable alternative propulsion system will generate the incentive for present refueling facilities to adapt or modify their capability so that they also serve the needs of the alternative propulsion system vehicle. Only should AHS evolve to a point where it resembles a toll road facility, which offers the only viable service in a travel corridor, would AHS need to provide refueling capability for all vehicles.

However emergency refueling capability for alternative propulsion system vehicles should be provided on a limited basis. Analysis concludes that in order to facilitate the extraction of vehicles which run out of fuel while on the AHS, the AHS must consider the refueling needs of all vehicles for the run-out-of-fuel problem. Failure of certain vehicle fuel/power source systems or the check-in process could result in vehicles running out of fuel while still on the AHS. The AHS malfunction response capability must include provision for refueling (and/or possibly towing) such vehicles from the AHS break down lane. A refueling capability on an emergency basis for all forms of vehicles is one response for consideration.

As to the question will industry wide standards be needed to ensure AHS vehicle performance? Reflection shows that some aspects of vehicle performance which do not presently come under specific regulation may need to be commonized or required to meet some minimum level. The responsibility for setting these requirements must be determined as part of the AHS planning effort.

A.3.14 Activity N - AHS Safety Issues

This analysis addresses the issues of safety from a system design standpoint. The automated highway system will be required to meet a certain standard of safety, regardless of the system configuration which is chosen. A primary goal of AHS is increasing the safety of the nation's highways. A general assumption is that by eliminating human error as an element in a large percentage of traffic accidents, the overall safety of vehicle travel will be significantly improved. This assumption may be valid if the AHS operates in isolation, neglecting the effects of all external factors, and if the number of failures due to AHS-specific equipment do not exceed those due to human error. A first area of study presents an array of factors which have the potential to impact the design and development of an AHS which meets the goal of collision free operation in the absence of malfunctions.

A stated goal in the development the AHS concept is collision free operation in the absence of malfunctions. Overall safety will also be affected by the extent to which external forces are capable of interfering with vehicles in the system. Operation of the AHS in conjunction with conventional travel lanes or in areas that are vulnerable to intrusion will create the potential for collisions with non-AHS vehicles. Accidents may be caused by unauthorized vehicles entering the AHS lane, by debris from accidents occurring in non-AHS lanes, or animals or pedestrians entering the roadway. A collision free environment can not be guaranteed unless all types of intrusions can be prevented, and there will remain a certain degree of risk which must be managed.

The role of the driver in the AHS is the center of debate in terms of safety. The human field of view and the benefit of experience allow a driver to anticipate and avoid many potential collisions in conventional driving. The AHS design must be capable of detecting and avoiding unplanned intrusions into the travel lane. A balance must be achieved between automated control and operator intervention. The spacing and grouping of vehicles has a great impact on the complexity of the problem. The potential for error in close following mode may be greater than the benefit of allowing the driver to intervene in a perceived emergency. One option which may be considered is allowing the lead vehicle in a platoon to retain some degree of manual control. This issue is one of the most pressing in terms of maintaining system safety, especially with respect to implementing platoons. The capability to prevent collisions is removed from system control if the operator is allowed to interrupt automated control at any time.

A major safety consideration involves the risk of collision during the transition between automated and manual control. The potential for human error exists if vehicles are allowed to enter or exit the AHS under manual control and the transition to automated control is made within the AHS lane. Similarly, if the vehicle is under AHS control in the non-AHS lane during a merge maneuver for entry or exit, then the AHS vehicle is susceptible to human error occurring among the vehicles operating manually in the non-AHS lane. One option to minimizing these risks is to dedicate entry/exit facilities to eliminate the risk of collisions in transition lanes caused by vehicles under manual control. A related issue in a configuration which allows the transition to take place in lanes with mixed flow is the assignment of liability in the event of a collision.

The degree of risk in terms of injury or destruction may be dependent on the system configuration. The failure of a critical function or a disruption such as a power failure in a close-following platoon has the potential to cause multiple collisions and/or injuries. The statistical probability of this type of event must be extremely small, placing high reliability requirements on the system. An important goal will be to maintain user confidence in the safety of the system, especially in the early stages of deployment. An analogy may be drawn with the airline industry, where accidents are very rare but can be catastrophic when they occur and often cause multiple deaths, adversely affecting public perception. This type of accident receives greater publicity in proportion to the number of lives lost than a comparable number of traffic accidents in the same time period. The system must be brought on line in a way which minimizes the risk of collision-inducing failures, allowing a safety track record to be established which will promote user confidence. This may be accomplished by evolutionary introduction of increasing levels of automation and deployment of a platoon configuration after automated control of individual vehicles has been widely accepted.

Classical safety analyses promote safe stopping distances between vehicles which allow a vehicle to stop without a collision when a "brick wall" failure occurs in the preceding vehicle. This stopping distance is greater than the current following distance commonly used on congested freeways. An AHS which requires large headway will sacrifice throughput. Alternative studies show that platoons with tightly spaced groups of vehicles with "brick wall" stopping distances between platoons can be safe, because in emergency maneuvers the vehicles traveling close together will be traveling at nearly the same speed and energy transfer between them in the event of a collision will be very small. The problem occurs when an intrusion to the AHS occurs, such as an unauthorized vehicle cutting into the safe gap, or an animal entering the roadway. These situations will cause a collision if the obstacle is closer to the lead vehicle than the safe stopping distance. The platoon of vehicles will be at a greater risk for multiple injuries than single vehicles spaced at the standard safe stopping distance.

The ability to safely maneuver incapacitated vehicles out of the flow of traffic will require instrumentation to support longitudinal and lateral control outside of the automated lane. A system configuration which places all of the functionality for latitudinal and longitudinal control within the vehicle will not be constrained to operation within an instrumented lane. Lateral and longitudinal control which depends on interaction with the roadway will require instrumentation in any travel way in which control must be maintained. One option is to implement a two lane AHS in which both lanes are used for travel, or configured as a travel lane with a breakdown lane or shoulder. One lane can be used by the traffic operations management to allow malfunctioning vehicles to be parked while oncoming traffic is maneuvered into the second lane and back as necessary. A concern with a single dedicated lane with barriers on each side is how much horizontal clearance is necessary to maneuver safely around incidents within the automated corridor.

Lanes dedicated to automated control introduce the concern over how to safely limit access. Barriers between the automated lane and manual lanes decrease the likelihood of intrusion into the AHS by unauthorized vehicles, animate obstacles, or debris. Allowing manually controlled vehicles to operate in the same lanes as system controlled vehicles makes it more difficult to design a collision free system. The AHS must be responsible for controlling all vehicles within the system; in mixed mode traffic, there is additional work load added by accounting for unpredictable movements of manually controlled vehicles.

There is a certain level of risk in traveling on conventional highways associated with such events as floods, earthquakes, and other natural occurrences. Evaluating the safety of the AHS must consider the vulnerability of the system to this type of occurrence. The susceptibility of the system configuration to natural disasters must be considered to prevent creation of a greater safety risk than that encountered on conventional highways in the event of these occurrences. The design of the AHS must also avoid increasing the cost associated with prevention of environmental effects out of proportion to the benefit attained. Safety can be maintained economically through a range of approaches, including such measures as rerouting traffic in adverse weather conditions or eliminating certain sites from consideration for AHS deployment.

The impact of system safety at the subsystem design level is another important concern. Safety can be improved by introducing higher levels of subsystem redundancy but this tends to increase the system cost out of proportion to the benefit. Improved component reliability and providing cross functionality among subsystems may provide higher safety benefits at lower overall cost to the system. AHS systems can use existing vehicle subsystems such as engine controllers or ABS as models for reliable, cost effective, safe implementation. The effect of the system architecture on the cost of safe system design will be a primary consideration in the flow down of subsystem functionality.

Safety has been established as one of the primary influencing factors on the success of AHS. It is an area of concern that permeates every level of the system design, and must be addressed at each stage of study, development and deployment. It is recommended that system safety be addressed as an integral part of subsequent contracts. A System Safety Program can be implemented which consists of safety related activities in the planning, design, construction, deployment, and operations phases of AHS projects. A primary goal of the safety plan is the elimination or mitigation of failures through design criteria which indicate areas of concern. System safety emphasizes the verification and demonstration of the overall safety of the system as implemented for subsequent long term operation. Identification of safety as a systems level issue and establishing design practices and standards at the outset of the development phase are important steps toward creating a system that will meet the safety design goals.

A.3.15 Activity O - Institutional And Societal Aspects

This activity is devoted to the investigation of institutional and societal issues and risks of importance for the implementation and operation of AHS, focusing on the following four areas of inquiry: impact on state and local transportation agencies, environmental issues, privacy and driver comfort, and driver/vehicle interface.

This report consists of an analysis of institutional and societal issues associated with AHS. Focus is placed on the following four areas of investigation:

- Impact on state and local governmental agencies.
- Environmental issues.
- Privacy and human factors.
- Public acceptance – user interface.

The first task is devoted to a discussion of the grouping of issues and concerns as summarized in table 4. Risk indices and risk indices descriptions have been chosen for quantification and prioritization ranking with an issue being of lower risk and a major concern, of highest risk. The relative risk priority index ranking used here, is as follows:

- An issue is *
- A concern is **
- A serious concern is ***
- A major concern is ****

Beyond PSA, it is strongly recommended that more definitive risk assessment(s) be made once a baseline AHS approach has been chosen from the RSC(s). For example, prior to a bid award, a detailed risk analysis should be performed to determine risk rating tradeoffs of, probability of occurrence vs. severity of impact (in dollars). Information and conclusions derived from Activity P - Preliminary Cost / Benefit Factors Analysis could be used as additional inputs in further quantifying, controlling, and re-evaluating risks during long-term AHS implementation.
Of all the design issues discussed and summarized, funding is a major issue which can lead to a number of other issues and accompanying risks. For example, inadequate institutionalized funding resulting in substandard AHS designs and inadequate system safety designed into AHS (e.g. design

for minimum risk concept-fail/safe, hazard analyses, hazard mitigation, systems assurance, etc.) causing AHS-related fatalities is unacceptable.

It is recommended that a plan of action using transit expertise to justify the necessary funding for adequate AHS design be a forum for discussion. The rationale for this approach is that System Safety design and much of the cost justifications and proven system design methodologies exist, especially in the area of train control (wayside and vehicle).

In summary, uniform design standards, educational and technical capabilities, agency coordination and cooperation, program management and cost-effective design are solvable if sources of risks have plans of actions early in post-PSA programs. Once these aforementioned areas are addressed then funding is fundamentally reduced to a liability concern related to how AHS is operated and maintained beyond the design phase.

Liability has been a long-standing issue that affects how one views the AHS concept implementation. In brief, in the AHS concept, the control of the vehicle is assumed by the AHS system. The issue of a privately-owned vehicle on a public right-of-way will have a variety of liability issues that depend on the chosen RSC (infrastructure or vehicle based). The safety issues that cause liability concerns for all RSC's are summarized in the Activity N - AHS Safety Issues report. There are two categories then to consider, liabilities common to all RSC's (e.g. system safety hazards-direct liabilities) and those liabilities unique to a specific RSC. Prior discussion on various ways to handle tort liability clearly depend on making a highly reliable and safe AHS.

Inadequate funding for operating and maintaining AHS that affects system safety impacts liability and would probably stop further funding of future AHS projects because of fatalities shown to be a direct result of inadequately operating and maintaining AHS.

As discussed earlier the acceptance of system safety and maintainability principles as a necessary step at all phases of AHS development is integrally related to the number of fatalities, injuries, and equipment failures on AHS. Increased emphasis on maintainability using preventive with corrective maintenance planning for AHS and non-AHS public right-of-ways is a paradigm shift in current thinking that is critical to the long-term success of AHS and the safety of our private citizens.

An analysis of environmental issues associated with AHS was made. The principal sources of information used in the analysis, individual interviews and focus group participants in the engineering, planning, economics, and environmental areas allowed for a deep probe into views that might otherwise not come to light.

Table A-1. Risk Assessment Rank Areas and Prioritization

RISK INDICES	RISK INDICES DESCRIPTION	DESIGN ISSUES (Risk Index in parentheses)	OPER. ISSUES (Risk Index in parentheses)	MAINT. ISSUES (Risk Index in parentheses)
* ** *** **** *,**: Solvable. ***,****: Requires more investigation to resolve.	ISSUE CONCERN SERIOUS CONCERN MAJOR CONCERN	-Uniform Design Standards(*) -Educational and technical capabilities(*) -Agency coordination and cooperation(*) -Program Management(*) -Funding(****) -Cost effective design(**)	-Adequately trained staff(**) -Emergency response(*) -Transition period(*) -Liability(***)	-Technical capabilities and equipment(**)

Environmental issues associated with AHS fell into three major categories: travel-related, infrastructure and urban form, and institutional. Travel-related issues arose from concerns over the consequences of AHS implementation and operation on how much additional travel will be generated, by what means, and its secondary impacts on vehicle emissions and fuel usage. The major infrastructure and urban form issues relate to impacts from infrastructure changes resulting from AHS such as visual impacts and seismic safety concerns, as well as the impact on the local neighborhood as a result of potentially substantial increases in vehicle access and egress to and from non-automated roadways. The institutional issues are centered around the relationships among the participants in AHS research, development, deployment, and operation. Examples of such issues are the barriers that exist between the two major groups of participants in this research, as well as the lack of complete and accurate information and attitudes that each group believes about the other group.

Primary suggestions for resolving these issues include:

- Further research into developing modeling tools to more accurately represent the automated highway driving mode to produce reliable estimates of the impacts in areas of travel volume changes, mobility, land use, emissions, and energy consumption.

- Investigation of current methods for environmental impact review processes for applicability to the AHS case, determining and making necessary modifications.

- Incorporating an aggressive process of education, communication, and participation to help dissolve the barriers and help forge a more common vision of a future transportation system with AHS as an integral component.

The most significant recommendation of all would be to make every effort to begin the process of resolving these issues as well as issues in other areas of investigation in the near term, and not delay this process. Delay would only add to the difficulty by contributing to the exacerbation of the issues and probably the expense of resolving them.

Privacy issues, driver comfort, and driver acceptance was next discussed. Current studies indicate that the driving public will be more likely to use the AHS if a concerted effort is made to offset the privacy issue. This can be accomplished by providing a full explanation of the AHS system operations and highlighting the benefits. The evolutionary deployment of AHS technologies, such as toll debit cards and incident surveillance cameras through ITS implementation, would be an initial step. The remaining AHS requirements including vehicle inspection and driver monitoring can be introduced with the added benefits of increased safety, reduced travel time and operating costs. Gradual introduction of control features and associated electronics will allow the driving public to benefit from the convenience of the system in proportion to the level of risk to privacy.

The level of driver comfort during the operation of a vehicle in automated mode is discussed from the perspective of in-vehicle AHS equipment and potential psychological stress factors. In-vehicle equipment the driver would use to operate the automated vehicle must be user friendly, easy to operate, and be designed for as complete a user capability profile as possible, including age and reaction time differences. A driver-vehicle interface must take into consideration the potential for driver work overload if manually entered input is required. The combination of high speed, automated control, potentially very close vehicle following would likely contribute to added psychological stress that must be addressed. Research is needed to accurately assess the extent of this problem and develop and assess potential solutions. Driving simulators could be used but their effectiveness may be limited since there really is no risk of an accident in a simulator, yet stress may still be present. Alternative test strategies to evaluate driver responses may include test tracks and demonstration rides. Methods to address the potentially stressful effects of automated driving by reducing the perceived trip length include diverting the driver's attention with information, either trip-related or recreational.

An investigation of the AHS vehicle-driver interface consisted of the development of concepts to depict the possibilities for driver interface and for representative AHS situations. Important design concerns for vehicle displays and controls include their orientation, method of implementation, styling, and illumination. Driver interface concepts include potential electronic interface units and their positions within the vehicle; typical AHS situations include check-in/out, entry/exit, various vehicle types (commercial and transit), maintenance situations, and potential driver activities while using the automated facility. These concepts generate numerous issues among which include the compatibility with malfunction management strategies of allowing certain vehicle components (steering wheel, foot pedals) to be moved to different positions to provide the driver more room for other activities, the potential need for standardization of details of AHS control and communication interfaces among vehicles, the degree to which driver-vehicle interface is extended to encompass the front seat passenger or possibly back seat passengers as well, the extent to which the AHS interface would be able to use components already present as part of the more general ITS interface.

A.3.16 Activity P - Preliminary Cost / Benefit Factors Analysis

The research in this activity area establishes a framework for the evaluation of benefits and costs of a hypothetical AHS. The willingness of state and local authorities to undertake AHS projects as well as the continuing federal support for AHS will depend on the potential for strong economic returns from AHS. The analysis of a hypothetical AHS project will expose risk elements as well as the principal sources of benefits. In so doing, these can be used to provide guidelines for deployment strategies and identifying areas of further research.
The following presents a summary of the key findings of the analysis:

- Travel Time - One of the principal AHS benefits categories is improved travel time. In the urban environment, the AHS will likely have a moderate impact on travel time during the peak hour of operation and a greater impact on travel times in the peak period outside the peak hours (the peak period margins). Under normal operating conditions, with adequate penetration of AHS-equipped vehicles, there will likely be a phenomenon of temporal shifting of demand to the peak hour: Many of the AHS-equipped vehicles will travel in the peak hour while the additional capacity made available in the non-AHS lanes, through the diversion of AHS vehicles, will result in a greater number of trips by non-AHS vehicles being accommodated in the peak hour. Consequently, greater traffic volumes would flow in the peak hour. However, more substantial improvements in time savings per trip would occur in the peak period margins which will operate with lower volumes of traffic.

- Improved Convenience - A greater number of trips being accommodated in the peak hour represents a significant benefit for many travelers. Urban congestion forces many commuters to travel at off-peak hours which results, sometimes, in lost economic opportunities as well as personal inconvenience (e.g., lost leisure opportunities, time spent with families, etc.).

- Improved Safety - The AHS has the potential to significantly reduce accidents by assuming control of vehicles in the AHS lane, and by reducing congestion in conventional lanes and arterial streets. Benefits associated with improved safety include fewer fatalities, injuries, and property damage. It is estimated that the AHS could reduce accidents by around 70 percent for users of the AHS by assuming control of AHS vehicles removing driver error as the cause of many accidents.

- Economic Activity Benefits from Congestion Relief - Urban traffic congestion represents a serious impediment to the development and retention of particular types of economic activity. Urban business centers grow and develop due to what has been called "economies of agglomeration." Many industries (e.g., wholesale and retail trade and business services) require that the majority of employees be on site during principal business hours in order to maintain smooth, profitable operations. Congestion frequently makes that difficult or costly resulting in businesses abandoning the urban centers. Relief of traffic congestion promotes conditions that enable cities to flourish as business centers. AHS, insofar as it accommodates greater numbers of people being able to commute to business centers for principal business hours, will likely contribute to improved economic activity.

- Urban Form and Livable Communities - The phenomenon of urban sprawl, low-density housing, and two-vehicle families have been facts of U.S. development for many decades. Many communities face the problem of growing congestion in daily commutes between suburbs and cities, contributing to both the decline of the cities as well as the quality of life in suburban communities. In the long run, rail and transit may represent a solution for some growing communities. However, achieving sufficient ridership thresholds to justify rail may be many years away. AHS may provide a lower cost and, overall, more acceptable solution for many communities. AHS could keep business centers attractive thus preventing further sprawl and contribute to more balanced regional development.

- AHS and Arterial Congestion - The highway and benefit-cost activities make clear that AHS represents a viable traffic alternative for regular commuting traffic only if congestion on surrounding arterial routes is relieved to an adequate degree. In the absence of arterial relief, AHS could be viable for periphery-to-periphery trips. An additional alternative might be a "many-to-few" AHS configuration where vehicles enter the AHS at many points but can only exit in the business district during rush hour at designated parking facilities. However, the many-on/many-off urban AHS would result in unacceptable ramp queuing if arterial congestion were allowed to exacerbate. A conclusion to be drawn from the above is that AHS needs to be developed within the framework of multimodal regional planning.

- Operation Thresholds - The benefit-cost analysis, which included an analysis of traffic distribution on a hypothetical AHS over the entire peak period (not just peak hours) reveals that a minimum penetration threshold for operating the AHS during the peak hour would be at about 9 percent (assuming that most of the AHS vehicles will choose to travel in the peak hour). For levels of penetration below 9 percent, AHS operations would actually reduce the total capacity of the highway system. In order for AHS to improve overall highway operations in the peak period margin hours, the estimated level of penetration would need to be 33 percent. Below this threshold, AHS operations would reduce total capacity in the peak period non-peak hour under the planning assumptions examined.

- Vehicle Cost - From the point of view of a consumer, the willingness-to-pay for AHS equipment and service will be a function of how the individual values his own time. If, for instance, AHS results in a 15 minute time savings per day, and, supposing that the consumer makes 200 commutes per year and values his/her time at $10 per hour -- then he/she would be willing to pay $500 per year for AHS. This, of course, assumes that the consumer derives no additional benefits (e.g., reduced stress, etc.) from AHS and that there are no other acceptance problems. Vehicle cost will be a key component in the acceptability of AHS -- for all stakeholders concerned (travelers, public sector, vehicle manufacturers). In order to attain the relatively high thresholds of penetration required in a timely manner, the cost of equipment and services need to be maintained at sufficiently low levels.

The results show that given the assumptions of the analysis, a hypothetical AHS project has a high likelihood of providing a strong economic rate of return. Key assumptions which are crucial to the analysis include the following:

- A successful evolutionary deployment of AHS and IVHS systems and products.

- The ongoing development of an AHS roadway network in Phoenix and other metropolitan areas.
- Continued public funding of AHS development.
- Implementation of multimodal planning and investment to relieve arterial congestion.
- Technological development and market acceptance keeps pace with scheduled deployment.

Highway projects, in general, generate most of their benefits through time savings and convenience benefits, with safety and other benefits a much smaller proportion of the total. The principal benefits which are expected to be derived from the AHS project are time savings and convenience made possible through added capacity in the peak hour. The benefits to non-AHS users are projected to comprise the majority of benefits even for levels of AHS penetration as low as 20 percent.

It was apparent from the highway operations analysis that AHS would be clearly not viable unless implemented within a multimodal planning context. Without complementary planning and improvements to supporting roadways, ramp queuing on the AHS would rapidly make any prospective urban AHS a non-starter. Within a multimodal planning context, AHS could potentially relieve congestion in crowded corridors. While not captured in direct benefits, the relief of congestion from AHS could contribute to the preservation of business districts and prevent continuing urban sprawl. This could be the case in areas with relatively low housing densities which could not support a rail project yet still need a cost-effective solution to congestion.

Further clarification of the deployment scenario will be crucial to firming up estimates for economic benefit-cost and rates of return. The benefits from added convenience and AHS benefits which are less readily quantified (i.e., reduced stress, mobility for the elderly) still require research to determine the value of these benefits.

Table A-2. Summary of Precursor Systems Analysis Database Items

Item #	Act.	Database Topic	Item Type	Contract Overview Report Section				
				Sys Ch	Op/Mt	Imp	Dep	Fnd
A01	A	Effective utilization in rural areas	conclusion	x				
A02	A	Availability of communications infrastructure	concern					
A03	A	Specialized equipment required for short headways may not be necessary in areas with low traffic densities	conclusion	x				
A04	A	Response delay to emergencies or incidents	conclusion					
A05	A	User costs may not be in balance with benefits	risk	x			x	x
A06	A	Congestion reduction must be addressed from aspect of improved throughput as opposed to increased capacity	conclusion	x		x	x	
A07	A	Evolutionary deployment has different goals in urban and rural scenarios	conclusion	x			x	
B01	B	What is the relative value of peripheral equipment during check-in?	issue					
B02	B	Safe management of check-in failures	concern	x				
B03	B	Determination and management of intermittent electronic failures	concern					
B04	B	What check-in techniques may be used for items which cannot be checked electronically?	issue	x				
B05	B	Detection of alterations of in-vehicle check-in data	risk					
B06	B	Can an information gathering system be developed to gather data for ranking check-in item?	issue					

Table A-2. Continued

Item #	Act.	Database Topic	Item Type	Contract Overview Report Section				
				Sys Ch	Op/Mt	Imp	Dep	Fnd
B07	B	Efficient check-in station design	conclusion	x				
B08	B	Automated equipment checking by dynamic check-in stations	concern	x				
B09	B	Intruder prevention at check-in station	risk					
C01	C	How can safe operations be maintained during check-out?	issue	x				
C02	C	What will be the additional cost due to check-out?	issue					
C03	C	False rejection of a qualified driver at check-out	risk					
C04	C	How can depots best be used to store inoperative vehicles and/or impaired drivers?	issue					
C05	C	Who assumes liability for collisions after AHS allows a driver to check-out?	issue	x				
D01	D	Intra-platoon headway policy	issue	x				
D02	D	Intra-platoon collision dynamics	concern	x				
D03	D	Driver involvement for vehicle control	issue	x				
D04	D	AHS simulation testbed	conclusion	x		x		
D05	D	Collision avoidance system detection/classification capability	concern	x				
D06	D	Communication interference	issue	x				
D07	D	Platoon air flow considerations	issue	x				
D08	D	Vehicle control on highway grades	issue				x	
E01	E	No adequate backup defined for use in the event of loss of lateral control	concern	x				

Table A-2. Continued

Item #	Act.	Database Topic	Item Type	Contract Overview Report Section				
				Sys Ch	Op/Mt	Imp	Dep	Fnd
E02	E	Driver participation in malfunction management	issue	x				
E03	E	Placement of breakdown lane	issue					
E04	E	Automated detection of roadway malfunctions	issue					
E05	E	Practicality of malfunction detection methods	concern	x		x		
F01	F	What impacts do heavy vehicles have on AHS capacity?	issue				x	
F02	F	Need of separate AHS lanes for trucks and buses	conclusion				x	
F03	F	How can heavy vehicles be handled at entry/exit points on dedicated facilities?	issue				x	
F04	F	Entry/exit strategies for commercial and transit vehicles	conclusion				x	
F07	F	Will trucks use AHS?	issue				x	
F08	F	Accommodation of trucks on AHS	conclusion				x	
G01	G	The public must be in agreement with the concept of AHS if it is to come to fruition	risk	x		x	x	
G02	G	AHS will require extensive system validation. The planning and execution of this is critical	risk	x		x		
G03	G	Sound human factors principles must be used in the design of the driver interface for an AHS	conclusion	x				
G04	G	Sound systems engineering principles must be used during the development of the AHS prototype	conclusion	x		x	x	
G05	G	Integration of AHS with ITS	conclusion	x			x	

Table A-2. Continued

Item #	Act.	Database Topic	Item Type	Contract Overview Report Section				
				Sys Ch	Op/Mt	Imp	Dep	Fnd
G06	G	Channel product liability concerns into higher product quality	risk	x				
G07	G	Handling political pressure in project development and implementation	conclusion					
G08	G	Including maintenance in project development and management	conclusion	x	x			
G09	G	Including reliability issues in program and project development	conclusion	x			x	
G10	G	Including safety issues in program and project development	conclusion	x		x	x	
G11	G	Technical involvement in program and product development	conclusion	x			x	
G12	G	Dealing with the public and potential loss of public confidence	conclusion				x	
H01	H,F	What AHS lane width should be used?	conclusion	x				
H02	H,F	Shoulders (area available for use as a breakdown lane) should be a standard design feature of AHS	conclusion	x				
H03	H,I,J	What capacity should be used in designing specific AHS segments?	issue	x		x		
H04	H,J	Addition of an AHS lane improves overall vehicle operation in the corridor	conclusion			x		
H05	H	Rural AHS should be on an added lane, not a lane taken away from mixed traffic	conclusion	x				

Table A-2. Continued

Item #	Act.	Database Topic	Item Type	Contract Overview Report Section				
				Sys Ch	Op/Mt	Imp	Dep	Fnd
H06	H,F	What operating speed should be used for AHS design?	issue	x				

H07	H	A physical barrier should separate AHS and non-AHS traffic in both the urban and rural scenarios	concern	x		x	x	
I01	I,J	AHS volumes on local streets will negatively impact neighborhoods	conclusion	x		x		
J01	J	What is the desirable minimum distance along the cross street from the AHS to nearest parallel street?	issue	x		x		
J02	J	In an urban setting, existing interchanges cannot be retrofitted for AHS entry/exit	conclusion	x		x		
J03	J	On-site check-in is not feasible	conclusion	x				
J04	J	Demand must be managed at AHS entry points	conclusion	x		x		
J05	J	Entry/exit ramps for dedicated facilities must be separated	conclusion	x		x		
K01	K	Can AHS operating agencies attract and retain quality personnel?	issue		x			
K02	K	Who should operate the AHS?	issue		x			
K03	K	Will the States (or other operating agencies) accept the added tort liability AHS may bring?	issue				x	
L01	L	What AHS research should consider about RF communications	risk	x				
L02	L	Will AHS vehicle components be produceable at an acceptable cost?	issue	x				x

Table A-2. Continued

Item #	Act.	Database Topic	Item Type	Contract Overview Report Section				
				Sys Ch	Op/Mt	Imp	Dep	Fnd
L03	L	Multiplexing systems in vehicles to reduce wires	conclusion					
L04	L	After market products for AHS vehicles	risk				x	
M01	M	Will APS vehicles have dynamic performance suitable for operation on AHS?	conclusion				x	
M04	M	Will the AHS check-in range of battery-electric vehicles be a real time function of environmental conditions?	issue					
M05	M	Will industry-wide standards be needed to ensure AHS vehicle performance? And, who will be responsible?	issue	x			x	
N01	N	What should be the role of the driver in handling emergency maneuvers?	issue	x				
N02	N	Transition between automated and manual control	concern	x				
N03	N	Effect of external factors on safety	risk	x		x		
N04	N	Safety must be designed into the system cost effectively	conclusion	x		x		
N05	N	Catastrophic disruptions	conclusion			x		
N06	N	How does the relative safety of platoon configuration impact relative safety?	issue	x			x	
N07	N	A single automated lane will not allow maneuverability in the event of malfunction or disruption	conclusion					
N08	N	Mixed mode traffic increases risk of collisions due to human error	concern	x			x	

Table A-2. Concluded

Item #	Act.	Database Topic	Item Type	Contract Overview Report Section Sys Ch	Op/Mt	Imp	Dep	Fnd
N09	N	What is the comparable level of risk due to natural disasters?	issue			x		
O01	O	Travel related issues	issue			x		
O02	O	Infrastructure and urban form issues	issue			x		
O03	O	Institutional issues	issue	x			x	
O04	O	Maintaining the infrastructure	issue		x			
O05	O	Public acceptance of platooning	concern	x			x	
O06	O	Secure adequate funding	issue					x
O07	O	Public agencies vs. driver's responsibilities	concern			x		
O08	O	How sensitive will potential users be to the operator qualifications and tests required for AHS travel?	issue	x		x		
P01	P	Manufacturers will widely use throttle-by-wire in response to normal market	conclusion	x				
P02	P	Manufacturers will widely use brake-by-wire in response to normal market	conclusion	x				
P03	P	Steer-by-wire is not clearly driven by market forces, however, it will be an enabling technology	issue	x				
P04	P	Vehicle communication and collision avoidance may not cost effectively meet the requirements of AHS	issue	x			x	
X01	X	Reliability/maintainability	issue	x				x
X02	X	National standards	concern	x			x	
X03	X	Evolutionary deployment	issue				x	
X04	X	Equipment development/emerging technologies/feasibility	conclusion	x			x	

APPENDIX B

HIGHLIGHTS OF CALSPAN OVERVIEW REPORT

This appendix contains highlights extracted from the Calspan Contract Overview report. The material is included as a convenience to the reader; the full Contract Overview report, as well as the reports on each of the 16 study areas, is available through NTIS. All of the findings in this appendix can be directly mapped to the Calspan findings in the PSA Database.

There are two sections: B.1: Major Findings by Activity Area
B.2: Cross-Cutting Analysis Findings

B.1 MAJOR FINDINGS BY ACTIVITY AREA

The material in this section contains the major Calspan findings by activity area studied.

B.1.1 AHS Comparable Systems Analysis Findings

The AHS is not the first large system that involved the introduction of new innovative technology, was intended for widespread public use, required coordination across Government and private industry, had potentially significant cultural and societal impact, and required large amounts of financial investment. Large innovative systems have come and gone. Some have been successful and changed society forever in fundamental and important ways (e.g., the automobile, computers). Many changed our world in small to moderate, yet important ways (e.g., ramp metering, electronic toll systems and traffic management systems). Others met with public and/or political resistance or technological and/or fiscal problems and ultimately failed (e.g., the supersonic transport—SST).

The results of the analyses are synthesized into 20 major conclusions. The following paragraphs describe each major conclusion and cite evidence from relevant comparable systems.

1. The public must perceive the overall benefits of AHS.

   In order for a new technology to successfully replace an existing technology, the new system must offer clear and obvious advantages and benefits over the older system. If these benefits are not provided or evident, potential users will likely be unwilling to give up the pre-existing trusted system for the newer system, especially if the changeover involves significant costs (e.g., money to purchase the new system, time to learn new procedures, license fees).

2. The safety and reliability of AHS must be clearly demonstrated.

   Any new technology must be proven safe and reliable before the general public is willing to accept and use it. Evidence from the comparable systems studied has shown that even systems that have a reputation for good safety may face loss of users if a safety incident does occur. Systems that have a reputation of safety problems have had a very difficult time achieving public acceptance.

   Evidence for this conclusion comes from the study of elevators, commercial flight, bank automated teller machines (ATMs), aircraft automation, and the Morgantown personal rapid transit system. Public concerns about health and safety have even been raised for electronic toll and traffic management (ETTM) systems. To illustrate, elevators have been around since the middle ages but, until after 1854, were limited to hauling freight because the public had serious concerns about their safety. In 1854, Elisha Otis dramatically demonstrated the safety of his "safety elevator" by having himself raised 40 feet in the air and having the elevator rope severed, demonstrating the effectiveness of the new elevator safety mechanism. From then on, elevators have been used to haul people (and, in fact, are the safest form of automated transportation in use today!).

3. Long-term and continuous financial support for AHS deployment must be secured.

   For the long-term success of AHS, it is important to ensure that funding for the project is sufficient and guaranteed. If the funding is not sufficient, it may be difficult to raise funds at a later date. If the funds are not guaranteed, they may be cut at any time, and battles for project financing will be ongoing. Further, funding needs to be specific to the goals of AHS, and pay-as-you-go financing is preferable to borrowing.

4. Support from influential persons in Government and industry is important for large programs.

   The importance of a strong proponent for large projects was evident in many of the systems studied during this program. The success of many large-scale projects has been facilitated through the commitment of high ranking officials from Government or industry who were willing to work hard to ensure the success of the projects. AHS will benefit from such an individual (or group) to help secure the necessary financing and support, and to help maintain enthusiasm for the project during all stages of design and implementation.

5. Evolutionary development of AHS is recommended.

   An evolutionary approach to the development and implementation of AHS is recommended, based on the experience of several large-scale public systems studied during this project. An evolutionary approach will provide for incremental development, allow safety and reliability to be demonstrated on a small scale before system-level integration is attempted, and provide a gradual approach to achieving public acceptance. This will also allow alternative technologies and design approaches to be compared prior to selection.

6. AHS should be designed for integration within the overall transportation system in the United States and worldwide.

   The AHS market should be defined in relation to other transportation forms. The AHS network and design should be developed based on this potential market. When AHS is included as an integral component of the U.S. transportation system, rather than as an independent competing mode, a realistic and stable user base will be encouraged, and the goals of the U.S. transportation system will be best served. AHS objectives should be developed on the basis of this integrated definition. Further, AHS components should be standardized for all AHS applications in the U.S. and worldwide and should be compatible with existing conventions. For example, AHS should be designed to be as compatible as possible with existing highway signs and procedures.

7. Cost and time estimates for developing AHS must be carefully and accurately determined.

Budget overruns and schedule slippage can lead to negative publicity, poor public acceptance, and reduced political support for the system. System design, testing, and implementation must remain within budgetary guidelines and time constraints for the project to ensure continued support. Cost and schedule "bad news" can reduce public acceptance of AHS, even when the shortfalls are due to estimation errors, rather than the more serious system problems. Also, it is important to plan for schedule and cost contingencies. Despite good planning, unforeseen problems are likely to emerge and require unplanned effort.

8. Consortiums of private and public agencies can facilitate AHS successful development.

A consortium approach to AHS development can help to ensure that the AHS system is successfully implemented. The consortium approach will allow the project to benefit from a wide range of expertise and perspectives, and to share the costs involved with implementation. Even more importantly, cooperation among the various industries and organizations interested in AHS will facilitate efficient and effective designs that can be supported by products and services developed independently, yet which must operate within a common infrastructure. The motivation for investment, participation in the consortium, and diligence in the task comes from the increased market share potential that results from design participation. Winners and losers are sorted out in the market place.

9. Community outreach and public involvement will be important to AHS success.

It will be wise to keep the public educated and informed throughout the AHS planning, design, and development phases. AHS developers and supporters should make the public aware of the benefits of AHS, and immediately deal with any criticisms and/or concerns raised. AHS developers and promoters should also build coalitions with opposition groups (or at least be prepared to counter negative arguments). Environmental concerns will be important considerations. Public education and outreach, in addition to maintaining support for the program, will help attract users to the system, by allowing them to understand how the system works and the benefits it offers. Also, our research has found that full public disclosure and education are important for avoiding liability problems.

10. AHS may produce significant changes in society that may be difficult to predict.

It is difficult to predict the effect that introducing AHS will have on the national highway system, and on society, in the United States. We have found that the introduction of new technology in the United States has often led to unforeseen effects. Research to explore the non-obvious affects of AHS should be undertaken as part of the AHS planning process (e.g., through focus groups and market research).

Evidence for this conclusion comes from our study of automobile history, the railroads (primarily interurbans), the elevator, and office automation (primarily the typewriter). To take an example, the elevator had far reaching effects beyond simply moving people between floors more quickly and comfortably. They made it possible to build taller buildings.

11. Potential markets for AHS should not be overlooked.

The wider the potential market-base, the easier it will be to gain widespread acceptance of the new technology. This may also help to keep operating costs low. Limiting the potential market for AHS could exclude potential users, and result in poor public perception of AHS. That is, it could be seen as having limited usefulness and value, or being toys for the rich and powerful. To maximize the potential for AHS success, it is best to open up the system to as many categories of users as possible (e.g., consider commercial and consumer markets). This approach of seeking the broadest possible market is recommended on the basis of the study of several comparable systems

12. A large return for AHS can be achieved with transit vehicles.

    AHS when combined with transit and/or HOV treatments can provide very significant improvements to the people-moving capacity of our highways. These treatments are especially applicable to (and perhaps limited to) AHS applications in urban areas and along congested corridors. When considering the AHS goal of congestion mitigation, the potential of these treatments cannot be overlooked.

13. AHS design insights and technology foundations can be found in comparable systems.

14. It should be anticipated that AHS will face liability issues.

    We live in a litigious society. It seems clear that AHS implementations will face legal challenges (like all other systems). These can stem from mismanufacture, defective design, failure to warn, and/or product/service misrepresentation. AHS development should be managed in a way that minimizes legal vulnerability.

15. AHS should be designed with maintenance and system upgrade in mind.

    AHS design must consider requirements for accomplishing system maintenance. This will include incident management, routine roadway maintenance such as snow removal, preventive maintenance and system inspection, and infrastructure repair. It must be possible to accomplish these functions without significant disruption of service.

16. Public acceptance will be critical for AHS success.

    If we build it, will they come? And will they support its development? Public demand for systems can drive the development and expansion of markets to worldwide levels. On the other hand, public opposition to systems can create serious obstacles to success. Issues of public acceptance for AHS will be very important.

17. The degree of centralized control and human decision making can slow system response.

    The degree of centralized control can slow system response time and reduce the ability to deal with local conditions. This could affect spacing and flow achievable. Highly centralized control approaches can create lags in the control system and make it difficult to deal with local conditions. The requirement for human decision making in the control loop is especially problematic and should be limited to global, non-time-critical-parameters.

18. AHS exit efficiency will be critical for handling high AHS flow rates.

    Bottlenecks can be created at popular exits if the exits cannot handle traffic demand. This could require closing an exit to avoid vehicles from backing-up onto the AHS lane(s). Approaches for mitigating this problem include proactive planning and the use of multiple parallel exits or buffer zones. Proactive planning could include placing, under system control, groups of exits in congested areas (e.g., near an activity center such as a stadium or CBD). Drivers desiring to exit could be assigned an exit by the system in a way that optimizes overall exit efficiency and flow. When there is room, an additional exit lane could be also added.

19. AHS marketability will be influenced by design and economic factors.

    AHS will be one of several options for travelers. Its design and pricing approach will affect its potential market base. Innovative approaches to AHS pricing and the sales approach used can increase the potential market achievable. For example, whether AHS systems must be purchased or leased will affect their price to consumers and impact their competitiveness within the transportation market. Also, the development of the AHS market can be facilitated by "piggybacking" on other markets (e.g., market to those using existing ETTM systems, offering commuter packages that include AHS and connecting mass transit passes).

20. There may be regions that favor AHS implementation over others.

    There may be regions in which geographic or traffic conditions favor AHS, while other areas may be less favorable. On the one hand, this will make it possible to select locations for AHS demonstration where AHS can provide significant benefits within the larger transportation system. It also will help guide the planning of AHS evolution and system expansion.

B.1.2 AHS Roadway Analysis

The AHS roadway analysis consists of these three task report summaries: (1) Urban and Rural AHS Analysis (Task A), (2) AHS Roadway Deployment Analysis and Impact of AHS on Surrounding Non-AHS Roads (Tasks H and I), and (3) AHS Roadway Operation Analysis (Task K)

B.1.2.1 Urban and Rural AHS Analysis

The following are conclusions from the analysis performed under this task:

The daily user of urban and suburban freeways wants travel time savings as a performance improvement. Acceptance of AHS equipment and traffic management costs will be based on the performance gain. A target goal for this savings is one minute per travel mile; totaling at least ten minutes on the freeway portion of the trip. This objective can, most likely, be accomplished by providing preferential lane and exit/entry provisions for AHS users, since automated control can regulate speeds above the current congested level.

Major sources of urban and suburban freeway congestion are incidents (non-recurring), bottlenecks at entry/exit points (recurring), and scheduled maintenance (non-recurring). AHS vehicle instrumentation and Traffic Management (TM) are tools to eliminate congestion, provided poor roadway geometry is corrected.

Worker commuter users of urban and suburban freeways are effective targets for early deployment of AHS. These individual users have a vested interest in making AHS a success as they gain time, reliability, and safer trips. As a daily user, they should be willing to equip their vehicles and pay for the service. HOV users and Transit are prime customers for AHS since they are currently part of the solution for urban and suburban congestion.

Optimize operational improvements on urban and suburban freeways along with introduction of AHS, as it a part of a TM package not a stand alone service. TM includes; surveillance and control systems, ramp metering, incident management, motorist information systems, HOV facilities, and low-cost geometric improvements. These TM techniques are required to supplement AHS full automation.

During early year deployments, AHS performance may not be ideal in terms of congestion relief, due to mix of manual and automated vehicles. Working with existing freeways to gain initial automation benefits, provides a wider and more immediately visible return than attempting to build new AHS guideways to serve a select few.

Understand and respect the social issues of AHS deployment. AHS deployment is not just a technical installation exercise to provide a service. Impacts on land use planning, air/noise pollution and public/political acceptance may be more important than solving mechanical/electronic/concrete problems.

Consider separated AHS lanes a high priority for suburban freeway deployment, provided equal provisions can be made for entry and exiting. A major infrastructure design issue for AHS deployment is solutions to the traffic mixing, weaving, entry and exit with non-AHS vehicles especially heavy trucks.

Assume that AHS on rural freeways will initially operate in mixed traffic lanes. When AHS use increases, and higher performance is needed, the minimum lane requirements appear to be one AHS lane and two general use lanes. This requirement will impact most of the dual two-lane freeways (outer suburban and rural). Although traffic volumes may show only a need for a single general (manual) lane, entrance/exit, passing, incidents plus operation during maintenance will probably require a minimum of two general lanes.

AHS can increase throughput during peak hours provided the supporting interchanges, feeder roads and city streets can accept this increase. At the proposed high flow rates, urban and suburban facilities now regularly fail. Only rural freeway feeders have the capacity required.

Research into AHS technology is important as this defines the "How". Equally important is research in the market to identify size and needs as this defines the "Customer". The "How" should be driven by the "Customers' Needs".

Envisioning AHS as a national system requires flexibility of design to accommodate urban, suburban, and rural needs. The urban, suburban, and rural environments cover a spectrum of needs. Therefore, a variety of configurations are required to meet each of the needs. Suburban would be more I3 driven and rural would be more I1 driven.

B.1.2.2 AHS Roadway Deployment and Surrounding Non-AHS Impact Analyses

Analyses were conducted by making certain assumptions about the AHS. These assumptions were used as constraints for the evaluation of a variety of AHS designs.

- The capacity of the AHS lane was assumed to be 5000 VPH with a usable capacity of 4500 VPH
- All AHS access and egress ramps were assumed to have a capacity of at least 1400 VPH
- The AHS access transition lane requires approximately 2500 feet.
- The AHS egress transition lane requires approximately 1600 feet.
- For the RSC I3, all AHS ramps enter and exit from and to a service road and/or a general use lane and/or a separate ramp. This eliminates the weaving movements of AHS equipped vehicles that utilize the AHS lane. Therefore, the AHS ramps can be placed closer to the traditional on and off-ramps.
- For the RSC I2, the access points to the AHS lane were placed at least 2000-3000 feet from the preceding on-ramp. Also, the egress points from the AHS lane were placed at least 2000-3000 feet from the next off-ramp. These distances were assumed to adequately facilitate weaving movements required by AHS equipped vehicles that utilize the AHS lane.

B.1.2.3 Infrastructure Design

This study concentrated on AHS infrastructure designs which provide separate lanes for AHS and non-AHS vehicles. The separate facility provides an environment which maximizes the constant speed and headway keeping capabilities of AHS vehicles. To create separate facilities, RSCs, with respect to the infrastructure, were developed. The RSCs developed were termed I2 and I3. RSC I2 provides for entry and exit to and from the AHS facility directly from the general use lanes of an expressway mainline. With the I2 design, the AHS lane can be physically separated by a barrier, a striped separation a few feet wide, or by a continuous transition lane for the length of the AHS lane. The continuous transition lane option for the RSC I2 design would require increased right-of-way as compared with the barrier option. Ingress/egress for the AHS lane would be allowed at any point. Finally, for RSC I2, both the transition lane option and the striped separation option require an impracticable level of enforcement to ensure exclusion of non-AHS vehicles. RSC I3 is achieved by providing separate ingress and egress for the AHS facility. The RSC I3 design was developed by separating the general use lanes from the AHS lane using physical barriers and providing AHS access/egress ramps that link directly to service roads or ramps.

B.1.2.4 AHS Performance Evaluation

Evaluation of the implementation of an AHS facility in urban, suburban, and rural environments provided the following results:

- AHS deployments using RSCs I2 and I3 on congested urban and suburban freeways can significantly improve speed and travel time on these facilities. Travel time improvements of up to 38 percent were obtained for the cases studied. Significant travel time improvements on the rural facility were only obtained when the AHS cruise speed was increased to 80 mph from the 62 mph speed used for the other cases.
- The selection of I2 or I3 AHS lane access techniques is best determined by the AHS access and egress volume requirements, by the general lane traffic of these locations, and by the level of service (LOS) on the general lanes.

- AHS deployments using RSCs I2 and I3 on congested urban and suburban freeways may significantly increase facility capacity to respond to future year demand. Depending on the origin-destination (OD) requirements, the capacity of the remaining general lanes rather than the AHS lanes may limit capacity.

- In areas which experience traffic congestion, such as Long Island, high levels of AHS utilization are obtained based on RSCs I2 and I3 type facilities at relatively low levels of AHS MP (15-25 percent).

- In congestion prone areas, the AHS may generate significant changes in the utilization of parallel facilities located several miles away from the AHS. However, as market penetration increases, as was evident on Long Island, the attraction of the AHS facility to distant parallel roadways decreases, and total VMT in the study area decreases.

- The need to access the AHS will, in many cases, cause saturation of surface street intersections. Geometric improvements and signal timing changes will be commonly required.

- Certain AHS control strategies call for queuing vehicles at AHS entry points (auxiliary lanes in the I2 configuration and ramps in the I3 configuration). Properly managed AHS traffic maintains queue delays and queue lengths at acceptable values.

- The attraction of the AHS facility in congestion prone areas results not only from increased capacity, but also, because of the facility's ability to sustain a constant comfortably high speed of 60 mph at increased volume.

- An AHS facility on a congested urban or suburban freeway might tend to reduce the total travel time vehicle-hours in comparison to comparable non-AHS facilities, while satisfying the trip demand. This finding, however, must be tested further using a more precise modeling technique.

B.1.2.5 AHS Roadway Operation Analysis (Task K)

Successful deployment of an AHS requires examination of all operational scenarios and associated operational elements under which an AHS will be utilized. The promise and the nature of automated highways, which involve instrumentation through electronic means, requires consideration of applications completely different from those associated with the way we operate and maintain our existing highway systems. For example, a fully instrumented infrastructure is subject to a wider range of preventive maintenance repairs and supervisory control as compared to existing highways. Assuming the evolutionary deployment of AHS, there are no show stoppers or operational barriers with

Current traffic management systems are primarily passive (and at best semi-automatic) and rely on macroscopic state variables such as density and speed to identify congestion and incidents. While traffic flow management requirements of an AHS would vary by RSC, configurations with central control will require a more discrete, microscopic orientation of traffic monitoring and management. The characteristics of traffic flow monitoring and management need to be examined and defined as AHS evolves.

Although it is the promise of the AHS to reduce the occurrence of incidents, the impacts of any incident on AHS will be catastrophic with regard to traffic operation. Therefore AHS must improve incident detection and shorten incident response time. The impact of traffic congestion and delay on an AHS lane will be much greater than current impacts to the existing highway system. Therefore, the incident response time must be reduced in order to maintain current highway levels-of-service.

For operation of an AHS, new or hybrid operating agencies and their organizational frameworks will need to be defined along with their potential operations responsibilities. The levels of association, coordination, and autonomy among the operations elements of existing highways, such as management, maintenance, police and emergency services need to be identified along with potential problems with existing arrangements of these operations elements. Each operating agency scenario and the operational impacts of a multi-jurisdictional framework need to be evaluated and studied. Evaluation criteria should include operations uniformity, effectiveness, and practicality of providing such service.

Current levels of expertise and staffing available at existing operating agencies can not support the requirements necessary for an AHS. The areas of expertise required for operation and management of an AHS need to be evaluated. Survey and review of current practices of in-house versus contracted-out functions at state DOTs and highway authorities are essential to final deployment of AHS.

AHS operations require preventive maintenance on a level similar to the airline industry. Existing levels of preventive maintenance performed by highway operating agencies, including operators of traffic management systems, will not satisfy the requirements of AHS. A target level of preventive maintenance for AHS needs to be defined through investigations of comparable systems.

It is anticipated that the AHS will need policing and involve policing tactics different from those practiced today. Dependent upon the RSC, the level of policing, police functions, and tactics will vary. Current policing practices need to be examined, including the level of policing, functions and tactics applicable to deployment of an AHS.

B.1.3 AHS Systems Analysis

The AHS systems analysis consists of these five task report summaries: (1) Automated Check-In (Task B), (2) Automated Check-Out (Task C), (3) Lateral and Longitudinal Control Analysis (Task D), (4) AHS Entry/Exit Implementation (Task J), (5) Vehicle Operations (Task L).

B.1.3.1 Automated Check-In (Task B)

B.1.3.1.1 Check-in tests should be performed on the fly.

We believe all check-in tests can be made without stopping the vehicle. Status of all vehicle equipment can be tested with a series of dynamic tests. Upon receipt of a command to perform a check-in test, either generated by the roadside or by the vehicle computer, the various tests are performed. If certain tests determine that some vehicle equipment fails the test, the vehicle's computer would prevent the engagement of the automatic modes, and would also communicate to the roadside infrastructure that the vehicle is not fit to operate on the AHS.

B.1.3.1.2 Actuators for steering, throttle, and brakes will require testing in a series of dynamic tests.

In order to test for the proper operation of the various actuators, it is necessary to command the actuator to move and measure its response to the test command. These dynamic tests, which will cause a steering maneuver and changes in the vehicle's longitudinal acceleration, need not be a large or long-duration displacement. Steering tests can be a series of short pulses that may result in displacing the vehicle only a few inches. These tasks can be made on an out-ramp or in a transition lane.

B.1.3.1.3 Vehicle testing will be performed continuously during AHS operation.

The vehicle equipment test sensors and built-in test systems used during check-in will also be used as part of the malfunction management system to monitor vehicle health when engaged on the AHS. Tests of all the vehicle systems will be performed at various rates; e.g., the lateral control system will need to be monitored at a high rate. The check-in function can be considered a subset of the vehicle malfunction monitoring and management system.
With such an approach, the check-in/monitoring system must be tamper-proof, thereby preventing an unfit vehicle from operating on the AHS roadway.

B.1.3.2 Automated Check-Out (Task C)

The check-out process is a critical component for ensuring AHS safety. It concerns the process of assuring safe transfer of control from the automated driving system to manual driving. Because the driver has been out of the driving loop during AHS operation, there is concern that the driver will not be ready or capable of assuming driving control and responsibility. Check-out is the procedure for transferring vehicle control to manual operation in a way that ensures driver readiness and capability, and tests the integrity of mechanical vehicle components needed for manual driving.

The conclusions/key findings from this analysis are listed below:

- There are two types of check-out that must be considered: normal check-out and emergency check-out.
- There are two parts to check-out: the testing of vehicle components, and testing for the driver's readiness to retake manual control.
- During the process of transition from automated to manual driving, the driver must take control of the vehicle rather than having the vehicle give control back to the driver.
- The check-out "test" should be an integrated part of the larger check-out process.
- If check-out "tests" are required during the automated portion of the trip (for the purpose of maintaining an adequate level of vigilance), these "tests" should be meaningful and not artificial and extraneous.
- The driver portion of the check-out process must account for the wide variability in capabilities within the driving population.
- The requirements and approach for check-out are interdependent with the requirements for, and design of, AHS features and infrastructure.

B.1.3.2.1 Driver Readiness Issues

There is a large body of research dealing with how humans process information that can be applied to the design of an effective (driver) check-out procedure. This research deals with the way humans detect and discriminate stimuli, recognize and comprehend information and situations, make decisions, and select and execute responses. Knowledge of human strengths and limitations, within these activities, is necessary to design an effective check-out process. For example, a check-out process that focuses the driver's attention on the most critical information will help avoid selective attention and distraction problems. In addition, redundant cues can shorten and improve the process of developing driving situation awareness, (e.g., alert the driver about special road conditions). By careful human factors design, the driver readiness portion of the check-out process can be fine-tuned to perform in the most optimal fashion.

Human monitoring performance and associated vigilance decrement problems (reduction in level of alertness) have also been extensively studied. This research base can also be applied to AHS design of level of alertness and monitoring performance features. For example, knowledge of task duration has been found to affect the vigilance decrement. This can be applied to develop different approaches for maintaining vigilance on rural and urban AHS segments. One approach to ensure that the driver remains vigilant and alert is to test the driver periodically throughout the trip. However, these tests should be meaningful and related to the trip on the AHS. People generally do not respond well to meaningless tasks, and may perform poorly if they do not believe the test is important. For example, AHS could alert the driver that an exit is approaching, and could ask whether the driver desires to check-out. The act of responding to the system is an indication that the driver is awake and alert.

The driver check-out process must be designed to ensure that the driver is capable and engaged with respect to each important aspect of driving performance. Figure B-1 shows a generalized model of the driving task including each important cognitive and control subtask. The check-out process must address each of these subtasks to keep the driver in-the-loop, ready, and capable of assuming driving responsibility.

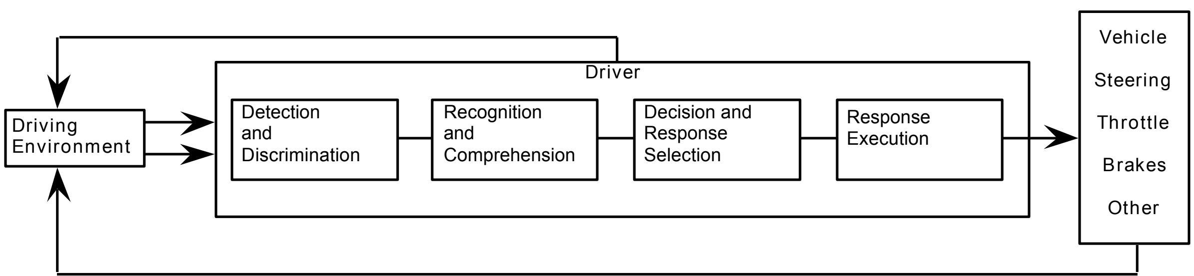

Figure B-1. Information Processing Model

Given enough time, testing for driver capability and engagement with respect to the driving subtasks, shown in the information processing model (figure B-1), would be straightforward. There are substantial research and tools available to support the measuring of human performance with respect to each of these activities. However, the practicality of implementing a driver assessment procedure within the check-out process must be considered. Drivers will not tolerate a system that requires a battery of tests each time the AHS is exited. Additionally, AHS flow requirements and infrastructure limitations dictate that the tests be accomplished quickly. Our AHS check-out challenge is to accomplish the goal of a comprehensive driver assessment within the worst-case time available. Further, this must be accomplished for AHS drivers varying in age, experience, and capability.

It would be most advantageous if the driver assessment procedure is accomplished within the process of transferring control from the automated driving system to manual driving. That is, the control transfer procedure should be designed to include steps that accomplish both transferring control to the driver, and assessing the driver's readiness to accept control. Table 8 shows each component of the

driving task, as illustrated in figure B-1, and identifies a general approach for assessing driver capability with respect to each. This is a very general model that needs to be further developed and tested during the next AHS program phase.
It must be emphasized that this is a very skeletal description of a possible driver readiness assessment process. The specifics of this procedure need to be determined and validated on the basis of further analysis and test. This generic example of a possible approach to meeting this requirement serves to demonstrate how the steps of driver readiness assessment can be embedded within the vehicle control transfer process in a way that is practical for AHS implementation.

One critical aspect of the driver readiness assessment process is that it never fails in determining that the driver is controlling the vehicle when automated control is relinquished. Our recommendation for meeting this important requirement is that the driver be required to take control rather than have the vehicle give up control. The driver should be required to initiate a positive action using the vehicle's manual controls to complete the control transfer process. This is very similar to the way drivers currently take control from today’s cruise control. The check-out process must ensure continuous active control of the vehicle, and has important liability implications. This is an important conclusion of this task.

In addition to verifying that the driver is ready and actively controlling the vehicle, the integrity and proper functioning of the critical vehicle control mechanisms must be ensured. Most vehicle control functions operate under both automated and manual driving conditions, and, therefore can be assumed to be working. However, the manual links to safety-critical actuators must be verified. These include actuators for steering, braking, and throttle. Three possible approaches to AHS design relevant to these tests have been identified.

In the first design approach, the manual vehicle control system or the automated vehicle system can be connected at a time. One can be connected only when the other is disconnected. The approach to verifying manual control integrity with this design may be mechanical; e.g., a mechanical switch can be engaged when manual controls are "locked-in." Automated control links can only be allowed to disengage when the mechanical engage switch is engaged.

The second approach, requires software logic and control response testing. In this approach, both control modes remain connected to the vehicle actuators at all times. An electrical switch is used to control which mode is to be recognized by the actuators at any one time. The verification of control integrity must be done through control response testing, and the switch to manual control can only occur after the automated system has been disengaged.

In the third approach manual control is always engaged. All that is needed to disengage the automated system is to provide an input to the manual system. Thus, the vehicle actuators can accept commands from both control modes simultaneously. We do not recommend this approach, since a driver who accidentally provides an input to the manual control system (e.g., bumping the steering wheel) will interfere with the automated control system. This could lead to a potentially dangerous situation.

B.1.3.2.2 AHS/Highway Design Issues

There are also issues of AHS infrastructure design that have been identified during this task. It is assumed that the check-out process will be performed while the vehicle is traveling, at regular highway speed (as determined by the automated system). It may occur on the AHS or in the transition lane. Thus, during the time required to perform the check-out tests, the vehicle will cover quite a distance. In addition, it will be necessary to allow the driver to retake the check-out test upon failure on the first attempt. This further increases the distance traveled by the vehicle. For example, a vehicle traveling at 60 mph will travel 1/4 mile in the time necessary to conduct a 15-second test, and 1/2 mile in the time necessary to conduct two 15-second tests. It is necessary to initiate the check-out process far enough in advance for all of the check-out tests, and retesting if necessary, to be conducted prior to reaching the driver's desired exit. The point where check-out must begin is determined by the speed of travel, the duration of the check-out test, and the maximum number of allowable retests. Roadway conditions may also affect where (and when) check-out is initiated. When the roadway is in less than optimal condition (e.g., rain, ice or snow), vehicles require a greater distance to decelerate, and may require additional time to perform the check-out process. Also, the check-out process may need to be modified in these situations, to reflect the increased difficulty of the driving task during non-optimal conditions.

The design of the check-out process may also affect the design of the entry/exit infrastructure, and may depend on how a check-out failure is handled by the system. AHS may either keep a driver on the system past the desired exit for further testing, or may park the vehicle at the desired exit. If a vehicle is allowed to continue to the next exit, it may be necessary to reemerge that vehicle back into AHS traffic (if the vehicle had been pulled into the transition lane for check-out testing.) If a vehicle is to be parked, it may be necessary to construct parking lots at exits, or to merge the vehicle back into traffic until a breakdown lane can be reached. Obviously, it is undesirable for vehicles that fail the check-out process to interfere with the AHS traffic.

B.1.3.3 Lateral and Longitudinal Control Analysis (Task D)

The main emphasis of the Lateral and Longitudinal Control analysis was directed toward: (1) a detailed review and study of the various technologies that may be utilized to provide sensors for lateral position measurement and longitudinal headway, and (2) a rather detailed digital simulation of a longitudinal control loop including the vehicle, engine, braking system, and control algorithms. To a lesser degree, consideration was given to communications associated with lateral and longitudinal control, obstacle detection, and a preliminary study of the cost trades between a system that employs an autonomous vehicle-follower longitudinal control and a point-follower system using an infrastructure base headway measurement system. Automatic lateral and longitudinal control is, of course, the heart of any AHS system. The studies conducted on this program barely scratch the surface of the automatic control problem. We do hope, however, that we have focused our efforts at some of the key design issues.

During the course of the studies, several results became apparent. Because these results will have significant impact on further studies and research, we have referred to them as key findings. Each of these findings is discussed below:

B.1.3.3.1 Sensors for lateral and longitudinal control must be capable of performing under severe adverse weather conditions.

An AHS system should be capable of operation during adverse weather such as very heavy rain, dense fog, and heavy falling snow. Many researchers are pursuing technologies that clearly will not function in severe weather. The argument that it is acceptable if it performs as well as a human does not make much sense to us. If, during severe weather, the lateral sensor can no longer locate the lateral position of the vehicle, or the headway sensor can no longer measure the headway, a serious safety condition exists. This is particularly true of lateral control. If a rain storm limits the performance of a headway sensor, other action can be taken, such as slowing (or stopping) all traffic. However, lateral guidance is required even if it is only used to steer the vehicle while a stopping maneuver is performed. During periods of severe weather, such as heavy rain or fog, the highway speed may be significantly reduced, provided that the sensors can continue to operate. To accommodate increased sensor errors, the gap spacing may be increased. Loss of lateral position information cannot be allowed to occur.

We must currently accept the limitations of the human sensors to function in severe weather, but we need not accept them for an AHS because sensor technology exists to provide for continued AHS operation in very dense fog, heavy rain storms, and blizzard conditions.

B.1.3.3.2 Most promising lateral control technology involves magnetic markers or overhead wires.

Of the many techniques that various researchers have explored to provide lateral position information, the magnetic markers or "nails" appear to be the most attractive. They are inexpensive and of low cost to install in a roadway. They are passive (requiring no power), extremely durable, and will provide control in all weather conditions. Component failure will occur gracefully; i.e., if a given magnet should fail, vehicle operation can continue because one missing magnet will not affect performance.

Lateral control based upon overhead wires that radiate signals, while more costly to install, also operates in all weather. The wires can also be used to provide a moving reference for point-follower type longitudinal control.

B.1.3.3.3 Headway radars will be required to provide high azimuth angle resolution.

Headway radars used on an autonomous vehicle will be required to measure and locate the position of vehicles to determine the driving lane they occupy over ranges of approximately a few meters (feet) to 60 or 90 m (200 or 300 feet). Azimuth look or scan angles of ±45_ are likely to be required to confirm slots for lane change or merge/demerge. Because of the need to locate the vehicle in the azimuth plane, the headway radar will be required to have a beam width of one to two degrees, thus the radar sensor beam will need to scan in azimuth, either mechanically or electronically.

B.1.3.3.4 Infrastructure-based systems may be cost effective.

An AHS system configuration which is based on the use of infrastructure-mounted sensors to obtain vehicle longitudinal position and to provide a portion of the longitudinal guidance signals and vehicle malfunction detection functions may have cost advantages over a system containing vehicle-based sensors which perform these functions. The component reliability of the infrastructure equipment can be made sufficiently high through redundancy so that component failure does not contribute significantly to the reliability of the overall system.

B.1.3.3.5 Communication between vehicles may not be required for vehicles following at gaps of 0.5 seconds, even during emergency maneuvers.

Results of simulations show that communication of the acceleration of the lead vehicle(s) is not necessary for braking maneuvers. The simulated design separated the brake controller from the throttle or accelerator controller. The accelerator controller is designed to maintain vehicle headway during normal maneuvers, while the brake controller is designed to avoid collisions. Simulation shows that no collisions occurred even with the lead vehicle braking up to 1 g. The conditions were 0.5 seconds plus 1.5 m (5 feet) nominal gap, 97 km/h (60 mph) speed, up to 15 following cars, and all cars had the capability of 1 g maximum braking. The reduction in headway as speed decreased to zero was more than enough to make up for distance lost because of sensing and braking dynamics. The acceleration of the preceding vehicle was estimated from the rate of change of the differential velocity. Up to 30 cm/sec (1 ft/sec) noise like errors on the speed measurements did not degrade the safety of the brake system. Speed and distance measurements were made at a 20 Hz rate, using an independent noise sample for each measurement. The minimum value for the gap to maintain safe braking has not been explored, but we expect it to be less than 3 m (10 feet). This finding is significant. Most researchers, ourselves included, have felt that each vehicle will need to pass its acceleration to following vehicles to prevent a collision during hard, emergency braking.

B.1.3.3.6 There is a tradeoff between longitudinal maneuver errors and noise immunity.

In the design of a longitudinal controller for an AHS, there exists a classical tradeoff between tolerable maneuver errors and noise immunity. Typically, a longitudinal controller is designed to maintain a certain headway from the preceding vehicle. When the preceding vehicle changes speed, the following vehicle's control system will generate an acceleration command to maintain the headway. During the speed change, the headway error could range from a few centimeters to meters (inches to feet) depending on the maneuver. In our simulations, an increase in speed from 80 kmph (50 mph) (73.3 ft/sec) to 97 km/h (60 mph) (88 ft/sec) at 0.1 g generated a 2 m (7 ft) distance error. The headway error gradually diminished to near zero ft/in about 25 seconds after the maneuver. If the bandwidth of the control system is increased, the headway errors can be reduced to less than 0.6 m (2 ft) with total recovery in less than 10 seconds. Although the tighter control seems more desirable, the effects of sensor errors in the system make a high bandwidth control system impractical. We believe that typical sensor errors for ranging and doppler devices are likely to be 0.3 m and 0.3 m/sec (1 ft and 1 ft/sec), respectively. When these errors are used in a high bandwidth simulation, throttle displacement is larger, causing accelerations of 0.6 m/sec/sec (±2 ft/sec/sec) during steady state cruising. The net result is an uncomfortable ride for the AHS user, not to mention reduced fuel economy. As the bandwidth of the control system is reduced, the ride may be more tolerable with accelerations for steady state cruising at 0.15 m (±0.5 ft/sec/sec). The net result is a tradeoff as shown in table B-1

Table B-1. Bandwidth Effect on Control

Control System	Steady State Accelerations	Max. Error	Recovery
High Bandwidth	±0.6 m/sec/sec	±0.6 m	10 seconds
Low Bandwidth	±0.15 m/sec/sec	±2 m	25 seconds

In order to provide a high bandwidth control system providing rider comfort, improvements in the control system could be made. Improved decisions using Kalman filters or a different controller may provide lower errors and lower accelerations, but for each design a tradeoff between noise immunity and maneuver error must be made.

It should be recognized that the simulation used on this program did not assume that lead vehicles would communicate with following vehicles. The control system derived the lead vehicle acceleration from the differential velocity measurement which contains noise-like errors. If the leading vehicle passed its acceleration data to the following vehicle, a "cleaner" acceleration signal would be available. Thus, a high gain loop could have been used with better performance.

B.1.3.4 AHS Entry/Exit Implementation (Task J)

Entry/exit is one of the major components of highway transportation service. Some might say it is the most important component since it ties directly to OD pairs, as airline service is tied to city pairs and airport capacity.

Entry/exit capacity can dictate a freeway system capacity. As we increase the freeway service lane capacity, demand increase can overload the entry/exits. Local street capacity in the vicinity will at some point reach capacity.

However, automation gives a new tool to deal with system overloads. The traffic controller can directly control sector speed and spacing analogous to a space age ramp meter. As we see in this chapter, the relationship between speed and "safe" capacity might contain an optimum, much as manual traffic achieves today, only it is higher and perhaps peaks at a higher speed. The controller can now choose to modify cruise speed, for increased capacity near an entrance region, to provide more space in the lane for a temporary increase in entry flow. Up to the capacity of the entry procedure, the need for queues or entry lane slowdowns can be reduced.

Entry/exit concept definitions are closely tied to our RSC definitions. In I2, there can be a dedicated lane from the manual lanes to the AHS lanes. In I3, this dedicated lane can originate from a local street. In I1 and I2 configurations with low participation (the fraction intending to be automated at the access point*), the lane is not dedicated to AHS vehicles exclusively.

Because low participation is associated with the early years of AHS deployment, the RSCs and their corresponding entry/exit concepts have an evolutionary interpretation. Entry/exit is also tied to the RSC communication aspect. As discussed in this chapter, the entry/exit procedures, we envision, involve predominantly the vehicle/vehicle (VV) communications link and C1 concepts in I1; the

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* Participation defined in this manner could be much different from market penetration. In particular, it could be much higher.

roadside/vehicle (RV) communications link and the VV link in I3; and a less complex RV link in I2, with a fully utilized VV link.

We feel confident that we can achieve higher vehicle densities with automation. However, if this brings higher person-miles traveled by attracting more and longer personal trips, real increases in travel efficiency are questionable. If, through various measures, we can keep vehicle-miles traveled VMT unchanged and, in addition, the total flow in all cruising lanes is not changed; then maximum flows at entry/exits are not changed and existing ramps and local streets are not overloaded. The benefit to the individual user is shorter trip time, assuming that cruising lane congestion was the problem in the first place. If, indeed, entry/exit capacity is the problem, it seems that, short of building more concrete infrastructure, aspects of ITS, other than vehicle automation, must be emphasized to solve congestion problems. There are concepts such as alternate routing and departure time specification, recognizing that everyone cannot use the same portion of concrete at the same time. This line of thinking leads us to emphasize rearrangement of flow from manual to automated rather than adding high automated flows to what presently exists.

Finally, it seems reasonable to anticipate, with the increasing presence of automated vehicles, an "automation" mind set beginning to dominate all driver behavior. Perceiving automated vehicles to be a benefit to the manual vehicles in terms of decreased congestion and trip time, automated travelers would help develop the cooperation and approval needed to share the road. In what follows, the entry/exit techniques can easily be foiled by irresponsible or uncooperative manual drivers in the same lanes. Thus, just as exists today, there must be recognition that if we and our transportation systems behave intelligently, we will all get to our destinations on time.

Analyses show that we can get higher lane flow with AHS than with manual driving. Where the entry/exit capacity and the local streets can allow, this might be the choice of ATMS. Such an example is a bridge or tunnel bottleneck, where cruise and entry/exit capacity upstream and downstream are adequate, but traffic backs up from the bottleneck.

At given speed and weather conditions, how close can we space automated vehicles safely? The answer depends not only on cruise speed but also on entry/exit or ingress/egress to an AHS cruising stream. Our analysis provides a framework for determining how much space is available to add more vehicles. This analysis, used maximum braking distance, collision severity, maximum relative collision speed DV for elastic bumper behavior, deceleration system time delay, VV link time delay, the number of collisions and DVs of those collisions for a given deceleration of the vehicle ahead, the vehicle masses, and the vehicle lengths as input parameters in addition to speed.

Although not part of this task, we also consider that due to control limitations there will be a minimum allowed gap between vehicles for lane changes, mainly affecting the ingress maneuver.

Given a way to define the relationship of flow capacity (or vehicle density) and lane speed, we now proceed to the next step which is to define how we will utilize the empty space to add more vehicles to the stream. The concept of space distribution is introduced and we make the point that the merging of two flows with the spaces in one matching the vehicles in the other minimizes flow disturbances. Through a simple manual spacing strategy and a regular space distribution in the AHS lane approaching an ingress point, the final vernier adjustment is straightforward with minimal flow disturbance. Rudimentary flow analysis, with participation as a parameter, was undertaken. It leads to the definition of a reasonable boundary between the highest participation for which we still benefit by having manual vehicles in the AHS operating lane and the lowest participation appropriate for I2.

Topics related to I3 were studied. The concept of a dedicated entry ramp directly from the local streets allows a "collector" lane to be postulated that can run at high volume because it is automated. The final stage of this entry method is the merging of two automated streams at cruise velocity. This same high-speed merge appears in the interface of two AHS highways.

The use of space manipulation and entry vernier adjustments is shown to be rather primitive in I1C1, more sophisticated in I2C2 and highly refined in I3. Entry/exit pairs are discussed with exit ahead or behind entry depending on the manual highway system interface and traffic patterns. It is shown that I1, I2 and I3 entry/exit procedures and infrastructures are also interface and traffic pattern dependent.

A summary of key findings and recommendations is below:

- Entry/exits are key to AHS practicality since they dictate maximum flows throughout the system, are a big cost driver, and are a primary impact on the community.

- Participation fraction is key to entry/exit design and indeed drives overall design. It is reasonable to estimate that participation fraction will be significantly higher than market penetration. However, AHS entry/exits feasible for low participation fractions are initially the most attractive.

- Entry/exit spacing is an important design criterion in the urban environment. LIE data shows that the average OD pairing involves only a few miles of freeway use. Yet, AHS conceptually is concerned with longer freeway segments.

- The different entry/exit techniques associated with the different RSCs may well all find application on a single AHS because the specific design requirements of each street and traffic situation dictates the best technique.

- One of the highest infrastructure impacts assigned to entry/exit requirements is the merging of two AHS streams starting at right angles. This is due to the large radii required if speed is maintained, and the lack of such a requirement in today's highway geometries.

- AHS traffic controllers, according to derived capacity-versus-speed estimates applicable to automated vehicles, will have the ability to provide a tradeoff between velocity and capacity to accommodate substantial volume variations.
- The relationship between AHS entry/exit and ATMS should be tested in appropriate traffic models.

- Realistic applications that minimize expensive infrastructure modifications (I1 and I2) should be given high priority in further development. Requiring an I3 early development has less appeal since it sets up high political and social hurdles.

- The minimum space into which an automated vehicle can be safely maneuvered should be defined on the basis of realistic control capabilities and reasonable wind gusts, roadbed unevenness and other disturbances.

B.1.3.5 Vehicle Operations (Task L)

Numerous issues/risks were identified under this study. Some of the significant findings are addressed below.

B.1.3.5.1 Impact of Reliability

The addition of the required AHS components may result in a decrease of the reliability of the vehicle as a whole. It is believed that through preventive maintenance, periodic inspections, use of redundancy, and system health monitoring, a failure rate at least as low as today's experience can be maintained. Consideration must be given to the impact on reliability during the design process.

B.1.3.5.2 Impact of Redundancy

Tradeoffs will need to be made between redundancy and cost impact. To make all AHS sub-systems redundant will, no doubt, result in pricing the AHS equipment out of the market. Car should be exercised during the design process to employ redundancy in areas where safety considerations dictate it, such as steering control systems. Built-in tests can be employed to detect a failure or below-specification performance, without the use of redundancy æ provided that the malfunction can be managed. For example, if a forward-looking radar system fails, the vehicle can be brought to a stop in a breakdown lane. If the radar has a low failure rate such that few failures occur, this approach of stopping the vehicle may be quite acceptable as opposed to providing redundant radar sensors.

B.1.3.5.3 Impact of the AHS Scenarios

Development and deployment of AHS components will be greatly affected by the selection of the AHS scenarios (e.g., a vehicle-based or roadway-based intelligence). Determining the feasibility of deployment of the proposed scenarios at an early stage, and selecting the appropriate scenario(s) for implementation is very crucial to the success of the project. This will provide a clear direction for research and development of the AHS components and also will speed up deployment process.

B.1.3.5.4 AHS Evolution

Progression for AHS evolution will probably be warning, control assistance, and then eventually AHS, i.e., full automated control stage. Our team does not consider the system to be AHS until the operation is hands-off, feet-off.

B.1.3.5.5 Deployment of the AHS Vehicle Components

Some of the early stage driving assist systems, such as intelligent cruise control will be entirely onboard the vehicle, without the need for involvement of any government agency or roadway facility. The addition of lateral control will probably require some additional infrastructure such as magnets or road stripes.

B.1.3.5.6 Software Cost

Software development process may become a major cost element of the system development costs of AHS systems. Software cost on a per vehicle basis will be modest due to the large number of vehicles. At a 70% market penetration (70 million vehicles) a cost of $5 per vehicle would amount to 350 million dollars of software development.

B.1.3.5.7 Software Verification and Validation

Since AHS Systems will employ sophisticated microprocessor-based systems for vehicle control, system health monitoring, and communication of signals and commands, software verification and validation monitoring will be of prime importance. Software verification must be part of the malfunction monitoring system and an integral part of the design process, rather than an after-thought, once the software is structured.

B.1.3.5.8 In-Vehicle Communications

Multiplexing of on-board communication systems has promising applications in the AHS vehicles. Some of the benefits of the system include: enhanced diagnostics, distributed control, and total wire reduction.

B.1.4 AHS Malfunction Management Safety Analysis

The AHS malfunction management and safety analysis consists of these two task report summaries: (1) Malfunction Management and Analysis (Task E), and (2) AHS Safety Issues (Task N).

B.1.4.1 Malfunction Management and Analysis (Task E)

Below, the major findings and recommendations are summarized.

- User data and analysis show that an automation failure rate of one per 2000 vehicle. hours. is feasible.
- The full answer to the cost question, both acquisition and lifetime maintenance, must remain uncertain until specific designs are considered, but we are optimistic.
- The key issues in the approach to the question of safety are the use of redundancy in vehicle equipment, and the use of a breakdown lane, entry/exit protocol, and handling communication failures. Our study suggests design approaches to deal with these issues.
- Barriers in the I2 scenario would reduce the probability of vehicles and other objects from moving into the AHS lane from the manual lanes. The ability of an automated vehicle to cope with such objects is problematical, making consideration of barrier use part of this malfunction management.
- Driver role in malfunction management remains a controversy. We examined two driver roles—one where the driver is continually alert to the vehicle's behavior and progress throughout the trip and one where the driver can turn attention to unrelated activities but can expeditiously tend to systems alerts and advisories. These two roles both find application depending on the proximity of manually-operated vehicles as dictated by RSC definition.
- Preliminary subsystem design studies should be performed and integrated into an overall system design containing life cycle cost/reliability tradeoffs.
- Redundant subsystems should be considered to obtain reliability goals with the following design questions addressed.
  - Use of dissimilar technologies as part of the redundancy
  - Failure detection availability
  - Failure identification technique
  - Transition without dynamic disturbance
  - Common mode failures

- The driver role in malfunction management should be studied in simulations and field tests.

- A target basic vehicle locomotion MTBF should be established by standards organizations and vehicle manufacturers.

- Further study is needed to resolve the issues of

  - a continuous breakdown lane
  - malfunctions during access and egress functions
  - management of communication failures

- Realistic affordable methods for managing the problem posed by an object in the lane must be developed. This study should consider the role of barriers in the AHS designs placing an automated lane contiguous to those used by manual traffic.

- A related study should address the legal implications of enforcing traffic laws addressing obstruction of AHS traffic. Such violators should be easily detectable and therefore easy to fine or at least bring to trial. The delay caused in the AHS lane is, in worst case, equivalent to stopping three or more lanes of today's congested manual traffic. There appears to be no method short of a physical gate or severe legal consequence to prevent intended or negligent obstruction.

B.1.4.2 AHS Safety Issues (Task N)

B.1.4.2.1 AHS Fault Hazard Analysis (What could go wrong?)

The fault hazard analysis of AHS operations addressed: (1) potential system failures or degradations, (2) their local and system-wide effects on the AHS, and (3) their criticality prior to any mitigating strategy. The analysis represented the individual phases of AHS operation as a time sequence of events for the six general RSCs. The main conclusions, after examining system impacts resulting from failure of AHS components, stress the need for system reliability and redundancy for a safe and successful AHS.

The key findings/conclusions stemming from the fault hazard analysis:

- Automated vehicles must have redundant steering and braking systems. The consequences of loss of vehicle control, which are detailed in the sections on individual crash types, emphasize the need for complete control at all times. Graceful degradation from an automated mode is dependent on the integrity of the basic system, and in particular, the vehicle controllers

- The question of a human driver as a participant in automated vehicle control is controversial, particularly as a malfunction management tool. As part of the fault hazard analysis, two driver roles were identified:

  - Role 1: Brain On, Hands and Feet Off, was assumed for assessment of local and system effects of component failures. Both roles require further investigation. Role 1 does not allow the driver to completely relax, but it maintains a very capable and intelligent system component that would be extremely expensive to replace.

- Role 2: Brain Off, Hands and Feet Off permits the driver to be completely detached from the system. This mode eliminates the concept of manual backup, increases the requirements for malfunction management, and raises concern for AHS exit policies.

- The object/animal in the roadway problem may remain a constant between today's interstates and an AHS. The magnitude of this problem is unclearly defined. Accident statistics indicate the number of times a vehicle strikes an object or animal in the roadway, not the number of times a driver successfully maneuvers around an obstacle and still maintains control of the vehicle. The cost of preventing these elements from entering the AHS emphasizes the need for detection devices. However, even if it is possible to detect an obstacle that truly needs to be avoided, the longitudinal and lateral control systems must be capable of diverting the stream of vehicles, and they must have the room to maneuver the vehicles safely around the obstacle.

- The general RSCs were not developed as evolutionary configurations, although they can be viewed as an evolving progression from I1C1 to I3C3. However, the consequences of faults and hazards at the higher levels of automation emphasize the benefits of an evolutionary approach to an AHS. These benefits will be derived in the form of costs, implementation, and ability to gracefully degrade to lower levels of command and control as the more sophisticated designs are developed and implemented. Evolutionary designs may also turn out to be the configuration of choice for specific locations, such as rural areas, where less demand means that cost of separate automated roadways is impractical.

B.1.4.2.2 AHS Crash Analysis (If something does go wrong, what are the consequences?)

The second phase of the safety task answered the question: if something does go wrong, what are the consequences. This second phase was addressed using accident data bases and served two objectives: raise AHS safety issues and risks for AHS design considerations and estimate potential AHS benefits. The highlights of the crash analysis are discussed in this section, and the potential AHS benefits are quantified in the following section.

B.1.4.2.3 Crash Analysis for Design Guidelines

The goal of the AHS, under normal operating conditions, is a collision-free driving environment. This goal is based on assumptions of full automation and fail-safe malfunction management under any and all circumstances. To investigate the consequences of deviations from these assumptions, specific crash types were analyzed. The deviations appear in the form of mixed manual and automated vehicles for the I1C1 RSC and the transition lanes of the I2C1 and I2C2 RSCs. Deviations may also appear as holes in the mitigating strategies prescribed by malfunction management for any RSC or as degradations from safe designs due to cost, implementation or increased capacity tradeoffs.

Crash types similar to those on today's interstates will probably become the crash types that occur on an AHS under non-normal operating conditions. The causal factors will be AHS unique, the number of vehicles involved will probably be greater, and the distribution of crash types will vary from today's interstate accident picture. The emphasis must be on fail-safe designs that will be geared to the lowest injury-producing crash types

Data from the Fatal Accident Reporting System (FARS) were used to rank crash types according to risk of a fatal injury. Table B-2 lists the individual crash types in order of decreasing likelihood of producing fatal injuries. The most common crash type to result in a fatal injury is the “not a collision with a motor vehicle in transport”. The collisions that do not involve another motor vehicle in transport consist of single vehicle accidents that are rollovers, barrier related, roadside departures or involve an object or animal in the roadway. Head-On and Sideswipe Opposite Direction are extremely low frequency events on interstates

Rear-end crashes were analyzed in detail since they are likely to be the most frequently occurring AHS crash type. The Crashworthiness Data System's (CDS) algorithms (PCCRASH) to estimate DVs for vehicles involved in a collision apply to rear-end crashes. The primary measure of collision impact severity is V, defined as the change in a vehicle's velocity, taking into account vehicle mass.

Table B-2. Ranking by Occurrence of Fatalities on Interstates

Crash Type	# Fatal Injuries	% of Total
Not Collision with a Motor Vehicle in Transport	612	54.1%
Head-On	199	17.6%
Rear-End	165	14.6%
Angle	111	9.8%
Sideswipe, Same Direction	34	3.0%
Sideswipe, Opposite Direction	7	0.6%
Total	1131	100.0%

Occupant injury levels and vehicle damage severities were expressed as a function of V. This analysis was performed to estimate "tolerable" Vs for collisions on an AHS. Once tolerable Vs are obtained, safe headways for travel speeds based on maximum deceleration of a lead vehicle involved in a crash can be calculated.

The highest level of medical treatment for striking vehicle occupants as a function of V. Vehicle occupants suffered injuries requiring transportation to a medical facility where they were treated and released from crashes in the 6 to 10 mph V range. Injuries requiring hospitalization resulted from crashes in the 11 to 15 mph V range. This not only implies the seriousness of the incident in terms of occupant injury, but also indicates the amount of time necessary to clear the accident scene, and its influence on the perceived safety of the AHS.

Barrier-related crashes represent another potential AHS crash type, particularly for the I2C1 and I2C2 RSCs, where automated lanes and manual lanes may be separated by barriers. CDS data show that left roadside departures account for approximately 78 percent of barrier crashes that occur on roadways with speed limits greater than 50 mph. This finding strongly supports the use of barriers on the AHS since, without a barrier between automated and manual lanes, left roadside departure vehicles from the manual lanes will intrude into the AHS.

The likelihood of a lane-blocking incident on an AHS under normal operating conditions may be viewed as the possibility of a crash with an object or animal in the roadway. Automation is capable of creating a “smart driver” that knows the state of the vehicle, and the limits of the vehicle’s handling capabilities for road and weather conditions, but automation cannot control objects or animals.

Therefore, automation must deal with them, particularly on the long stretches of suburban and rural highways where the problem is most significant.

Table B-3 shows the likelihood of a lane-blocking incident on an AHS under normal operating conditions. Crashes involving objects or animals represent 5.2 percent of all interstates crashes. Given the 490,336 million vehicle miles of travel on U.S. interstates, this equates to a rate of 0.03 incidents per million VMT. Additional events, under non-normal operating conditions, that may lead to "AHS roadway obstacles" or lane-blocking incidents are:

- Loss of lateral control
- Offset rear-end crashes
- Rear-end crashes on low traction surfaces (perhaps due to fluid spills)
- Lane/change merge crashes
- Crashes related to driver impairments

Table B-3. Likelihood of Lane-Blocking Incident on an AHS

Interstate Object / Animal Rate of Vehicle Collisions per Million VMT			
Location	Urban	Suburban	Rural
Number of Incidents	1,678	7,496	5,802
VMT (million miles)	190,217	95,108	205,011
Rate	0.01	0.08	0.03

B.1.5 AHS Benefits Analysis

The goal of the AHS, under normal operating conditions, is a collision-free driving environment. This assumes full automation and fail-safe malfunction management under any and all circumstances. Based on these assumptions, existing studies on accident causal factor analysis provide a quantification of benefits from an AHS. Estimates of the improved accident picture for an AHS are treated separately for each crash type, where data are available. An assessment of the overall safety benefits derived from an AHS is presented as a range of percent reduction in crash frequencies in table B-4.

The lower limit is based on General Estimates System (GES) data where a vehicle defect, driver impairment, or inclement weather may have contributed to the crash. Only police-reported information is included in this estimate; there is no assessment of crash cause. This analysis resulted in a 31 percent improvement for all locations combined (table B-4).

The upper estimate of AHS safety improvement is based on data derived from a causal factor analysis of rear-end crashes (Knipling, 1993) and the Indiana Tri-Level study (Treat, 1979). This estimate is based on an assumption that the combination of automated control and vehicle system monitoring/inspection has the potential to remove human and vehicular factors and most (80 percent) of the environmental factors. This approach yields an 85 percent reduction in vehicle collisions. The data, which pertain to crashes on all roadways, are not limited to interstates.

Table B-4. Percent of Interstate Collisions where Vehicle Defects, Driver Impairment, and Inclement Weather are Involved

Percent of All Interstate Collisions by Location			
	Location		
Factor which may have contributed to cause of crash:	Urban	Suburban	Rural
Vehicle Defects, Driver Impairments	28,316 (11.2%)	23,191 (12.7%)	18,033 (26.6%)
Vehicle Defects, Driver Impairments, Inclement Weather	65,707 (26.0%)	59,198 (32.5%)	30,986 (45.7%)
Number of Interstate Vehicle-Collisions	252,362	182,028	67,733

*Vehicle-Collisions refer to the total number of vehicles involved in an accident as opposed to the number of accidents that may involve more than one vehicle.

Causal factor results from the Indiana Tri-Level Study are based on 420 in-depth investigated accidents where a “certain” rating was applied to the causal factor. A “certain” rating is applied when there is absolutely no doubt as to a factor’s role, and is considered analogous to a 95 percent confidence level. “Certain” cause of the accident means that, assuming all else remains unchanged, there is no doubt that if the deficient factor had been removed or corrected, the accident would not have occurred.

The data in table B-5 show the rate of vehicle collisions per million VMT for today’s interstates and estimates of the AHS rate when full automation is assumed. The range of improvement is shown to be 31 to 85 percent. These estimates are based on reductions in collisions; they do not include a factor for increased collision potential due to higher speeds and shorter headways. Collision numbers are from the 1992 GES. They are nationally representative estimates of police-reported interstate accidents by location. Vehicle collision rates are based on VMT on interstates, FARS, 1991.

Table B-5. AHS Safety Improvements

Interstate and AHS Rate of Vehicle Collisions per Million VMT			
Location	Urban	Suburban	Rural
Vehicle-Collisions*	252,362	182,028	67,733
VMT (million miles)	190,217	95,108	205,011
Interstate Rate	1.33	1.91	0.33
Percent Improvement	26.0 - 85.0	32.5 - 85.0	45.7 - 85.0
AHS Rate	0.2 - 0.98	0.29 - 1.29	0.05 - 0.18

*Vehicle-Collisions refer to the total number of vehicles involved in an accident as opposed to the number of accidents that may involve more than one vehicle.

B.1.6 AHS Alternative Propulsion System Impact (Task M)

B.1.6.1 Approach

Three types of vehicles were evaluated in this task. All of these APVs are similar in that they have batteries and electric motors. The differences lie in how power is supplied to their batteries. They are:

- Electric vehicles (EVs) - All power is supplied by rechargeable onboard batteries.
- Hybrid vehicles - There are two types of hybrids, series and parallel:
  - Series: A combustion engine is used to charge the vehicle batteries directly.
  - Parallel: The combustion engine can be used to either charge the batteries or to directly power the vehicle.
- Roadway powered electric vehicles (RPEVs) - RPEVs are electric vehicles that can be charged dynamically while moving, receiving power through induction from a powered roadway.

The technical approach used assumptions based on our estimates for APV influence in the near-term vehicle population. We assumed that APVs may only reach the levels stated in California Air Resources Board (CARB) regulations. Estimates of battery storage capacity are stated within the calculations that they are used in. No breakthrough battery that increases range by a factor of two or three times is likely. More details concerning assumptions are provided in the individual examples cited. We believe our assumptions are real world, moderate in nature; unlike many inaccurate assumptions made about APVs in previous years. The APV goals of range, performance, refueling, and consumer acceptance have not been met.

The current and future generation of alternative propulsion vehicles (APVs) researched suffer decreased performance compared to most conventional spark ignition (SI) vehicles. These deficits encompass all aspects of vehicle performance, from acceleration and braking to vehicle range. The performance deficiencies, most notable in vehicle acceleration, result from the lack of an adequate power storage media for electricity. Current designs compromise vehicle performance for range, with battery technology the limiting factor. The present-generation batteries store only limited, and inadequate, amounts of electric charge. The range deficiency is the major drawback for APV market potential. This feature inhibits the manufacture of APVs with range and performance comparable to conventional vehicles. Therefore, because of interstate travel, AHS effectiveness will be reduced if APV battery technology is not improved.

The current and near-future APVs may encounter problems on the AHS, depending upon the system's speed limit. Although many APV designs are capable of speeds in excess of the current national speed limit, these vehicles are electronically limited to speeds in the range of 110 to 130 kmh (68 to 81 mph) to maintain battery charge. The operating speed limit will be critical to APV impact on the AHS.

The acceleration performance of most APVs are within the range of current economy class vehicles and light trucks. These values are acceptable for the acceleration and deceleration lanes of current highways under American Association of State Highway and Transportation Officials (AASHTO) guidelines. No modifications are required of the road infrastructure to incorporate APVs.

At present, a large proportion of APVs are conventional SI vehicles that have been converted to APV use. These vehicle conversions result in substantially higher design weights. This factor, along with low rolling resistance tires and a modified weight distribution, can seriously impair vehicle dynamics. Without changes to vehicle braking systems, APV braking distances are significantly longer than the original vehicle. This will cause problems for AHS platooning and emergency maneuvers. Ground-up electric vehicle designs do not suffer from these braking difficulties; at present, only one vehicle, the GM Impact, falls into this "purpose-built" category. The limited number of purpose-built vehicles illustrates the high costs involved in vehicle development. For the near-future, the APV fleet will consist predominantly of converted SI vehicles, and have a negative effect on performance.

Vehicle range is the biggest handicap facing alternative propulsion vehicles today. EV range is dependent on the battery storage system utilized. The only certainty of battery technology is that it is uncertain; it is difficult to extrapolate into the future. In the 1960s, researchers were predicting that electric vehicles would be commonplace in the seventies. This prediction was repeated in the seventies. Because current battery technologies do not provide APVs with range and performance comparable to SI vehicles, this prediction has not yet come to fruition. Research is making evolutionary progress in battery technology with no "revolutionary" breakthroughs on the horizon. The pace of battery system development will presage the closing of the performance and range gap of APVs to SI vehicles. Because of these trends, battery-powered electric vehicles will not have AHS interstate travel range.

As with battery technology, electric vehicle recharging is advancing at a slow pace. Newer, quicker ways of vehicle charging need to be developed for consumer acceptance to rise. Goals for recharging of vehicles need to be in minutes, not hours, as is currently the case. Without the installation of special charging equipment, home electric vehicle recharging cannot be performed in one to three hours. Older homes may not have the capacity to use this equipment without a complete rewiring. For apartment dwellers, the problem is magnified. The specialized charging equipment will initially require charging stations similar to gas stations to allow quick-charge of these vehicles. Electric vehicle quick-charging will have to be performed at recharging stations, possibly co-located with gas stations or AHS service areas.

If the future holds a breakthrough battery, the interim solution may be hybrid vehicles, due to their increased range capabilities and reduced emissions. Of the two types of hybrid vehicles, series and parallel, series hybrids hold the most promise since they are less complex, produce fewer emissions per distance traveled, and operate as zero emission vehicles (ZEVs) for a greater portion of their driving cycle. With the use of a small onboard SI engine, hybrids have greatly extended range capabilities as compared to EVs, and therefore provide promise as AHS vehicles.

Decreased emissions is a major goal of future transportation systems. However, APVs must represent a large share of the vehicle population, or the benefits will be insignificant. Regionally, the reduction in emissions depends directly on the different types of fuel used (the generation mix) to generate electric power. A vehicle's emissions may one day be a selling point similar to present-day features like styling, safety equipment (anti-lock brakes, airbags) and fuel consumption. APVs, especially electric vehicles, will have the lowest emissions of all vehicles. The major manufacturers' disdain for APVs is similar to their general attitude toward small cars, catalytic converters and airbags in earlier years.

Vehicle reliability will be equal to or greater than conventional SI vehicles, and electric motor reliability may be much greater. Depending on the type of APV, the need for instrumentation monitoring may decrease because of the less complex overall system. The only specialized training needed is training for AHS operation, which may be identical for all vehicles. Overall, APVs will be easier to use (less complex, no transmission, less maintenance) than comparable SI vehicles.

Fleet use is the first and best use for APVs. Even with the limited present range (approximately 100 miles), APVs can be used as many types of delivery vehicles. Initially, APVs will be developed for fleet use, independent of the AHS. With further development, they may be suitable for AHS operation. Our findings, on daily miles driven, match other surveys. The majority of fleet vehicles travel less than 70 miles per day, which is within the range of present APVs. In this regard, electric vehicles can safely operate on the AHS, but they will have limited range. Initially, EVs will be best suited for inner city travel and not for intra city or cross-country travel.

The use of roadway power as a range extender for EVs complements electric vehicle driveability. RPEVs will initially be used in transit/commercial applications where the vehicle routes are always the same. Initially, RPEV deployment will consist of public transportation operations. Roadway power presents a practical solution for eliminating emissions in densely populated areas. RPEVs are ideally suited for bus routes, shuttle services, airport shuttles, and use in pollution sensitive areas. RPEVs can play a significant role in transit applications if EV range does not improve. A battery breakthrough could render commuter RPEVs obsolete, while transit RPEVs would be modified to electric-electric vehicles. With battery advancements, RPEV status may change. Transit station recharging could be eliminated if an APV is able to recharge quickly for a entire day's use. RPEVs are still in the experimental stage but the technology is available, mature, and appropriate for present day systems. RPEVs for transit use are a deployable system. Rubber-tired RPEVs would make an excellent replacement for diesel buses, trams, and trolleys.

RPEVs can be operated on the AHS with minimal effect. The electro magnetic field (EMF) emitted by RPEVs is equivalent to household appliances or less. This is acceptable at the present known standards. No interference should occur with non-RPEVs operating on or near a powered RPEV roadway or vehicle. There does not appear to be a problem with EMF emissions from RPEV induction. But, RPEV EMF needs additional study due to the potentially serious consequences of EMF in general. The RPEV induction system is a likely candidate to be used for EV recharging, as it eliminates plugs and cables and is passive to use. If use of RPEVs is widespread in the future, it will tax power resources in New York State beginning around the year 2011.

The inductive coupling required in the RPEV/AHS lane could act as a lateral guidance system available to all vehicles. Many EV designs are adapting "fly-by-wire" steering to reduce weight in the vehicle. Inductive lateral guidance systems have already been adopted and proved effective.

The emissions reductions achieved using an RPEV-based AHS would be much larger than those of a non-RPEV AHS. This is an attractive alternative which promotes compliance with the 1990 Clean Air Act.

Accidents related to APV technology on the AHS will not be a major concern. Battery safety has improved such that battery spills will cause no great threat or harm to the environment and can be safely dealt with by trained emergency crews. Use of APVs will be a stimulant to the businesses created to manufacture, design, and develop these vehicles. Considerable expertise in APVs lies not only in major auto manufacturers, but in vehicle converters and small businesses. APVs are efficient in their conversion of energy to propulsive power, are as safe as a conventional vehicle, and less harmful to the environment.

The top design issues jointly affecting APVs and AHS are:

- Range/charging - If current battery and charging technology are not improved by the time of AHS implementation, APVs will experience reduced AHS capabilities. Limited vehicle range can impair AHS interstate travel.

- Top speed - Future APV designs must be capable of matching AHS design speeds. Limited top speed can negatively impact AHS throughput and increase travel time.

- Fleet/Transit use - To meet CARB mandated sales goals, designers have focused on APVs for fleet use. This feature will facilitate AHS equipment implementation.

- RPEV lane design - If RPEVs are used on the AHS, overall lane design must be standardized and power, billing, and EMF issues resolved. RPEV lanes can provide lateral guidance to all vehicles using the RPEV/AHS road.

- The major limitation is the range issue. The use of hybrid vehicles, which can extend the range of APVs, transitions the use of all the different types of APVs on the AHS. The differences in performance characteristics (acceleration, braking, and handling) between APVs and SI vehicles is decreasing and may be eliminated by the time AHS is implemented.

B.1.7 Commercial and Transit AHS Analysis (Task F)

If the implementation of AHS can result in improved highway travel time reliability, reduced delays, and lower accident rates for commercial vehicles as well as increased attractiveness of public transit for intercity as well as intra-urban travel, the potential benefits will also be accrued by passenger vehicle drivers and occupants who share these highway corridors.

This brief overview of the trucking industry has revealed its enormous contribution to the nation's economy, employment, and productivity. Its diverse types of companies, commodities carried, vehicle types, haul lengths, labor concerns, competitive pressures, and government regulations indicate that the AHS program will need to address multiple trucking industry as well as competing mode issues and concerns. The basic question will be "what's in it for us?" Issues of primary concern to the trucking industry include environmental regulations, safety and health, taxes, labor and emerging technologies.

As the tractor-trailer combination truck appears to be the "workhorse" of the trucking industry, it must be decided whether this vehicle type should be the design standard for deployment and control. The integration of mixed and separate commercial vehicles within the traffic stream must also be considered. Analyses presented within section 3.3 illustrate implications of trucks on the traffic stream for both rural and urban scenarios. If commercial vehicles are to be included, should all types, sizes, weights, and combinations be permitted, or should the AHS lane or lanes only allow smaller single unit trucks with dynamic characteristics similar to passenger vehicles?

While heavier and longer vehicles are viewed as needed by the trucking industry, what place do they have, if any, on the initial and subsequent AHSs that will be developed and constructed over the next decades? What, if any should the truck type and size restriction be? What are the cost implications for pavements and bridges? Should AHSs be designed only for passenger vehicles, vans, buses, and single unit trucks with a weight limit of 10,000 lbs, allowing the other commercial vehicles to remain on separate but non - instrumented sections of the Interstate System in both urban and rural areas? Or, should longer and heavier trucks be allowed, as is being lobbied for by the trucking industry. In theory, AHS will permit the drivers' tasks to be automated except for ingress and egress, and the risk of truck driver and / or passenger vehicle driver error leading to accidents will largely be eliminated.

The control and maintenance requirements needed for longer combination vehicles (LCVs), if they are permitted, need careful evaluation, in view of the greater accident potential of these commercial vehicles. The industry is, judging from the accident rate reductions achieved over the past decade, focusing on safety and proud of its accomplishments. It should, accordingly, be participating in the AHS efforts, to lend its expertise and experience in those vehicle and driver-related areas which will produce the most benefits in the early phases.

B.1.7.1 Transit

AHS must be seen by the Local/Express Bus and Intercity transit industries as a cost effective, significant means to maintain current patronage and encourage new ridership.

The transit industry will need to demonstrate to the American public reasons for becoming competitive with personal autos. If AHS can provide the transit industry with the technology, service, reliability, frequency, direct routing (minimal transfers), at competitive costs with personal auto, there will be a demand for it. Contrary to the trends experienced over the last few decades, the emphasis in urban and suburban transportation is towards increased transit use, particularly based upon new federal legislation mandating change in travel habits by the public. The success of these new programs in accomplishing their goals will depend on transit's ability to provide more reliable, safe, and efficient transportation.

With AHS lanes or roadways available in high density travel corridors, buses, vans and qualifying high-occupancy vehicles will be afforded the opportunity to consistently meet on-time performance standards and schedules. Improved reliability and travel time will enhance customer service and attract 'choice' users from other modes.

AHS offers improved service and safety by reducing the potential for driver-related accidents. Removing the driver from the continuous operation of the vehicle and providing guidance and warning systems will enhance the performance of bus transit service on AHS facilities in high travel demand corridors. Continuous, predictable reliable service and well-maintained vehicles will eliminate excessive acceleration and deceleration rates which also cause numerous passenger injuries. The required increased maintenance practices would enhance vehicle operations and improve service reliability and safety.

Similar to the advantages of busways, buses and HOVs on AHS would include the following cost and service advantages:

- Relatively low initial construction is required; i.e. convert existing HOV lanes to AHS, use existing central bus terminals, and expand as bus demand increases.
- AHS transit lanes can be utilized by trucks during non-rush hour periods of the day.
- Dual service buses provide manually driven feeder service, non-transfer trunk line AHS service, and downtown manually driven distribution service.

Expected time savings for HOVs can range from 0.5 to 2.0 minutes/mile. Carpooling has increased on HOV lanes in some cases up to 100 percent, and transit ridership has increased between 10 and 20 percent. The technology inherent to AHS would allow greater travel time savings and, potentially, higher ridership. In general, HOV lanes have shown good ridership growth and proven congestion mitigation. As travel demand grows and peak period capacity requirements outstrip available HOV lane capacity, AHS offers the next solution, with at least a doubling of vehicle carrying capability, and much greater multiples of person carrying capacity.

Improvements in the design of transit vehicles, and introduction of user-friendly transit information systems through IVHS programs, as well as additional government support through the mandates of the Clean Air Act Amendments and incentives introduced in ISTEA legislation, will lead to transit's evolution to a much more attractive alternative than it has been in the past. AHS offers the potential to make transit even more reliable, safer, and less time consuming. In light of the current legislation and support of transit by government policy to move people more efficiently, transit can be an integral, if not leading, component of initial AHS systems. Incorporation of transit into an AHS would allow transit agencies and their passengers to reap significant benefits, provided that the implementation and operating cost changes over existing conditions are viewed as worthwhile in terms of the benefits achieved. These potential benefits to the transit industry and its passengers Include:

- Increased ridership due to better customer service
- Reduced travel time: ability to compete with other, faster, modes of transportation
- Improved safety, reduced insurance costs, fewer third party claims from injuries sustained on-board buses, reduced fuel, energy consumption reduced bus down-time
- Reduced labor costs due to vehicle productivity increases
- Contribution to environmental goals of the CAAA, ISTEA.

Incorporation of AHS technologies into an existing HOV lane or roadway would provide a cost effective transition from existing infrastructure. Transit vehicles and HOVs would be among the first to benefit from AHS.

B.1.7.2 Case Studies

From the analyses conducted for the Long Island Expressway, the New York State Thruway, and the New Jersey Turnpike, it is evident that each type of interstate highway, urban or rural, exhibits varying capabilities for incorporating AHS technology.

From the analyses, based on the stated assumptions, it appears that the most efficient travel will occur with passenger vehicles in separate AHS lanes, as well as all commercial and transit vehicles in separate AHS lanes.

AHS technology would be theoretically viable to alleviate congestion. The findings in the analyses for the LIE indicate that Option A for Scenario #4, with an ultimate capacity of 8,900 pcph, would be most beneficial for people-moving efficiency. These options also exhibit favorable average vehicle occupancies for compliance with the CAAA/ECO Program goals. Along the east Spur of the New Jersey Turnpike Option A for Scenarios #1 and #4, with an ultimate capacity of 8,900 pcph, prove to be the most efficient. Option A for Scenarios #1 and #4 for the combined section of the Turnpike would also be relatively efficient in people-moving efficiency. These options would require carpools 2+ persons and aid in the effort to achieve the CAAA/ECO Program goals.

'No Build" conditions in 2024 on the New York State Thruway would not require excess capacity. An AHS could be implemented in this corridor for reasons of safety and efficiency. Option A, with one (1) AHS lane and two (2) GULs, would be the most effective option. None of the Scenarios/Options would meet CAAA/ECO Program goals.

B.1.7.3 Analysis of Commercial and Transit Markets for AHS Services

Major Conclusions for AHS Service of Inter-City Freight

- The commercial freight inter-city market has most of its driving cycle on rural, uncongested interstate highways.
- Class 8 trucks, on average, log more than 125,000 miles per year of travel, of which 100,000 is on the interstate highway system.
- The market for class 8 trucks (over 33,000 pounds) is approximately 20,00 per year.
- Motor carriers have aggressively bought new technology that provides improved safety, comfort and convenience for the driver and advanced communication systems that improve the management of the truck fleet.
- A vehicle-borne, infrastructure-free RSC 2-type system that would be usable on much of the nations interstate and expressway highway system without any infrastructure improvement would be extremely attractive to motor carriers (and the inter-city bus industry). A good price point for these systems would be a capital outlay of about $5,000 , and a maintenance cost of less than $500 per year. At this level this adds about one cent per mile to a truck's operating costs.
- At a 50% market penetration of new sales, there is a $250 million annual market for a $5,000 vehicle-borne RSC-2 type system that is installed as optional equipment on new class-8 trucks. Conversions of existing trucks increases proportionately the size of this market.
- An infrastructure-based, RSC 8-12-type AHS has a clear evolutionary path starting with dense 1,200 mile corridor along I-80 between Chicago and Salt Lake City. Each mile of such a system could serve as many as 1.8 million truck movements per year if the economics are right. Because such a system would serve only a small portion of the driving cycle of most trucks using the system, the on-vehicle hardware costs can't be amortized over as many miles as an RSC 2, infrastructure-free system. It will be paramount to keep the on-vehicle costs extremely low so as not to stifle market entry by those trucks that could otherwise use the system.
- Future evolutions of an RSC 10-11-type AHS could grow to an 11,000 mile system that could serve roughly 50% of the current truck-served, inter-city freight market.
- Even by assuming a 100% market penetration, the 11,000 mile RSC 8-12-type AHS would only generate toll revenues of $110,000 per route mile at toll rates of $.10 per mile. This level of tolls can service the capital debt of about $1 million per mile. It is unlikely that motor carriers would be willing to pay AHS tolls that are much greater than $.10 per mile

- A driverless, SVE, RSC-8/9-type, Phase 3 AHS concept could serve a substantial amount of LTL demand. If toll charges are limited to approximately $.10 per vehicle mile, then, LTL demand patterns, shipment size, vehicle costs and existing freight rates suggest that each mile of such a system could serve as many as 600,000 of these shipments per year. Assuming a 50% market penetration, traffic densities on a Phase 3 network could generate toll revenues of about $30,000 per route-mile per year.

- Comparing the basic economics of the market for a driverless, RSC-2-type AHS with an infrastructure-intensive RSC 10-11-type AHS suggests that an RSC 2-type system is much more attractive to the inter-city freight industry. It's on-board costs can deliver benefits over much more of the driving cycle, the system has a much lower cost of entry (infrastructure does not have to be built), and even a mature RSC 10-11-type AHS does not serve enough volume, even at a large toll ($.10/mile) to service the cost of the infrastructure. This finding suggests that R&D investment focused on reducing the cost of reliable vehicle-borne, infrastructure-free RSC-2 type systems is the best way to have AHS successfully serve the inter-city freight market.

Conclusions for Intra-City Freight Movement

- Intra-city freight and the collection and distribution of inter-city freight are extremely difficult to serve with automation. The small shipment size and the multiple stop character of the operation are not conducive to automation.

- As with inter-city commercial bus operation, the driver performs more functions than simply driving the truck. The driver is the service interface with the customer.

- The geographic diffusivity of this traffic is such that much of the intra-city goods movement driving cycle takes place on road segments that are not compatible with an RSC-2 type AHS. Because each vehicle logs relative low annual mileage vehicle-borne AHS hardware can be amortized only over those few miles. An infrastructure-intensive RSC 8-12-type AHS serve even less of the driving cycle.

- AHS does not seem to be particularly attractive to this market.

Conclusions for the Commercial Inter-City Passenger Market

Table B-6 summarizes some of the major characteristics facing the commercial inter-city market.

Table B-6. Major Characteristics of the Commercial Inter-City Passenger Market

Existing Mode	1992 Market Size (billion p-m)	Opportunities for AHS	Notes
Inter-city bus	24	An RSC 2 system would be very attractive to this market	Major portion of bus fleet could covert to AHS operation
Inter-city rail	14	Little shift to private AHS vehicle, some markets could convert to inter-city AHS bus operation	AHS incursion into this market causes some public policy problems
Air passenger	340	Small opportunities for private vehicle AHS in short haul non- Northeast corridor markets	
Private air	13	No real competitive opportunity for AHS	

The major conclusions are:

- The commercial inter-city market is small in comparison with the inter-city passenger market served by the private automobile.
- The only likely short term commercial inter-city passenger market for AHS is that of inter-city bus. This is a very small market. Only 1,000 new inter-city buses are sold each year. However, the driving cycle of an inter-city bus is similar to that of an inter-city truck. Thus, it could provide a good secondary market for an RSC 2-type AHS that was designed to serve the inter-city freight market.
- The bus market is less conducive to a driverless AHS because the driver provides substantial benefits other than driving.
- An infrastructure intensive AHS has better opportunities than commercial freight to serve geographically contained sub-markets, because commercial buses can be managed to operate in constrained corridors. Such a system could better serve geographic segments of the automobile market because the driving cycle of a particular automobile is much more geographically constrained than that of an inter-city truck.
- The large inter-city market is served by the private automobile. Unfortunately, on average, the private automobile travels too few miles on inter-city expressways to justify spending even a modest amount for an RSC 1/2 type system. However, there may exist some significant sub-markets, such as traveling salesmen, that could easily justify investment in an RSC 1/2 type system. Such systems also become more attractive if they could be used for the daily commute portion of the automobile's driving cycle.

Conclusions for the Intra-City Passenger Transit Market

- Urban transit, that is, for-hire, intra-city passenger transportation is only a small fraction of intra-city person transportation which is dominated by the private automobile. Nationally, transit serves only 3% of intra-city person trips.

- Only the express bus sub-market of transit is conducive to the early stages of AHS. A particularly attractive example of such a system is the exclusive counter-flow bus lane leading to the Lincoln Tunnel. This is the busiest bus corridor in the U.S.

- There are several fundamental characteristics that make the Lincoln Tunnel XBL a particularly good application for AHS. First, there is a monumental problem on the horizon if a substantial capacity improvement is need in this facility. There is no place to put another access lane and the cost of boring another tube is enormous. Thus, capacity through automation would surely be the most cost effective solution. Even without need for capacity improvement, automation would smooth out the flow of buses and improve the travel time reliability of the buses. The application is on a very short corridor, less than five (5) miles, and the same busses use the facilities repeatedly. The institutional challenges are "minimal". All buses are the property of NJ DOT and were purchased with PA/NY/NJ money. NJ DOT and PA/NY/NJ have authority over all operations and construction in the corridor. For these major reasons, this is an excellent candidate "early winner" for AHS

- A Dual-mode service over a 750 mile NJ AHS network could provide auto-like service 780,759 passengers (71 %) out of NJ's 1,116,985 daily auto-based work trips that are greater than 5 miles in length. A $.10 per passenger mile fare would generate annual revenues of about $800 million. It may well be that fares would need to be more like $.20 - $.25 per mile for such a system to begin to contribute to the debt service payments for the AHSway.

- The average vehicle occupancy is 4.68 passengers per dual-mode vehicle. This is an enormous average vehicle occupancy, especially when compared with that of the current automobile's value of 1.1 for work trips. Because of this high average vehicle occupancy, the densest link on the network needs to serve a maximum of only 2,000 VPH.

- Dual-mode is an interesting transit concept for a mature AHS. It needs to have access to an rather extensive network of AHSways in order to serve a significant portion of urban/suburban travel demand.

- A driverless AHS transit application could piggy-back onto the economies of scale associated with private vehicle development and the AHSway construction.

- A driverless AHS transit system could serve metropolitan trip demand nearly as well as dual-mode without the need of drivers and with less confusion in the collection and distribution. This concept make more sense as the size of the network of AHSways grows, thus, reducing the access problem.

B.1.8 AHS Institutional, Societal, and Cost Benefit Analysis

The AHS institutional, societal, and cost benefit analysis consists of these two task report summaries: (1) Institutional and Societal Issues (Task O), and (2) Preliminary Costs/Benefit Factors Analysis (Task P).

B.1.8.1 Institutional and Societal Issues (Task O)

Key findings of this activity area are as follows:

- Perhaps, the most important finding of this task is that there are likely to be no insurmountable institutional and societal barriers – show stoppers – to the evolutionary deployment of AHS. This does not mean that surmounting some barriers will necessarily be easy. There is much to do before AHS deployments – beyond initial test sites – is feasible.

This finding itself rests on two of the earliest conclusions of this research effort:

- Institutional and societal issues and risks vary enormously depending on the RSC to be deployed; and an important conclusion that seemed a bit daring when we first stated it early in the year, but which came be accepted with a surprising near-unanimity as of the conclusion of the April 1994 Interim Results Workshop, that

  Based on an analysis of the history of the introduction and acceptance of comparable, earlier technologies; the likely availability of funding, and the need to resolve some institutional and societal barriers incrementally as part of the process of deploying ITS technologies – even before AHS – AHS must develop evolutionarily from less infrastructure and outside-the-driver command and control technologies to more infrastructure dependent/greater outside command and control technologies.

Additional findings include:

- Beyond confirming early (pre-PSA) predictions that AHS would be expected to provide air quality benefits – based on the assumption that carbon monoxide would be reduced simply because vehicles would move more consistently at higher speeds – it is likely that AHS will provide air quality benefits not only by reducing CO emissions, but also by reducing both the hydrocarbons and nitrogen oxides that create the more serious air quality problem of ground-level ozone.

- Many institutional/societal issues that arise in connection with AHS are not unique to AHS, but rather, related to any plans to build roads today or in the future. The AHS effort cannot be expected to address, let alone resolve, all of these larger societal and historical issues. On the other hand, these issues can become barriers to the deployment of AHS. And to the extent that AHS may accentuate the effects of how some of these issues are perceived, for example, urban sprawl, the AHS effort must be aware of its place in this larger context of institutional and societal issues and be prepared to address such issues in its deployments.

- The awareness that AHS is likely to evolve evolutionarily from ITS technologies and that the ITS effort is addressing many of the same institutional and societal issues does not mean that all of these issues will be resolved through the ITS deployment process prior to the time when it is technologically feasible to deploy AHS. Nor can the AHS effort expect that even those institutional and societal issues that are "resolved" in the process of deploying ITS will necessarily simply "go away" for AHS. Moreover, there are institutional and societal issues that are likely to arise specifically with AHS, as opposed to ITS, technologies.

- If the AHS technology is not generally available at modest cost, there are important equity issues involved in reserving or constructing a lane for the use of relatively wealthy private vehicle owners.

- The AHS effort must play "catch-up" with the long-term state and regional transportation planning already well underway in response to previous state and federal mandates and the more recent 1990 amendments to the Clean Air Act and 1991 ISTEA. Transportation plans for the next 20 years in congested areas in many cases are looking to rail projects to address many of the same transportation issues that an AHS might conceivably address.

- Application of the technology to a mode of transportation that serves moderate-income commuters in an existing, heavily used corridor under the institutional jurisdiction of relatively few actors provides the kind of setting that could allow an early AHS success. AHS proponents must focus on both short-term and long-term opportunities by being aware that it is the institutional and societal milieu that determines if, when and where new technologies such as AHS will be deployed and being prepared to: (1) maximize the use or imminent improvement of existing facilities to demonstrate the benefits of AHS, even, or perhaps particularly, when the technology is used exclusively for non-personal vehicles, and that such an early win opportunity may be represented by the desirability of automating the existing Lincoln Tunnel exclusive bus lane in New Jersey; and (2) support the development of non-AHS facilities where there may be a good opportunity for later conversion to automation.

B.1.8.2 Preliminary Costs/Benefit Factors Analysis (Task P)

Formulating the expected costs and benefits of an AHS requires the use of a conceptual framework for determining types of costs and benefits, measures of cost and benefits, and an understanding of the uncertainty involved in the range of estimates derived as a result of the framework. We have developed an analytical matrix that accomplishes this task. We have also evaluated the major factors affecting the incremental costs of an AHS system, from initial research, to early deployment, through ongoing operations. Similarly, we have identified the most important benefit measures to be travel time savings, from the point of view of AHS road users themselves; accident avoidance and congestion avoidance benefits, from the societal point of view; and traffic throughput from the road operator's point of view. In addition, there are significant construction and ongoing operations and maintenance benefits to be gained as a result of secondary or "multiplier" effects of spending resources in deploying such systems regionally, or even nationally. Other benefits, such as productivity improvements at the workplace, will have to be an area for further research. It is conceivable that these may be significant, but quantifying such benefits, when little is known or predicted about the share of (say) commuting trips that are taken on AHS roadways the produce travel time savings or other user comforts/conveniences, is difficult if at all possible.

On the cost side, AHS roadways will incur substantial infrastructure construction, operating and maintenance costs. In addition, there are the costs of on-board electronics, as well as the added costs of the system infrastructure. A proper evaluation of AHS systems will thus have to consider these cost components.

We also examined traffic data for several actual roadways that could implement candidate AHS systems. Considering estimates of both benefits and incremental costs for these actual roadway scenarios, we found that, on the whole, AHS roadways do not produce sufficient economic gains to outweigh potential costs. Only in one of our roadway scenarios did we find that AHS roadways would pass a numerical cost-benefit test. However, we cautioned against over-interpreting these results. Our estimated performance gains were just that: estimated. Our cost estimates could be subject to wide variation when real systems would be actually deployed. But this exercise provided us with some useful insights into some of the more prominent relationships between benefits and costs when considering AHS.

Our research focused on the major benefit and cost factors that should enter into proper evaluations of candidate AHS systems. We first defined the economic rationale behind cost-benefit analysis. The strongest principle of a sound investment in a project is its internal rate of return, which is the discounted present value of its projected income stream net of its initial investment and all other costs to be incurred during its projected lifetime. A project with a projected rate of return that is both large and positive is indeed a project that should be undertaken. Alternatively, we reviewed the net present value appraisal method. A project should be undertaken if its net present value, or its net discounted stream of future income minus costs, is positive. For example, we found that travel time savings will accrue to some roadway users after implementing an AHS system. These savings, expressed in dollars, constitute one component of the annual stream of expected benefits. On the other hand, annual periodic payments need to be made for the upkeep of the roadway, to take another example. These payments are counted in the future stream of costs.

Following our discussion of cost-benefit principles, we discussed the importance of considering cost-benefit analysis for the policy context. There will be many goals expected from future AHS systems. Roadway operators will be concerned with performance gains, such as increased vehicular throughput and gains in operational efficiency, particularly in inclement conditions. Users will be concerned with increased in comfort and convenience and reductions in operating costs, delay and congestion, as well as better schedule reliability. To society as a whole, AHS roadways will have to deal with the roadway safety issue, with traffic congestion, with better personal mobility, with trip and schedule reliability, and so on. Concurrent with such benefit categories, AHS roadways will have to accomplish such gains while keeping deployment, operation, maintenance and renewal costs to a minimum. The importance of cost-benefit analysis, then, in this policy context, is to outline these categories of expected system benefits and costs so that AHS can be evaluated effectively, or even tailored so that it can achieve the maximum gain for the least amount of cost in general.

Our next objective was to ensure that we could capture the major components of system benefits and costs. To do this, we research several possible evolutionary deployment scenarios for representative AHS roadways. At each step in the evolutionary process, the costs of deploying systems would generally increase, with often either a corresponding or a less than corresponding increase in expected benefits. We took care in distinguishing between performance gains themselves, and the perceived value to users or others of such gains. We included at first all of the major components of benefits and costs, and then judged several distinct components to be more than significant than the others using currently accepted standards of evaluation.

In particular, we judged travel time savings, accident cost savings, and the secondary economic effects of ongoing operations and maintenance activities on societal output and employment to be among the most important categories of economic benefits that are the most easily quantifiable. Other benefit measures, such as general increased in workplace productivity or better schedule reliability are certainly important, but do not readily lend themselves to reasonable quantification. On the cost side, we found that the major component of system costs is the actual construction cost of the AHS roadway. Other important costs include system infrastructure costs, vehicle electronic costs, and the costs of ongoing operations and maintenance.

To apply our general principles, we then considered four candidate real roadways where deploying some form of AHS would be possible and even desirable. We looked at New York's Long Island Expressway and the New York State Thruway, Baltimore's section of Interstate 495 and Boston's Interstate 93. Our analysis of these roadways suggested that, at least conceptually, AHS deployment would pass a numerical cost-benefit test on only one roadway scenario, New York's Long Island Expressway, a particularly congested roadway with parked peak hours of congestion, and a roadway with significant commercial vehicle access as well as transit (bus) use. However, that is not to suggest that AHS as currently configured does not make economic sense anywhere else. There are several reasons for this. One, our current evaluation methods are relatively crude, and cannot capture the major societal effects of general improvements in living standards or in workplace productivity as a result of reducing the stress, fatigue and accidents involved with major commuting patterns. Two, our analysis is preliminary and is entirely limited by the many assumptions used in our traffic analysis, cost estimates, and roadway deployment scenarios. It is entirely possible that as we refine our work in these and other areas, we will derive performance gains that are much more substantive. Three, there are too many uncertainties with regards to the possible makeup of future AHS systems that concluding at this stage that AHS has only limited economic applicability would be too premature. Clearly, AHS displays a considerable amount of promise with regards to potential economic gain, and this needs to be carefully developed further. Particularly since AHS will undoubtedly involve a significant commitment of public resources, its justification will hinge on the ability to develop and achieve such gains.

B.2 CROSS-CUTTING ANALYSIS FINDINGS

The conclusions and key findings in the individual tasks reports, presented above, already identify a number of cross-cutting conclusions. The cross-cutting conclusions in this section represent the major findings, but more importantly, are organized in a manner that consolidates the results.

One major difficulty in effectively synthesizing the task results is the extent to which the individual tasks are based on common assumptions. The definitions of the RSCs provide one level of common assumptions; however, it is possible that some task conclusions arise from different and possibly contradictory assumptions. Therefore, we have been careful to only combine conclusions that come from similar assumptions.

It is important to state at this time five major themes associated with our study approach. They are:

- The AHS analysis was performed with a priority towards breadth of research rather than depth of research. For example, the comparable systems task, the lateral and longitudinal guidance task, the institutional and societal task, and others all were very broad in scope.
- A conservative approach to safety impacted most all design analysis. For example, the costing of the infrastructure included the cost of a breakdown lane for malfunction management purposes.
- Detailed infrastructure analysis was performed. Since the infrastructure is such a costly component, the costing exercise utilized actual scale drawings of the roadway design to provide greater accuracy.
- Travel time benefits for four representative roadway scenarios were carefully calculated. Most benefits models are driven by time reduction calculations. Therefore, the INTEGRATION model was exercised to supply estimates of travel time savings.

- A comprehensive study was performed of the market potential of commercial and transit applications of AHS.

This section is organized into the four topics: (1) AHS Configuration and Deployment, (2) Technical System, (3) Benefits and Costs, and (4) Institutional and Societal System Impacts. These topics were chosen to represent a high level systems view of AHS design, implementation, and operation issues. They are the researchers own choice and are not the only system level view available. However, they are a convenient structure to frame the major conclusions. The major element of the synthesis approach was to organize, analyze, and combine the individual task key findings into this new structure.

B.2.1 AHS Deployment

B.2.1.1 Deployment Strategy

The deployment strategy analysis consisted of three separate parts. Initially, the various RSCs were analyzed for applicability to generalized deployment scenarios that cover the full spectrum of AHS applicable roadway environments (i.e., urban, suburban, and rural). The results of this general analysis were then used to guide studies of specific roadway deployments, with both SVE-only and mixed SVE and MVE AHS use. A third area of analysis then focused on the issues associated with the evolutionary aspects of deployment.

B.2.1.2 Urban, Rural, and Suburban Environment Analysis

The target for AHS deployment is our national freeways, the backbone for worker commuter, inter- and inter-city travel and the major roadway choice of America. Freeways, pressured to carry more traffic, are experiencing crippling and prolonged congestion. The remedy for congested freeways is not to build more of them but to make them work more efficiently. AHS analysis is based on this premise.

Experienced transportation engineers recognize the fact that freeway problems are not the same for urban, suburban and rural environments. They were not built for the same purposes, were not engineered the same, and do not operate the same. Therefore, the three environments provide different market potential, different design problems, and different operational considerations.

Our major conclusion in this area is that envisioning AHS as a national system requires flexibility of design to accommodate urban, suburban, and rural needs. The urban, suburban, and rural environments cover a spectrum of needs. Therefore, a variety of configurations are required to meet each of the needs. Suburban would be more I3 driven and rural would be more I1 driven. As discussed above, the I1 configuration would be more compatible with C1 control. The I2, I3 or mixed I2/I3 configurations would be more appropriate with C2 or C3 control. (UR11)

This study centered around deployments in the northeast U.S.. Within this region, sufficient roadway diversity exists to support the requirement for a flexible implementation strategy.

Other major infrastructure related conclusions involve (1) minimum AHS and general use lane requirements, (2) use of manual lanes for access to the AHS lanes, and (3) the impact of increased throughput on surrounding roads.

The key findings in these areas are:

- If one assumes that rural AHS will initially operate in mixed traffic lanes, when AHS use increases, and higher throughput performance is required, the minimum lane requirements appear to be one AHS lane and two general use lanes. This requirement will impact most of the dual two-lane freeways (outer suburban and rural). Although traffic volumes may show only a need for a single general (manual) lane, entrance/exit, passing, incidents and operation during maintenance will probably require a minimum of two general lanes. This step in the evolutionary process is the most costly and the greatest risk to evolutionary advances of AHS. More detailed discussions about evolution of AHS is presented in section 5.2.2.4. (UR8)

- Suburban freeway deployment is a prime candidate for initial implementation of separate AHS, since the increased throughput is required and the right-of-way may be available. However, equal provisions need to be made for entry and exiting. A major infrastructure design issue for AHS deployment is finding solutions to the traffic mixing, weaving, entry and exit with non-AHS vehicles especially heavy trucks. (UR7)

- One of the highest infrastructure impacts assigned to entry/exit requirements is the merging of two AHS streams starting at right angles. This is due to the large radii required if speed is maintained, and the lack of such a requirement in today's highway geometries. (EE5)

- Infrastructure design issues, including exit and entry location and techniques, are not easily generalized. The four separate freeway case studies concluded that the placement of entries and exits significantly impact the traffic flow. Depending on the OD requirements, the capacity of the remaining general lanes rather than the AHS lanes may limit overall capacity. Likewise, the specific street and traffic situations dictate requirements on exit and entry techniques.(RDPE3, EE3, EE4)

- AHS can increase throughput during peak hours provided the supporting interchanges, feeder roads and city streets can accept this increase. At the proposed high flow rates, urban and suburban facilities now regularly fail. Only rural freeway feeders have the capacity required. (UR9)

B.2.1.3 Specific Deployment Case Studies

Four case studies were developed to assess the performance and potential benefits of AHS within these representative roadways. The four scenarios included one urban, two suburban, and one rural freeway. Traffic loading for AHS and general lane configurations were developed for each case study. The INTEGRATION traffic model was adapted for AHS evaluation purposes, and the performance of each AHS design was evaluated relative to a baseline or no build case. The effects on nearby surface street intersections were evaluated in some cases.

B.2.1.4 Urban and Suburban Case Studies

Three of the studies were performed using roadways that are characterized as either urban or suburban. They are segments of: the Maryland Beltway (I495) near Washington DC, the Long Island Expressway (I495), and the Southeast Expressway in Boston (I93). Six conclusions from these studies are:

- Deployments on congested urban and suburban freeways can significantly improve speed and travel time on these facilities. Travel time improvements of up to 38 percent were obtained for the cases studied.

- The selection of access techniques is best determined by the AHS access and egress volume requirements, by the general lane traffic of these locations, and by the LOS on the general lanes.

- In areas which experience high levels of traffic congestion, such as Long Island, high levels of AHS utilization are obtained based on relatively low levels of AHS Market Penetration (15-25 percent).

- In congestion prone areas, the AHS may generate significant changes in the utilization of parallel facilities located several miles away from the AHS. However, as market penetration increases, as was evident on Long Island, the attraction of the AHS facility to distant parallel roadways decreases, and total VMT in the study area decreases.

- The need to access the AHS will, in many cases, cause saturation of surface street intersections. Geometric improvements and signal timing changes will be commonly required.

B.2.1.5 Rural Case Study

The rural case study was for a segment of the New York State Thruway (I87) north of New York City.

One conclusion from this study is that significant travel time improvements on the rural facility were only obtained when the AHS cruise speed was increased to 80 mph from the 62 mph speed used for the urban and suburban case because the roadway runs at the speed limit with no recurring delay.

B.2.1.6 Commercial and Transit Case Studies

The deployment results presented above are based on only passenger vehicle types. The assumptions used vehicle headways, and associated capacities, that were based on passenger vehicle characteristics. Three separate case studies were used to study the effects of mixing commercial and transit vehicles with passenger vehicles. These case studies were for the Long Island Expressway, the New York State Thruway, and the New Jersey Turnpike. The results indicated that each type of interstate highway, urban or rural, exhibited varying capabilities for incorporating AHS technology over a mix of vehicle types. Four of the more significant conclusions are:

- The most efficient travel occurs with passenger vehicles and large commercial and transit vehicles separated, either both in AHS lanes or one type in AHS lanes and the other in the manual lanes.

- AHS technology is viable to alleviate congestion. The findings for the LIE indicate that an exclusive AHS lane for all commercial and transit vehicles and all passenger cars distributed evenly between two general use lanes, with an ultimate capacity of 8,900 pcph, would be the most beneficial case for people-moving efficiency. These options also exhibit favorable average vehicle occupancies for compliance with the CAAA/ECO Program goals.

- Along the east spur of the New Jersey Turnpike an exclusive AHS lane for only passenger vehicles and two general use lanes for all vehicle types or an exclusive AHS lane for all commercial and transit vehicles and all passenger cars distributed evenly between two general use lanes, with ultimate capacities of 8,900 pcph, prove to be the most efficient. These options for the combined section of the Turnpike would also be relatively efficient in people-moving efficiency. These options would require carpools of two or more persons and aid in the effort to achieve the CAAA/ECO Program goals.

- 'No Build" conditions in 2024 on the New York State Thruway would not require excess capacity. An AHS could be implemented in this corridor for reasons of safety and efficiency. One AHS lane and two general use lanes would be the most effective option. None of the Options would meet CAAA/ECO Program goals.

B.2.1.7 Evolution versus Revolution

The question continually surfaces as to the extent, cost and associated benefits of the initial implementation. Simply stated, the question is one of evolutionary deployment versus revolutionary deployment. The evolutionary approach would entail simpler, less costly systems that provide compatible benefits. It would then grow incrementally, with appropriately scaled costs and benefits, to a more complete system. Each stage would be driven by the market. The revolutionary approach is much different from this strategy. It is driven by the need to implement a complete system in order to generate sufficient benefits to outweigh the costs. The assumption is that the market will not drive the incremental growth; it needs to be orchestrated in one collective effort.

B.2.1.8 AHS Operations

Deployment strategies must include operational issues along with the more visible design and development issues. The long term viability of the system depends heavily on the effectiveness of systems operation, which is highly focused on organizations and procedures. Key findings follow:

- For operation of an AHS, new or hybrid operating agencies and their organizational frameworks will need to be defined along with their potential operations responsibilities. The levels of association, coordination, and autonomy among the operations elements of existing highways, such as management, maintenance, police and emergency services need to be identified along with potential problems with existing arrangements of these operations elements. Each operating agency scenario and the operational impacts of a multi-jurisdictional framework need to be evaluated and studied. Evaluation criteria should include operations uniformity, effectiveness, and practicality of providing such service.

- Current levels of expertise and staffing available at existing operating agencies can not support the requirements necessary for an AHS. The areas of expertise required for operation and management of an AHS need to be evaluated. Survey and review of current practices of in-house versus contracted-out functions at state DOTs and highway authorities are essential to final deployment of AHS.

- AHS operations require preventive maintenance on a level similar to the airline industry. Existing levels of preventive maintenance performed by highway operating agencies, including operators of traffic management systems, will not satisfy the requirements of AHS. A target level of preventive maintenance for AHS needs to be defined through investigations of comparable systems.

- It is anticipated that the AHS will need policing and involve policing tactics different from those practiced today. Dependent upon the RSC, the level of policing, police functions, and tactics will vary. Current policing practices need to be examined, including the level of policing, functions and tactics applicable to deployment of an AHS

- AHS should be designed with system upgrades in mind. System upgrades and expansion need to be accomplished with only minimal disruptions of service. System upgrades should accommodate earlier AHS users after it is upgraded.

B.2.2 Market Potential

The specific AHS system configurations and the various deployment strategies should be driven by the market need. That is a clear result of this study and a mandate for any follow-on program. The market has many facets however and all need to be included. It includes the public and private system operators, who are responsible for building, operating and maintaining the roadways that serve potential AHS customers. It also includes the various private vehicle operators that use the roadways for work commutes, inter-city business travel, vacation travel, etc. It includes the private and public commercial and transit industry. It also covers the various manufacturing elements of the system; vehicle manufactures, roadway electronics, etc. that will be driven to find cost effective methods to supply products.

Our study offers a broad base of results as to the potential of enticing these various elements of the market to invest in the future of an AHS. We have organized our findings into: (1) the overall market potential of the system; and (2) the market strategies that are required to demonstrate the potential.

Our research into overall market potential of the system focused more on the quantifiable traffic related benefits of the system rather than the more subtle benefits of user comfort and convenience and increased productivity.

Our key findings in this area follow:

- Research into AHS technology is important as this defines the "How". Equally important is research in the market to identify size and needs as this defines the "Customer". The "How" should be driven by the "Customers' Needs".

- The daily user of urban and suburban freeways wants travel time savings as a performance improvement. Acceptance of AHS equipment and traffic management costs will be based on the performance gain. A target goal for this savings is one minute per travel mile; totaling at least ten minutes on the freeway portion of the trip. This objective can be accomplished by providing preferential lane and exit/entry provisions for AHS users, since automated control can regulate speeds above the current congested level.

- Worker commuter users of urban and suburban freeways are effective targets for early deployment of AHS. These individual users have a vested interest in making AHS a success as they gain time, reliability, and safer trips. As a daily user, they should be willing to equip their vehicles and pay for the service. HOV users and Transit providers are prime customers for AHS since they are currently part of the solution for urban and suburban congestion.

- In areas which experience significant traffic congestion, such as Long Island, high levels of AHS utilization are obtained based on RSCs I2 and I3 type facilities at relatively low levels of AHS Market Penetration (15-25 percent).

- A large AHS benefit can be achieved with transit vehicles. AHS when combined with transit and/or HOV treatments can provide very significant improvements to the people-moving capacity of our highways. These treatments are especially applicable to (and perhaps limited to) AHS applications in urban areas and along congested corridors. When considering the AHS goal of congestion mitigation, the potential of these treatments cannot be overlooked. For example, an AHS implemented in the Lincoln Tunnel Express Bus Lane could potentially provide people-moving capacity greatly exceeding that possible with heavy rail mass transit (although this would require expanded terminal capacity). Even HOV treatments on AHS could potentially provide service comparable to existing light rail systems.

B.2.3 Technical Aspects

The RSCs are generalized approaches to specific AHS technology implementations. They served a useful purpose for supporting the generalized deployment studies, reported in section 5.2 above. However, all of the analysis assumed: (1) the technology was available to safely and reliably deliver the level of automation required by the market, and (2) the system design appropriately accounted for driver capabilities. This section reports on our research findings relating to these two broad assumptions.

It is organized into three major subsections. The first subsection, entitled Automation Capability, covers the areas of automated control, driver role, and safety, reliability, and malfunction management. The next subsection covers the more global automation issue of traffic management. Lastly, a subsection is included that reports on AHS vehicle propulsion system alternatives to the conventional SI engine.

B.2.4 Automation Capability

Automation of manual operations has been an ever increasing element of our society over the last few decades. A few examples are unmanned elevators, robots for manufacturing, aircraft automation, and ATMs. The surface transportation industry’s experience with automation is not as extensive as other aspects of society. It is mostly relegated to transit vehicles operating on fixed guideways. Therefore, the automation of rubber tired vehicles using interstate highways is a very significant and challenging technology initiative.

Our key findings are:

- The most promising lateral control technology involves magnetic markers or overhead wires.

- Headway radars will be required to provide high azimuth angle resolution.

- Infrastructure-based systems may be cost effective.

- There is a tradeoff between longitudinal maneuver errors and noise immunity.

- Sensors for lateral and longitudinal control must be capable of performing under severe adverse weather conditions.

- Communication between vehicles may not be required for vehicles following at gaps of 0.5 seconds, even during emergency maneuvers.

- Entry and exit techniques are key to the derivation of traffic flow related benefits since they dictate maximum flows throughout the system.

- The different entry/exit techniques associated with the different RSCs may well all find application on a single AHS because the specific design requirements of each street and traffic situation dictates the best technique.

- The check-out "test", associated with exit from the AHS lane, should be an integrated part of the larger check-out process that has the driver take control of the system rather than the system give control to the driver.

B.2.4.1 Driver Role

The manual driver is a very significant component of the existing interstate transportation system. He or she performs a variety of tasks that are critical to the safe operation, trip reliability, and overall system performance. He or she will have a new role in the AHS. By definition it will be less time consuming but it will still require retention of some of the old skills and, importantly, development of new skills.
Some key driver-role related findings in the check-out area are:

- During the process of transition from automated to manual driving, the driver must take control of the vehicle rather than having the vehicle give control back to the driver.

- The check-out "test" should be an integrated part of the larger check-out process.

- If check-out "tests" are required during the automated portion of the trip (for the purpose of maintaining an adequate level of vigilance), these "tests" should be meaningful and not artificial and extraneous.

- The driver portion of the check-out process must account for the wide variability in capabilities within the driving population.

One, often discussed, driver role associated with AHS travel is "Brain Off as well as Hands and Feet Off". This is in contrast to a "Brain On, Hands and Feet Off" role. We studied both roles as part of our fault hazard analysis work in the safety and malfunction management tasks. Both roles require further investigation but our preliminary conclusions are:

- Not allowing the driver to completely relax maintains a very capable and intelligent system component that would be extremely expensive to replace.

- Allowing the driver to be completely detached from the system eliminates the concept of manual backup, increases the requirements for malfunction management, and raises concern for AHS exit policies.

B.2.4.2 Reliability, Malfunction Management and Safety

The reliability, safety and malfunction management aspects of the system are critical to the AHS market driven strategy. These characteristics are not products of the system design. They are drivers of the design. Therefore, a number of issues relating to reliability, safety, and malfunction management need to be addressed as the AHS system design moves forward.

One comparable systems study conclusion clearly states the compelling case for designing a safe and reliable AHS system: “The safety and reliability of AHS must be clearly demonstrated”.

The major key findings are:

- Check-in tests should be performed on the fly.
- Actuators for steering, throttle, and brakes will require testing in a series of dynamic tests.
- Vehicle testing will be performed continuously during AHS operation.
- User data and analysis show that an automation failure rate of one per 2000 vehicle. hours. is feasible. This would provide acceptable levels of service for an AHS.
- The full answer to the cost impacts associated with delivering a specific failure rate performance, both acquisition and lifetime maintenance, must remain uncertain until specific designs are considered, but we are optimistic in terms of realistic market costs.
- The key issues in the approach to the question of safety are the use of redundancy in vehicle equipment, and the use of a breakdown lane, entry/exit protocol, and handling communication failures. Our study suggests design approaches to deal with these issues.
- Barriers in the I2 scenario would reduce the probability of vehicles and other objects from moving into the AHS lane from the manual lanes. The ability of an automated vehicle to cope with such objects is problematical, making consideration of barrier use part of a realistic malfunction management strategy.
- The check-out process needs to check vehicle components not utilized during the AHS travel.
- Crash types similar to those on today’s interstates will probably become the crash types that occur on an AHS under non-normal operating conditions. The causal factors will be AHS unique, the number of vehicles involved will probably be greater, and the distribution of crash types will vary from today’s interstate accident picture.
- The most common crash types to result in a fatal injury are the single vehicle accidents that are rollovers, barrier related, roadside departures or involve an object or animal in the roadway. Head-on and Sideswipe Opposite Direction are extremely low frequency events on interstates.
- Rear-end crashes are likely to be the most frequently occurring AHS crash type, especially under some very small headway concepts. The primary measure of collision impact severity is V, defined as the change in a vehicle's velocity, taking into account vehicle mass. Occupant injury levels and vehicle damage severity’s were expressed as a function of V.

This analysis was performed to estimate "tolerable" Vs for collisions on an AHS. Once tolerable Vs are obtained, safe headways for travel speeds based on maximum deceleration of a lead vehicle involved in a crash can be calculated.

- Vehicle occupants suffered injuries requiring transportation to a medical facility where they were treated and released from crashes in the 6 to 10 mph V range. Injuries requiring hospitalization resulted from crashes in the 11 to 15 mph V range. This not only implies the seriousness of the incident in terms of occupant injury, but also indicates the amount of time necessary to clear the accident scene, and its influence on the perceived safety of the AHS.

- Barrier-related crashes represent another potential AHS crash type. CDS data show that left roadside departures account for approximately 78 percent of barrier crashes that occur on roadways with speed limits greater than 50 mph. This finding strongly supports the use of barriers on the AHS since, without a barrier between automated and manual lanes, left roadside departure vehicles from the manual lanes will intrude into the AHS.

- The likelihood of a lane-blocking incident on an AHS under normal operating conditions may be viewed as the possibility of a crash with an object or animal in the roadway. Automation is capable of creating a “smart driver” that knows the state of the vehicle, and the limits of the vehicle’s handling capabilities for road and weather conditions, but automation cannot control objects or animals. Therefore, automation must deal with them, particularly on the long stretches of suburban and rural highways where the problem is most significant.

- The magnitude of the object in the road problem is not clearly defined. Accident statistics indicate the number of times a vehicle strikes an object or animal in the roadway, not the number of times a driver successfully maneuvers around an obstacle and still maintains control of the vehicle. The cost of preventing these elements from entering the AHS emphasizes the need for detection devices. However, even if it is possible to detect an obstacle that truly needs to be avoided, the longitudinal and lateral control systems must be capable of diverting the stream of vehicles, and they must have the room to maneuver the vehicles safely around the obstacle. (SI3)
- Crashes involving objects or animals represent 5.2 percent of all interstates crashes. Given the 490,336 million vehicle miles of travel on U.S. interstates, this equates to a rate of 0.03 incidents per million VMT. However, this does not account for the situations where the driver encountered an object and successfully avoided the crash. Additional events, under non-normal operating conditions, that may lead to “AHS roadway obstacles” or lane-blocking incidents are:

  - Loss of lateral control
  - Offset rear-end crashes
  - Rear-end crashes on low traction surfaces (perhaps due to fluid spills)
  - Lane/change merge crashes
  - Crashes related to driver impairments

B.2.5 Traffic Management Aspects of AHS

Full automation of vehicles operating on an AHS roadway, when viewed collectively, is a form of traffic management. It is a natural extension of the initiatives that are taking place in ITS research and deployments nationwide. These advances in Advanced Traffic Management Systems will be directly applicable to aspects of AHS operation as well be required as a seamless interface to the manual system. Therefore, lessons learned from these initiatives are useful for current and future AHS research.

One key finding from the comparable system study involves the desirability of designing for fully centralized control. “The degree of centralized control and human decision making can slow system response”.

B.2.5.1 Traffic Management Impacts related to Exit and Entry

- Entry/exits are key to AHS practicality since they dictate maximum flows throughout the system, are a big cost driver, and are a primary impact on the community.

- AHS exit efficiency will be critical for handling high AHS flow rates.

- Certain AHS control strategies call for queuing vehicles at AHS entry points. Properly managed AHS traffic maintains queue delays and queue lengths at acceptable values.

- Major sources of urban and suburban freeway congestion are incidents (non-recurring), bottlenecks at entry/exit points (recurring), and scheduled maintenance (non-recurring). AHS vehicle instrumentation and TM are tools to eliminate congestion, provided poor roadway geometry is corrected.

B.2.5.2 Traffic Management Benefits for AHS

- The attraction of the AHS facility in congestion prone areas results not only from increased capacity, but also, because of the facility’s ability to sustain a constant comfortably high speed of 60 mph at increased volume.

- An AHS facility on a congested urban or suburban freeway might tend to reduce the total travel time vehicle-hours in comparison to comparable non-AHS facilities, while satisfying the trip demand. This finding, however, must be tested further using a more precise modeling technique.

- AHS traffic controllers, according to derived capacity-versus-speed estimates applicable to automated vehicles, will have the ability to provide a tradeoff between velocity and capacity to accommodate substantial volume variations.

- Optimize operational improvements on urban and suburban freeways along with introduction of AHS, as it a part of a TM package not a stand alone service. TM includes; surveillance and control systems, ramp metering, incident management, motorist information systems, HOV facilities, and low-cost geometric improvements. These TM techniques are required to supplement AHS full automation.

B.2.5.3 Traffic Management Operations

Current TM systems are primarily passive (and at best semi-automatic) and rely on macroscopic state variables such as density and speed to identify congestion and incidents. While traffic flow management requirements of an AHS would vary by RSC, configurations with central control will require a more discrete, microscopic orientation of traffic monitoring and management. The characteristics of traffic flow monitoring and management need to be examined and defined as AHS evolves.

Although it is the promise of the AHS to reduce the occurrence of incidents, the impacts of any incident on AHS could be more severe, due to the higher capacities, with regard to traffic operation. Therefore AHS must improve incident detection and shorten incident response time. The impact of traffic congestion and delay on an AHS lane will be much greater than current impacts to the existing highway system. Therefore, the incident response time must be reduced in order to maintain current highway levels-of-service.

B.2.6 Benefits and Costs

There economic goals (potential benefits) and potential costs of an AHS system program are many. To roadway operators, who are concerned with operational parameters, AHS should increase vehicular throughput and operational efficiency, particularly in inclement conditions such as adverse weather. To society as a whole, an AHS corridor should reduce trip times, improve trip and schedule reliability, improve safety, and enhance personal mobility. An AHS system should accomplish these and other goals while reducing vehicle operating costs, reducing societal insurance costs, and perhaps reducing the cost of making an individual trip by automobile. Achieving these very broad goals through implementation of such an advanced technological system is an extremely challenging task.

The cost benefits task, conducted within this study, was only able to begin to determine economic feasibility for a system at this stage of development. This task was not designed as a final say in whether to proceed with any particular AHS program. Rather it only sheds light on methods to properly evaluate and appraise an AHS.

Our specific charge was to develop a conceptual framework for analyzing costs and benefits; determine cost and benefit measures; list and rank by importance of impact such measures; examine how such measures are affected by the evolutionary deployment of AHS systems; and, finally, examine the critical threshold points of incremental costs and benefits across various system configurations. Also, we were to examine four specific roadway deployment scenarios and report on benefit and cost measures to support the more generalized analysis.

Four candidate real roadways where deploying some form of AHS would be possible and even desirable were analyzed. We looked at New York's Long Island Expressway and the New York State Thruway, Baltimore's section of Interstate 495 and Boston's Interstate 93. Our analysis of these roadways suggested that, at least conceptually, AHS deployment would pass a numerical cost-benefit test on only one roadway scenario, New York's Long Island Expressway, a particularly congested roadway with parked peak hours of congestion, and a roadway with significant commercial vehicle access as well as transit (bus) use. However, that is not to suggest that AHS as currently configured does not make economic sense anywhere else.

There are several reasons for this. One, our current evaluation methods are relatively crude, and cannot capture the major societal effects of general improvements in living standards or in workplace productivity as a result of reducing the stress, fatigue and accidents involved with major commuting patterns. Two, our analysis is preliminary and is entirely limited by the many assumptions used in our traffic analysis, cost estimates, and roadway deployment scenarios. It is entirely possible that as we refine our work in these and other areas, we will derive performance gains that are much more substantive. Three, there are too many uncertainties with regards to the possible makeup of future AHS systems that concluding at this stage that AHS has only limited economic applicability would be too premature. Clearly, AHS displays a considerable amount of promise with regards to potential economic gain, and this needs to be carefully developed further. Particularly since AHS will undoubtedly involve a significant commitment of public resources, its justification will hinge on the ability to develop and achieve such gains.

B.2.7 Institutional and Societal System Impacts

All of the preceding analysis hinges, to a very large degree, on the view of AHS by transportation related institutions and society as a whole. The importance of the institutional and societal aspects of AHS design, development and deployment cannot be understated. AHS deployment is not just a technical installation exercise to provide a service. Impacts on land use planning, air/noise pollution and public/political acceptance are probably more important than solving mechanical, electronic, and concrete problems. If the development of the system is to be market driven, it must earn support from the myriad of associated transportation institutions. Since transportation is so pervasive in our society, these institutions are numerous. The support must also be enduring and that is why it is characterized as “earned” support. It will take work to earn the required support and the work must begin now.

During this study we documented the panoply of institutional and societal issues and risks that confront the effort to deploy AHS. The methodology involved a multi-stage process of reviewing all available literature regarding the subject of automated vehicles and highways and of ITS. The initial research lead to a categorization of AHS-specific issues and risks that was later modified to conform with commonly accepted categories being used by the ITS community.

Perhaps, the most important finding of this task is that there are likely to be no insurmountable institutional and societal barriers – show stoppers – to the evolutionary deployment of AHS.

Other key findings in the areas of air quality, land use, ITS versus AHS issues, social equity, transportation planning and liability:

- Beyond confirming early (pre-PSA) predictions that AHS would be expected to provide air quality benefits – based on the assumption that carbon monoxide would be reduced simply because vehicles would move more consistently at higher speeds – it is likely that AHS will provide air quality benefits not only by reducing CO emissions, but also by reducing both the hydrocarbons and nitrogen oxides that create the more serious air quality problem of ground-level ozone.

- Many institutional/societal issues that arise in connection with AHS are not unique to AHS, but rather, related to any plans to build roads today or in the future. The AHS effort cannot be expected to address, let alone resolve, all of these larger societal and historical issues. On the other hand, these issues can become barriers to the deployment of AHS. And to the extent that AHS may accentuate the effects of how some of these issues are perceived, for example, urban sprawl, the AHS effort must be aware of its place in this larger context of institutional and societal issues and be prepared to address such issues in its deployments.

- The awareness that AHS is likely to evolve evolutionary from ITS technologies and that the ITS effort is addressing many of the same institutional and societal issues does not mean that all of these issues will be resolved through the ITS deployment process prior to the time when it is technologically feasible to deploy AHS. Nor can the AHS effort expect that even those institutional and societal issues that are "resolved" in the process of deploying ITS will necessarily simply "go away" for AHS. Moreover, there are institutional and societal issues that are likely to arise specifically with AHS, as opposed to ITS, technologies.

- If the AHS technology is not generally available at modest cost, there are important equity issues involved in reserving or constructing a lane for the use of relatively wealthy private vehicle owners.

- The AHS effort must play "catch-up" with the long-term state and regional transportation planning already well underway in response to previous state and federal mandates and the more recent 1990 amendments to the Clean Air Act and 1991 ISTEA. Transportation plans for the next 20 years in congested areas in many cases are looking to rail projects to address many of the same transportation issues that an AHS might conceivably address.

- Application of the technology to a mode of transportation that serves moderate-income commuters in an existing, heavily used corridor under the institutional jurisdiction of relatively few actors provides the kind of setting that could allow an early AHS success. AHS proponents must focus on both short-term and long-term opportunities by being aware that it is the institutional and societal milieu that determines if, when and where new technologies such as AHS will be deployed and being prepared to maximize the use or imminent improvement of existing facilities to demonstrate the benefits of AHS, even, or perhaps particularly, when the technology is used exclusively for non-personal vehicles. Such an early win opportunity may be represented by the desirability of automating the existing Lincoln Tunnel exclusive bus lane in New Jersey.

- AHS will face liability issues. These should be anticipated and plans made to avoid or overcome legal challenges. We live in a litigious society. It seems clear that AHS implementations will face legal challenges (like all other systems). These can stem from manufacture errors, defective design, failure to warn, and/or product/service misrepresentation. AHS development should be managed in a way that minimizes legal vulnerability.

- Long-term and continuous financial support for AHS deployment must be secured. For the long-term success of AHS, it is important to ensure that funding for the project is sufficient and guaranteed. If the funding is not sufficient, it may be difficult to raise funds at a later date. If the funds are not guaranteed, they may be cut at any time, and battles for project financing will be ongoing. Further, funding needs to be specific to the goals of AHS, and pay-as-you-go financing is preferable to borrowing.

- Support from influential persons in Government and industry is important for large programs. The success of many large-scale projects has been facilitated through the commitment of high ranking officials from Government or industry who were willing to work hard to ensure the success of the projects. AHS will benefit from such an individual (or group) to help secure the necessary financing and support, and to help maintain enthusiasm for the project during all stages of design and implementation..

- Cost and time estimates for developing AHS must be carefully and accurately determined. Budget overruns and schedule slippage can lead to negative publicity, poor public acceptance, and reduced political support for the system. System design, testing, and implementation must remain within budgetary guidelines and time constraints for the project to ensure continued support. Cost and schedule "bad news" can reduce public acceptance of AHS, even when the shortfalls are due to estimation errors, rather than the more serious system problems. Also, it is important to plan for schedule and cost contingencies. AHS developers must carefully make realistic estimates concerning the amount of time the system will take to implement, and the amount of money it will cost to complete. Overly optimistic budget and schedule estimates look good at planning time but lead to almost certain failure, at least as measured against budget and schedule.

- The successful development of AHS requires that all stakeholders, both public and private, have a significant role in AHS development. A consortium approach to AHS development is needed to ensure that the AHS system is successfully implemented. It will allow the project to benefit from a wide range of expertise and perspectives, and to share the costs involved with implementation. Even more importantly, cooperation among the various industries and organizations interested in AHS will facilitate efficient and effective designs that can be supported by products and services developed independently, yet which must operate within a common infrastructure. The motivation for investment, participation in the consortium, and diligence in the task comes from the increased market share potential that results from design participation. Winners and losers are sorted out in the market place.

APPENDIX C

SUMMARY OF THE INTERIM RESULTS WORKSHOP DISCUSSIONS AND FINDINGS

This appendix summarizes the major systems-oriented findings from PSA Interim Results Workshop held in Chantilly, Virginia in April, 1994. Information for this appendix is drawn from the US DOT document FHWA-RD-94-101, Automated Highway Systems Precursor Systems Analyses Interim Results Workshop., or MITRE Working Paper WP 94W0000114, by the same name. The materials, which have been edited only to summarize the findings, are included in this report for the convenience of the reader. Separate sections are provided for each below. Contents include the following:

C.1 SYSTEM-ORIENTED ISSUES OVERVIEW

This section focuses on those aspects of an AHS that are cross-cutting and will impact all facets of an AHS.

C.1.1 System Malfunction

One of the major concerns for AHS is its robustness. To this end, one of the PSA activities was to identify the potential malfunctions of the system, and postulate strategies for reducing and/or managing them.

Six of the PSA contractors are conducting this activity; each has a somewhat different approach:

- Battelle - Identifying the types of malfunctions that may occur for each of their RSCs
- Calspan - Researching and analyzing hazards and fault statistics and correlating them to AHS
- Delco - Focusing of relevant automotive systems and their implications for AHS
- Honeywell - Correlating system check-in and check-out to identification of AHS malfunctions
- Rockwell - Using a software tool to simulate both vehicle and communications malfunctions
- Raytheon - Classifying AHS malfunctions by their level of severity in order to determine type of malfunction management that is appropriate

System Safety

This aspect of the system design addresses the safety of the vehicle occupants as well as the system operators. It includes the likelihood of injury or death in cases of system malfunction, but it also goes into the other aspects of the system dealing with personal safety. For example, the design of roadways so that vehicle occupants can get out in case of a fire, the ability to minimize personal injuries in cases of natural disasters, personal security, etc.

Four of the contractors addressed system safety:

- Battelle - Characterizing AHS operation under varying operating rules, including platooning; the intent is to derive safety issues and risks

- Calspan - Analyzing national highway safety database statistics, and characterize accidents and the implications for AHS

- Delco - Identifying hazards, and the operations required under various hazardous conditions

- Raytheon - Examining safety of AHS versus safety on future non-AHS roadways; also looking at the safety implications of taking the human out of the control loop

Transit

Transit is an important aspect of any SIP; it is viewed as one of the most likely approaches for reducing VMT. Transit bus ridership, however, has steadily declined. Part of the reason for this is that buses often must suffer from the same highway congestion and unpredictable travel times as automobiles.

These companies are specifically addressing the application of AHS to the movement of multiple-passenger vehicles:

- BDM - Evaluating current automated transit use and research in Europe and the US; they are also examining past research on the dual-mode bus in the US from lessons learned.
- Calspan - Examining potential for automated bus operations in the Lincoln tunnel.
- Raytheon - Reporting on the automated bus operation in Germany

Commercial Freight

The AHS technology can be applied to heavy trucks used in commercial shipping. These vehicles could be inter-mixed on the AHS roadways with light vehicle traffic, or they could be segregated from the light vehicular traffic, either by separate platoons or on dedicated lanes. These companies are specifically addressing the application of AHS to freight movement:

- BDM - Evaluating current automated transit use and research in Europe and the US; they are also examining past research on the dual-mode bus in the US from lessons learned.
- Calspan - Examining potential for automated bus operations in the Lincoln tunnel.
- Raytheon - Reporting on the automated bus operation in Germany

Alternative Propulsion Systems

An AHS must have the ability to accommodate the vehicles that will be operating on the nation's highways over the next 50 years. Given the nation's concern for pollution and its impact on the environment, the impact of alternate propulsion vehicles on AHS was examined.

This subject is being address by these researchers:

- Calspan - They have dedicated one RSC to RPEVs, in this way, this approach will be examined in all of the PSA activity areas
- Delco - They are conducting a review of internal combustion engine baseline characteristics, and (1) comparing these characteristics to various APS; (2) predicting likely availability of each APS; and (3) determining the likely impact o AHS design
- TRW - They are assessing the characteristics of alternative APS and assessing their impact on AHS design

Comparable Systems Analyses

This activity examines various system implementations and operations in the past, and attempts to derive lessons-learned form those system efforts for AHS.

Researchers addressing this area are as follows:

- Calspan - They began with a potential list of f38 possible systems; this list has been narrowed to a handful that will be analyzed
- Delco - Their focus is on automobile safety systems (in particular, the air bag), vehicle navigation systems (TravTek), and rapid transit systems (BART)
- Honeywell - They have selected a single system for comparison--air traffic management

C.1.2 Systems-Oriented Briefings

This session had seven briefings as follows:

- AHS System Functional Decomposition, Raytheon
- AHS Fault Trees and Malfunctions, Calspan
- AHS Accident Analyses, Calspan
- Check-in/Check-out Role in Malfunction Management, Honeywell
- Impacts of Commercial and Transit, Calspan
- Impacts of Alternate Propulsion Systems, TRW
- Comparable Systems: Air Traffic Management

C.1.3 Breakout Group Summary

After each plenary session, each attendee participated in one of ten breakout groups where issues were assigned for discussion. In addition, the groups could choose to also address other issues that they felt were relevant. The notes from the breakout groups that followed the Systems-Oriented Issues plenary session are given in Appendix B.

Generally, it was felt that there are no "show-stoppers"; however, there are many areas in which careful attention must be paid. Below, the comments and discussions relevant to the system-oriented topics are summarized.

Robustness

Discussions in the breakout groups relevant to system robustness focused on the public's perception of AHS if there are frequent system breakdowns. The feeling was that AHS must be very reliable--more than today's highway system--to the extent that users accept its reliable operation as a given. This has implications for the system design, including redundancy and built-in malfunction management capabilities to handle the different kinds of malfunctions that may occur:

- Warning level - The vehicle is moved to exit at the next available exit when one of these malfunctions occur. Causes could include low-on-fuel indication, engine overheating, etc.

- Serious level - The vehicle is slowed down in traffic, and it is moved into the first available breakdown lane, hopefully before it becomes inoperable. This could be caused by a flat tire, partial failure of either lateral or longitudinal control (e.g., the primary control failed and the backup is operational, but at a lesser degree of accuracy), or the engine stopped running and the car is coasting (should the driver be given control to restart the engine?).

- Critical - The vehicle is brought to an immediate, controlled stop in the lane possibly with hard braking. Potential causes could include total loss of lateral or longitudinal control, stuck throttle or loss of steering. it could also result from an on-board "panic button" that the driver has pushed. crashes could occur for these malfunctions depending on the type of failure.

- Imminent crash - The vehicle is given emergency maneuvers that may include full braking and/or evasive steering. This would be caused by detection of an obstacle in the roadway whose movement is slow enough that a crash is likely, perhaps even if immediate action is taken. Causes could be a system breach by an animal or by vandals, or instrument failure or loss of control by an adjacent vehicle.

Safety

As with system robustness, safety was a topic of considerable concern in the breakout groups. For AHS to gain public acceptance, it must be safe; that is, it was felt that the AHS must be viewed by the public as being safe enough that it is not thought about. For example, when people climb on a train, most do not think about the train having an accident--the same should be true for AHS.

It was also generally agreed that this perception of safety could be undermined early in the implementation of AHS if: (1) the system was not much safer than the non-AHS roadways (how much is enough was discussed, and estimated ranged from 50% better to order-of-magnitude better); (2) the system was designed so that a mega-accident could occur (i.e., 20 cars smash into a piano that fell off the back of a truck, and several people were killed); and/or (3) the frequency of low-velocity accidents is high enough that everyone knows someone who was in one of these minor fender-benders.

Discussions also focused on the factor that affect system safety; it was generally agreed that they are different in urban areas (accidents from non-AHS vehicles impinging on the AHS lanes) versus rural areas (animals breaching the system).

It was felt that attempts to drastically reduce the likelihood of serious accidents may actually raise the number of less severe accidents, thus lowering overall system safety.

Transit

AHS use for transit (i.e., multiple passengers per vehicle) was a topic of considerable interest. It was felt that an AHS-based transit system, particularly one that incorporates dedicated lanes in high-congestion areas, may have many advantages:

- Attractive per-passenger costs
- Predictable, and probably faster, travel times
- Provides an additional option to regional planning agencies; e.g., the agency may choose to offer multiple passenger vehicles priority on AHS during rush hour, or establish dedicated lanes where justified
- Transit may offer meaningful early winners to the AHS program; e.g., Lincoln Tunnel (high benefits, low infrastructure costs)

On the freeways, transit will realize the same benefits from AHS as passenger vehicles

AHS has the potential to substantially improve transit operations in urban and central business districts by allowing operation on narrow, close-tolerance guideways, much as rapid transit vehicles do; however, then operate on regular freeway lanes in less dense areas to eliminate the need for high-cost infrastructure with relatively low utilization.

Unmanned transit uses such as airport shuttles or special intra-urban transit systems also appeared to offer promise for AHS technology

There was some sentiment to consider making transit part of the 1997 demonstration

Freight

Freight is an important market pull for AHS; but, its a very segmented market and cannot be easily discussed as a single entity. Some factors to consider in examining potential AHS use in commercial shipping include:

- Long-haul (over 500 miles) is often competitively served by intermodal (rail); this is because of driver availability and cost; but there is still substantial long-haul trucking that is not intermodal because of the nature of the shipment or the OD locations
- AHS may allow truck operation without drivers (at least partially, gradually);
  - Very desirable economically for long-haul operation, but
  - Raises many perceptual and engineering problems
- Better opportunities may exist for short-haul (under 1,000 miles) where shipments are smaller (less-than carload), and the demand for time-sensitive delivery is growing (just-in-time delivery)
- The trucks used for this short-haul market (usually not semi-trailers) are somewhat more compatible with light vehicles

- Many trucking companies are already investing in IVHS; the incremental cost of AHS electronics for a truck is much smaller than the incremental cost for a light vehicle (because of its high initial cost)--also, trucking companies will invest if they believe there is a positive cost/benefit ratio

Mixing of heavy vehicles with light vehicles creates many problems:

- In a single lane AHS, system performance (acceleration, speed, etc.) would degrade to the performance characteristics of the truck

- People may feel uncomfortable being closer to heavy vehicles, even though safety factors are being maintained

- At the least;

  – Heavy vehicles in urban areas should be separated from light vehicles, either in dedicated lanes or in separate platoons with passing lanes to allow faster traffic to pass

  – Heavy vehicles in rural areas should have dedicated lanes; however, because of the cost, they may need to share the same lane with light vehicles--this means that there must be frequent passing lanes

Trucks can (and may want to) operate at times other than commuter rush hours; thus, trucks may not require separate lanes since they can use the HOV lanes in off-hours--kills two birds with one stone--supports HOV and rush hour transit with separate lanes, and support trucks in separate lanes in non-rush hours.

Alternate Propulsion Impact Analyses

AHS will need to accommodate the APS of the twenty-first century. If the performance characteristics of those vehicles are similar to today's predictions of some APS, then they will probably negatively impact the operational efficiency of the system unless a special lane is provided for them. A special APS lane within the next twenty years or so is unlikely based on predictions of APS market penetration.

Most of the discussions fell on EVs. It was generally felt that based on known technology, the problems are difficult; however, it was felt that we must keep looking.

AHS seemingly provides a stronger basis for feasibility of roadway-powered EVs. Power could be provided to the EVs periodically or on steep hills. This could significantly extend the EV's range and perhaps ease some of its operational restrictions (e.g., if it climbs a long, steep hill at a reasonable speed, then it quickly drains the battery). The AHS lanes would need to be designed to safely accommodate both RPEV and regular AHS vehicles.

The public perception is that EVs are non-polluting. However, given a recent report regarding the pollution that would be caused in the northeast by coal-fired power plants producing power for RPEVs, a further examination of RPEV impact on pollution may be warranted.

Operational Observations

Eventually there will be a need for a single functional breakdown for AHS . This will be the task of the consortium; the alternative breakdowns developed as strawman breakdowns by the PSA contractors, will be used by the consortium as input

It was generally felt that an evolutionary AHS is very important; the end-goal is achieved by evolving along a step-wise feasible path that contains several intermediate successes. This means that each step taken must show some benefits. What those steps are and which path is to be followed needs further examination. There may be a risk in tying the AHS to intermediate steps that may not be popular with the public.

Major safety benefits will probably not be realized until there are dedicated AHS lanes. major efficiency and capacity benefits may not be realized until AHS is proven and the public has trust in it; intermediate goals need to established with this in mind.

In moving from AHS goals to operational requirements, a balance will need to be struck between conflicting goals. Also, an air of reasonableness will need to be maintained; for example, requirements for AHS operation in adverse weather must be achievable.

Automation has a tendency to evolve to a "lowest-common-denominator" operational mode that degrades system performances; until the system expands to the point where there are multiple AHS lanes and lane changing is possible, this could be the case. This means that initial AHS design must avoid an approach in which AHS performance is lower than what some humans would choose or decide to do.

C.1.4 Reporter Summary

This summarizes the materials presented by the systems-oriented Working Group at the final Plenary session of the Workshop.

Transit

- Transit must be taken seriously; an automobile-only AHS may be a show-stopper.
- The program must have more transit stakeholder involvement, both operators and agencies.
- An automobile-only AHS segment may decrease transit usage.
- Advantages may include:
  - Attractive passenger costs
  - Predictable travel times
  - A regional planning agency may choose to give transit (i.e., multiple passengers per vehicle) priority on AHS
  - Transit can offer substantial early winners to AHS program; e.g., Lincoln Tunnel (high benefits, low institutional costs, highly politically correct)
  - Consider making transit part of the 1997 demonstration?

Freight

- Freight is an important market pull for AHS; but, its a very segmented market:

- Long-haul may be competitively served by intermodal (rail)
- Better opportunities may exist for short-haul where smaller, time-sensitive demand is growing
- This short-haul market is more compatible with light vehicle AHS

• Taking the driver out of the freight-AHS (at least partially, gradually) is:
  - Economically desirable
  - Raises many perceptual problems

• Trucks can and want to operate at times other than commuter rush hours; thus, trucks may not require separate lanes--use the HOV lanes in off-hours--kills two birds with one stone--supports HOV and rush hour transit with separate lanes, and support trucks in separate lanes in non-rush hours.

Alternative Propulsion

• Electric is difficult; need to keep looking

• Seems like an unnecessary complication; will EVs really be less polluting by the year 2010?

• Perceptually, has many social benefits

• Becomes more realistic if AHS speeds are modest, and there is roadway-provided power--implications for urban versus rural use need to be further examined

Operational Issues

• Evolution is very important; the end-goal is achieved by evolving along a step-wise feasible path that contains several intermediate successes. This means that each step taken must show some benefits. Is there a risk in tying the AHS to intermediate steps that may not be popular with the public? Need to keep this in mind.

• Requirements for AHS operation in adverse weather must be reasonable

• Large capacity benefits will probably not be realized until AHS is very successful and the public has trust in it; intermediate goals need to established with this in mind.

• Automation has a tendency to evolve to a "lowest-common-denominator" operational mode that degrades system performances; until the system expands to the point where there are multiple AHS lanes and lane changing is possible, this will be the case. The problem is that initially, AHS performance may be lower than what some humans would choose/decide to do.

Safety

• Safety is a "minimum operational standard" (a floor, a necessary condition, etc.)

• Mega-disasters cannot be allowed since this will cause perceived safety to be less than actual safety

- Attempts to drastically reduce the likelihood of serious accidents may actually raise the number of less severe accidents, thus lowering overall system safety.
- Be careful to readily accept a system in which there are low-velocity collisions; these will worsen the public's perception of AHS safety.
- MOEs are multi-dimensional

Human-in-the-Loop

- There will need to be some involvement by the human in AHS, including option selection, display of what is going on, etc. This may evolve with increasingly more functions being assumed by the system.

Overall Summary

- There are no obvious show stoppers that can't be circumvented. Lots of optimism, but there are areas where (1) there is much work needed; and (2) we must be careful.

C.2 VEHICLE-ORIENTED ISSUES OVERVIEW

This section focuses on issues related to all aspects of operating a vehicle on AHS. These issues include vehicle functionality, reliability, maintainability, and vehicle evolution.

C.2.1 Vehicle-Oriented Activities

Automated Check-In

The automated check-in activity area focuses on identifying the issues related to certifying that a vehicle and its driver are functioning properly for AHS operation. The check-in function is performed prior to entry on the AHS and should be conducted in such a manner as to provide a smooth flow onto the AHS system. Effective pre-check of the vehicle and driver is necessary for safe and reliable AHS operation. The check-in function could incorporate periodic (remote) inspections, verification when entering the AHS, and continuous checks of the vehicle (and possibly its driver) as it moves on the AHS lane.

Five of the contractors are addressing automated check-in. Their focus areas and some of their unique features are as follows:

- Calspan - Assessing on "on-the-fly" check-in, that is, performing the check-in function without requiring the vehicle to stop or significantly slow down.
- Delco - Focusing on implications of having to stop the vehicle during check-in. Also, looking at remote check-in and check-in of special service vehicles (e.g., fire, police, ambulance).
- Honeywell - Focusing on an integrated "health management" system for the roadside, vehicle, and the driver. This combines the activity areas of automated check-in, automated check-out, and malfunction management.

- Northrop - Incorporating knowledge and experience from flight-test instrumentation approaches.

- Raytheon (University of Southern California [USC]) - Examining evolutionary aspects of the role of the driver and the levels of automation. Coordinating the automated check-in activity closely with the automated check-out activity.

Automated Check-Out

The automated check-out activity area focuses on identifying the issues related to transitioning control to the human driver and certifying that the vehicle equipment is functioning properly for manual operation. This function takes place while the vehicle and driver are operating on the AHS. The primary focus area for this task is on the issues associated with checking that the driver is ready to assume manual control of the vehicle. The issues associated with the transition of the vehicle from automated to manual control appear less problematic given that the vehicle was operating properly on the AHS.

Four of the contractors are addressing automated check-out. Their focus areas and some of their unique features are as follows:

- Calspan - Building on the Honeywell Human Factors Study. This includes the applicability of cognitive and physiological measurement technology to driver readiness testing.

- Delco - Focusing on an overall systems approach.

- Honeywell - Focusing on an integrated "health management" system for the roadside, vehicle, and the driver. This combines the activity areas of automated check-in, automated check-out, and malfunction management.

- Raytheon (USC) - Focusing on evolutionary aspects with respect to the role of the driver and the levels of automation. Coordinating the automated check-out activity closely with the automated check-in activity.

Lateral and Longitudinal Control Analysis

This activity area focuses on identifying the issues related to automated vehicle control. Analyses of issues related to various control options are being performed.

Six of the contractors are addressing lateral and longitudinal control analysis. Their focus areas and some of their unique features are as follows:

- Calspan - Analyzing control with different vehicle spacing requirements. Incorporating vehicle dynamics modeling in their analyses.

- Delco - Addressing asynchronous vehicle behavior. Addressing the differences in characteristics and benefits of automated versus manual control.

- Martin Marietta - Incorporating experience from DOD autonomous land-vehicle programs. Producing sensor and maneuver taxonomies.

- Raytheon (USC) - Focusing on system control and its evolution from human to AHS lateral and longitudinal control.

- Rockwell - Conducting a high-level systems operational control study. Investigating the tradeoffs of safety versus capacity and traffic-stream stability given different control options.

- SRI - Taking a unique look at GPS carrier phase technology for AHS control applications.

Vehicle Operational Analysis

The vehicle operational analysis activity area focuses on identifying the issues related to the operation of an AHS vehicle. This includes issues such as functionality, reliability, and trends in future vehicles. Issues related to the retrofitting of future vehicles for AHS operation are also being studied.

Four of the contractors are addressing vehicle operational analysis. Their focus areas and some of their unique features are as follows:

- Calspan (Farradyne) - Focusing on the current status of vehicle components and AHS requirements for vehicle-based components. Special attention is being given to vehicle interfaces.

- Delco - Focusing on the automobile industry experience in developing, marketing, and fielding of vehicle features.

- Raytheon (USC) - Focusing on the evolutionary deployment of vehicle systems and their corresponding reliability, maintainability, and safety.

- Rockwell - Conducting an overall functional breakdown of an AHS vehicle. Focusing on self diagnosis and interaction with malfunction management strategies.

C.2.2 Vehicle-Oriented Issues Briefings

The following briefings were presented during the Vehicle-Oriented Issues session:

- Vehicle Functional Requirements Decomposition, Rockwell.
- Analysis of Automated Vehicle Control Evolution, Raytheon/USC.
- Vehicle Check-In Information Acquisition Approaches, Northrop.
- Analysis of Platooning Characteristics, Rockwell.
- Sensor Requirements and Trade Study Results, Martin Marietta.
- Vehicle Design Trends Impacting AHS, Delco.

C.2.3 Vehicle-Oriented Issues Breakout Group Summary

After the Vehicle-Oriented Issues plenary session, each attendee participated in 1 of 10 breakout groups where issues were assigned for discussion. In addition, the groups could choose to also address other issues that they felt were relevant. The notes from the breakout groups that followed the Vehicle-Oriented Issues plenary session are given in appendix C.

Below, the comments and discussions relevant to the vehicle-oriented topics are summarized. These thoughts and exchanges of ideas are being made available to the PSA researchers for their consideration as they complete their study efforts. These materials will also be provided to the national AHS consortium for consideration as they begin their AHS concept selection activities.

Vehicle Evolution

The general thought was that an evolutionary path to AHS (i.e., full vehicle control) is a desirable approach. It was felt that the vehicle evolutionary paths presented at this IRW will not happen without government participation. AHS could occur by natural evolution, but this would take a much longer time without a focused AHS program. Some of the Advanced Vehicle Control Systems (AVCS) technologies will be driven by market forces and will evolve independently of AHS. Vehicle control evolution must work in parallel with the evolution of the roadway system.

Mixed-Mode Traffic

Mixed-mode traffic involves partially automated and manual vehicles operating together on the same roadway. Mixed-mode traffic was seen by the participants as a possible evolutionary step to AHS. However, mixed-mode traffic was seen as adding complexity (and cost) to the vehicle system, while at the same time reducing gains in safety and efficiency because of the continued presence of human control in the system. A concern that was raised was whether accidents and perceived safety degradation would be blamed on the introduction of the automated vehicles. There could be other major concerns with mixed-mode traffic if commercial vehicles are the first to incorporate automated vehicle features.

A possible mixed-mode scenario was that of automated vehicles operating together with manual vehicles on HOV lanes. Road pricing could be used for the automated vehicles operating on the HOV lanes.

A question is whether the world market will be mixed-mode-oriented. If so, the partially automated vehicle systems that are suitable for mixed-mode traffic, may have a broader worldwide market.

Research is needed to determine what level of market penetration for partially automated services is required to justify a dedicated lane.

Driver Role

The issue of the role of the driver during AHS operation was discussed in the breakout session. Some felt that if the driver is to have any role, it should be meaningful. Does the driver need to be given a role in order to stay alert to retake control? The issue of the driver in the loop was thought to be a potential influence on cost for AHS. Some felt that the driver would not be taken totally out of the loop, but would be a part of the system for a long time. The inclusion of the driver in the control loop would add randomness to the AHS system and degrade its safety and performance.

Vehicle Design

The issue of smart versus dumb vehicles was discussed in the breakout. This issue was determined to be a major costing factor (e.g., who pays; impact on maintenance and installation; driver versus government responsibilities). The smart/dumb vehicle discussions also raised the issue of reliability impacts. Reliability of equipment, especially communications equipment, could be increased in a centralized (dumb vehicle) system. On the other hand, concern was raised that the continued addition of sensors to the vehicle would make the vehicle less reliable. It was recognized that AHS will likely be a combination of vehicle and infrastructure "smarts" and this allocation should be determined through good systems engineering efforts. The issues of good systems engineering and "needs driving the requirements" were reinforced when the vehicle functional decomposition was discussed.

With respect to comparable systems in the automotive industry, the participants brought up many good points. They felt that the first system will be a baseline that will evolve over time. As proven by the airbag system, the perception that safety cannot be sold is changing. It was discussed that drivers and the government already share full economic cost of driving. Public education was highlighted as an essential ingredient to acceptance of the AHS concept.
The participants were asked to discuss design trends (other than the ones briefed) that could positively or negatively influence AHS. Standardized interfaces were discussed as a trend that is essential for AHS. It was pointed out that since IVHS functions are more imminent, many functions will already be standardized. Some of the trend towards more vehicle electronics (other than Anti-lock Braking Systems [ABS] electronics, airbag collision detectors, etc.) was viewed as convenience-oriented as opposed to vital. The trend for smarter vehicles was seen as lacking a corresponding trend in the increased education of the driver.

With respect to vehicle-related costs, the participants indicated that the requirements (accuracy, range, etc.) would influence the costs. Safety and redundancy requirements were seen as having a big influence on cost. It was mentioned that the first production costs would be high and that as volume increased, the costs would come down.
An area for further research was to determine consumer willingness to pay for AHS features as a percentage of the total vehicle cost.

Vehicle Reliability

The breakout groups were asked to discuss the tradeoff between a highly reliable system and the impacts of a less reliable system with respect to non-safety-critical system performance. These non-safety-critical system performance measures were thought to include throughput, travel time predictability, and communication links. It was noted that non-safety-critical performance reliability will most likely vary, depending on the regional/local application of AHS. For example, efficiency may be more important in one geographical deployment than another. Reliability of vehicle systems must be high enough so as not to annoy the users. People will pay for reliability; reliability is market-driven.

Roadway-Powered Electric Vehicles

Several issues were raised when discussing the impacts of RPEVs for AHS. Implementation of RPEVs could also be used for vehicle control, and thus simplify the vehicle-control hardware. There may need to be some way of monitoring electric power usage (pricing). RPEVs could lead to more electromagnetic interference (EMI) problems. A thought was that RPEVs could be more appropriate for transit vehicles that travel along a fixed route.

Automated Check-In

The participants discussed issues related to the automated check-in process. Some felt that it was necessary to put as much responsibility as possible on the vehicle owner/driver. This would require a certain amount of preventative maintenance requirements. BIT should be used as much as possible and the system should be most thorough for safety-critical-systems (e.g., brakes, sensors, steering). The question of whether a driver would need special training or certification was raised, and if so, how different would this be from today's certification.

Some of the automated check-in cost influences included checking of mechanical subsystem status (e.g., brakes). Electronic subsystems can be monitored fairly inexpensively with vehicle diagnostics. In general, the cost depends on the thoroughness of the tests. Costs of off-line maintenance and testing could be influenced by the level of education required for the maintenance personnel.

Technologies

The topic of maturity of technology was discussed in the breakout groups. The participants felt that the maturity of sensor technology is a function of the application for which it is being used. For example, radar is a mature technology for ACC, but not necessarily for full longitudinal control. It was felt that mature technologies for lateral control have not yet been selected.

Some of the areas where the participants felt that more technology and/or engineering development and research was needed include:

- Obstacle detection (vision system not yet mature).
- ACC.
- Lateral/longitudinal control.
- Communications (vehicle-to-vehicle and vehicle-to-infrastructure).
- True ground-speed indicator (for accurate measurement).
- Standardization of vehicles to add sophisticated electronics for AHS.
- Sensors need more work to reach the levels needed.
- Software control algorithms—for exception control (some disagreed).
- Computer power and bandwidth for in-vehicle systems.
- Technology for lane changes (needed for road-follower technology solutions, i.e., magnetic nails).
- Predictive diagnostic systems.
- Electronic steering.
- Localized road-surface detection (ice, environment, etc.).

Vehicle Operation

The participants discussed issues associated with establishing a safe gap between vehicles operating on the AHS. Their discussions indicated that safe gap is a major area for further research. Other areas that need further definition/research include: reliability of vehicles (malfunctions that will cause accidents); acceptable change in velocity (delta V) or impact; vehicle performance variability (acceleration, braking); road condition (for dynamic/adaptive gap size); human factors; and public acceptance.

One of the major public acceptance questions is determining willingness for a large number of very small delta-V collisions versus a very small number of higher delta-V collisions. The participants also recommended research into events that cause a lead vehicle to decelerate significantly greater than the trailing vehicle. What are the probabilities of these occurrences?

The need for platooning was discussed by the participants. The question was raised whether AHS needs the kind of capacity that can potentially be provided by platoons. The overall design goal should be based on moving people, not vehicles. Another concern was related to incident management for small delta-V platoon collisions. Will incident management be slow due to the multiple vehicles involved in the collision? It was felt that platoons must be made as safe as trains (e.g., linkage of functions such as braking).

Operation under adverse weather and road conditions was discussed by the participants. It was agreed that operating conditions should be adjusted for weather conditions; this includes gap spacing, operating speed, and sensor management. The AHS should be designed so that weather conditions will not be show stoppers. It was suggested that the interaction of reduced lane width and weather conditions be considered in the design of AHS.

C.2.4 Reporter Summary

This summarizes the materials presented by the vehicle-oriented Working Group at the final Plenary session of the Workshop.

Vehicle Evolution

- Mixed-mode traffic evolutionary stage likely, full automation is goal.

Vehicle-Control Evolution

- Market-driven by safety needs.
- Need government participation.
- Vehicle/roadway evolve together.
- Consistent with current design trends.

Mixed-Mode Traffic Implications

- May cause real or perceived safety degradation.
- Fosters evolutionary development.
- Limits AHS performance gains.
- Complex, costly vehicle manufacturing.
- Research: Breakout to dedicated lane.

Impact of Shared Driver/Vehicle Role

- If driver has a role, it must be meaningful.
- Driver's role may keep driver alert.
- May add randomness to system.
- Driver may initially be part of the system.

Non-Safety-Critical Reliability Tradeoff

- Cannot afford to annoy the user.
- Tradeoffs are market-driven.
- Non-critical performance needs clarification.
- Regional variation.

Smart/Dumb Vehicle Design Tradeoff

- Smart vehicle simplifies implementation.
- Vehicles already becoming smart.
- Smart trends support AHS.
- Drive-by-wire will evolve.
- Smart-car trend requires driver education.
- Research: Cost benefit to government, consumer, and auto manufacturer.

Vehicle Design Comparable Systems

- The first system will be baseline.
- Safety can be sold.
- Government, driver share driving cost.
- AHS acceptance depends upon public education.
- Development of control will take time.
- Perceived success of initial AHS will have major impact on AHS acceptance.

AVCS Evolution

- AHS requires long-term planning.
- AVCS driven by market forces.
- Jerry Ward's evolutionary strategy.
- Private venture may create AHS.

Time frame

- Affected by automated lane acquisition.
- Advanced-feature time frame shorter than AHS.
- Government funding driven by AHS advancement.
- Retrofit driven by standardized interface.

Vehicle Designs

- Design varies with cost.
- Inadequate redundancy for AHS.
- Trend toward more electronics.
- More sensors.

Contradiction

- Overly complex.
- Reliability from simplicity.

Technology Development Programs

- Lane-change technology.
- Advanced communications.
- Lateral/longitudinal control.
- Electronic steering.
- Road-surface detection.

- Lateral sensor.

Vehicle Functional Decomposition

- Add check-out.
- Change pause?
- Add operations and maintenance.
- Some functions specific, some broad.
- Change incident management.
- Needs should drive requirements.
- Placement of communication operation unclear.

Roadway-Powered EVs

- Monitor electric power usage (pricing).
- Modular pavement design.
- Transit vehicles first.
- More electromagnetic interference.
- Potential for improved control.
- Continuous power supply required.
- Simpler instrumentation.

Check-In Requirements (* indicates mentioned more than once)

- *Responsibility on vehicle owner/driver.
- BIT for safety-critical systems.
- Periodicity impacts test quality.
- *Equal emphasis on vehicle and roadside.
- Combination of maneuver and on-board diagnostics to:
  - Check vehicle performance characteristics.
  - Driver characteristics.
  - Fuel, tire pressure.
  - Sensors.
- *Institutional responsibility for results.
- *Possible need for training.
- *Queues lead to negative trip quality.
- Diagnostics should "learn."
- Check-in is system configuration dependent.
- *Standardization between systems.

Check-In Cost Drivers (* indicates mentioned more than once)

- Mechanical system test, on-/off-board.
- BIT designed now for electronics.
- Coverage.
- *Location - off-line, during check-in.
- *On-board/off-board.
- *Improved sensor technology.

Check-In System Issues (* indicates mentioned more than once)

- Many sensors versus driver involvement.
- *Human in loop with panic button.
- On-board versus remote via communication.
- *No sensors for:
  - Obstacle detection.
  - Driver monitor.

Mature Technology—Sensors (* indicates mentioned more than once)

- Application-dependent:
  - Sensor performance - RADAR, etc.
  - Algorithm development.
- Video, scanning systems.
- Certification tags.
- *No sensors for:
  - Obstacle detection.
  - Driver monitor.
- Research:
  - Traction sensing, many cost tradeoffs.
  - Platooning, more human factors.
  - Obstacle detection.

Gap Distances (* indicates mentioned more than once)

- Trade - driver acceptance:
  - Large number of low delta-V collisions.
  - Small number of high delta-V collisions.
- Varies - urban versus rural.
- *Platooning the right answer?
- *Depends on system reliability.
- Depends on vehicle performance.
- Adaptive to road conditions.
- Platoon group dynamics.

Weather Impact (* indicates mentioned more than once)

- Manage gap and speed.
- *Sensor limitations.
- Slow to driver-capable operation.
- Lane-width requirements.
- Roadside versus in-vehicle.

Evolution of Platoon/Close Headway (* indicates mentioned more than once)

- *Is it needed? Throughput study needed.
- Safe as trains.
- *How is low delta-V collision quantified for damage.

Subsystem Cost Drivers (* indicates mentioned more than once)

- First production high.
- *High accuracy, high reliability.
- Technology development status.
- Good dynamic performance.
- Research:
  - Manufacturing trades, retrofit.
  - Drive-by-wire concepts.
  - *Level of public willingness to pay.
  - More market surveys.

Conclusions

- Evolutionary approach important.
- Bullets on summary sheets did not do justice to discussion.
- "Leap to Auto Lane Hold":
  - Reliability and safety.
  - Cost.
  - Evolutionary problems.
  - Human interface.
- Discussions were good exchanges of ideas and concerns.
- Provided a level of education due to the mix.

C.3 ROADWAY-ORIENTED ISSUES OVERVIEW

The roadway issues investigation focuses on issues that relate AHS impacts to existing infrastructure, the different operational environments such as urban and rural, AHS configuration impacts to the environment, and AHS facility operations. The research has been divided into five PSA activity areas:

- Urban and Rural AHS Comparison.
- AHS Roadway Deployment Analysis.
- Impacts of AHS on Surrounding Non-AHS Roadways.
- AHS Entry/Exit Implementation.
- AHS Roadway Operational Analysis.

C.3.1 Urban and Rural AHS Comparison

The urban and rural activity area focuses on identifying and analyzing the technical and operational requirements of AHS in both urban and rural environments. Issues and risks relating to deployment of AHS in both environments and the transition between environments are being identified. Each of the contractors researching this activity area are using different methodologies to identify the operational environment as explained below:

- Battelle (BRW) - Utilizing Minnesota DOT roadway inventory statistics to identify roadway characteristics that are common or unique to urban, rural, and fringe area operating environments. These characteristics will then be evaluated against the analyses of the team to identify the AHS issues and risks.

- Calspan - Identifying the important parameters that characterize the operating environment by categories, such as infrastructure, traffic, safety, and power availability.
- Delco (Hughes) - Categorizing the urban/rural issues and risks that they identify as functional, operational, or environmental.
- PATH (CalPoly) - Constructing a matrix that contrasts the characteristics of each operating environment to the operating demands of that environment.

C.3.2 AHS Roadway Deployment Analysis

The focus of the roadway deployment activity is to identify issues and risks related to deployment of AHS in both urban and rural environments, from the perspective of impacts on roadway infrastructure and the surrounding environment. Below is an explanation of each contractor's unique methodology being used to identify these issues and risks:

- Battelle (BRW) - Incorporating comments and input for various State DOT's on their initial set of issues and risks.
- Calspan (Dunn Engineering) - Analyzing the trade-offs between alternative roadway cross-sections for each AHS concept.
- Delco (DMJM) - Incorporating the needs of a range of vehicle types in their AHS configurations to determine the impacts of providing for vehicles such as trucks.
- PATH - Utilizing the California DOT's (Caltrans) video log to identify roadway characteristics; assess the impact of these characteristics on AHS; and derive the frequencies of occurrence for these characteristics and their implications for AHS. Using the frequency and impact information, they have located a couple of the most issue-intensive roadway segments in California in which to assume AHS deployment. These issue-intensive segments are now being used in the last part of this analysis in order to analyze the specific deployment impacts an AHS configuration would encounter on these segments.

C.3.3 Impact of AHS on Surrounding Non-AHS Roadways

An important aspect to the deployment of AHS is what impacts will an AHS facility have on the surrounding roadway system and how will these impacts affect the surrounding community. This research activity is designed to investigate, identify, and analyze the impacts that may arise due to deployment of AHS in a community. The following is a summary of each contractor's research efforts in this activity:

- Battelle (BRW) - Investigating AHS impact on roadway segments located in Minnesota using a transportation planning model. The investigation includes examination of traffic's sensitivity to changes in frequency and position of entry/exit points, and the demand on the AHS facility due to changes in market penetration.
- Calspan (Dunn Engineering) - Utilizing a planning model for AHS on the LIE. They are looking at entry/exit placement, market penetration, and the relationship of AHS facility

capacity to the capacity of the roadways from which AHS traffic enters and to which it exits.

- Delco (DMJM) - Using a corridor class model to study the roadway areas that border an AHS facility. This border area can be described as the first parallel, non-AHS roadways on each side of the AHS facility and the cross streets that connect these parallel roadways. Also, due to this corridor model's capability, they are also investigating specific lane impacts between the AHS and non-AHS lanes that reside on the same right-of-way.

C.3.4 AHS Entry/Exit Implementation

This research activity consists of a detailed investigation of the issues and risks associated with the access to and egress from an AHS facility. This research entails identifying various entry/exit strategies, identifying the MOE's that can be used to evaluate and optimize the various strategies, and analyzing each strategy's deployment impacts. Below is an explanation of each contractor's area of interest regarding entry/exit:

- Battelle - Analyzing the impacts that each of their entry/exit configurations may have on roadways of the urban, suburban, and rural operating environments.

- Calspan - Identifying the service rate of various configurations and how to service the entrance of packs of vehicles.

- Delco (DMJM) - Also analyzing service rate, however, they are converting the service rate into a level of driver comfort. They are also investigating possible queuing impacts by each configuration to indicate the amount of entry and exit plaza storage that may be necessary.

- PATH - Investigating the characteristics and operations of an AHS transition lane or area for the PATH platoon concept using computer simulation. They are identifying the issues and risks of transition area/lane operations, and the interaction between automated and non-automated vehicles.

- Raytheon (Ga. Tech) - With input from the urban and rural analysis task, Raytheon is developing specific entry/exit strategies customized to the specific operating environments, both urban and rural.

C.3.5 AHS Roadway Operational Analysis

The roadway operational analysis entails the identification and analysis of issues and risks that may be involved in undertaking the responsibility of operating and maintaining an AHS facility. The analyses address organizational structure, operational functions, and maintenance activities. The analysis areas covered by the contractors include a wide range of AHS operational aspects. Each contractor's specific area of emphasis is described below:

- Battelle - Identifying the possible daily tasks and functions an AHS facility will have to perform or support. Examples of these daily tasks could include traffic monitoring and sensor maintenance.

- Calspan - Analyzing and evaluating possible organizational structures for an AHS facility based on the administrative and operational tasks that it may be required to perform or support.

- Delco (DMJM) - Identifying the issues and risks that may arise in the evolutionary process of converting already-established Freeway Management Systems to an AHS facility.

- UC Davis - Investigating the unique possibility of automating some of the AHS construction and maintenance activities.

C.3.6 Roadway-Oriented Issues Briefings

The following briefings were presented during the Roadway-Oriented Issues session:

- Influence of Urban/Rural Characteristics on AHS, Battelle/BRW.
- Potential AHS Roadway Characteristics and Configurations, Battelle/BRW.
- Alternate Approaches for AHS Entry/Exit, Raytheon/Ga. Tech.
- Effect of AHS on Surrounding Non-AHS Roadways, Delco/DMJM.
- Issues of AHS Roadway Operations, Calspan/Parsons Brinkerhoff.
- Comparable Systems: HOV Lanes, Ramp Metering, Calspan.

C.3.7 Roadway-Oriented Issues Breakout Group Summary

After the Roadway-Oriented Issues plenary session, each attendee participated in 1 of 10 breakout groups where issues were assigned for discussion. In addition, the groups could choose to also address other issues that they felt were relevant. The notes from the breakout groups that followed the Roadway-Oriented Issues plenary session are given in appendix D.
Below, the comments and discussions relevant to the roadway-oriented topics are summarized. These thoughts and exchanges of ideas are being made available to the PSA researchers for their consideration as they complete their study efforts. These materials will also be provided to the national AHS consortium for consideration as they begin their AHS concept selection activities.

Urban and Rural AHS Analysis

A summary of breakout discussion comments pertaining to operational environment influencing AHS design and operation related the influence to some general urban and rural characteristics. For the urban operational area, the participants considered entry/exit spacing, capacity impacts, and right-of-way (ROW) availability as being the major factors affecting AHS urban design and operations. The participants also identified safety, higher speed, lane conversion, commercial vehicle operations, and maintenance as the factors that would affect AHS in a rural operating environment.

Roadway Deployment

The participants in the breakout sessions concerning roadway deployment stressed the need for the development of a strategic plan for AHS deployment. To develop this strategic plan, they cited the need to involve the State agencies very early in the development stage. The content of the strategic plan should consider issues related to market growth and what comes first, the vehicle capability or the infrastructure. The plan should also identify the possible benefits envisioned from each stage of the development. Besides the strategic plan, the participants also considered lane conversion and the combination of HOV and AHS-equipped Single-Occupancy Vehicles (SOVs) on the same lanes.

More work is needed to identify the operational issues and how these issues may impact the drivers' potential uses, which will vary from region to region and from State to State.

Participants discussed various deployment strategies. Issues surfaced concerning a transition strategy that involves operating partially automated vehicles with manual traffic. With mixed or segregated traffic, what would happen at the merge points? What impacts are there to traffic flow when automated and non-automated vehicles interact? Would driver training be needed? Could the confusion and cost of a mixed system cause increased consideration of an "exclusively trucks" system first?

Narrow lanes were another topic of discussion. Most participants identified both good and bad issues concerning the use of narrow-lane AHS configurations. The narrow lane has potential in those limited ROW situations. However, how would narrow lanes fit into an evolutionary deployment sequence? Would the public accept these narrow lanes? How would trucks be handled? How would narrow lanes affect activities such as snow removal?

In any deployment situation, all participants agreed that rapid response to incidents is essential. To implement this ability to respond rapidly to an incident, the following were essential: automatic incident detection, special emergency equipment and staging locations, and vehicle mayday capability.

Impact of AHS on Surrounding Non-AHS Roadways

The major concern of participants was the problem of the non-AHS roadway being inundated by the volume of traffic exiting the AHS facility. Many of the participants expressed concerns about the ability of States or local jurisdictions to update or expand the capacity of their local streets to accommodate an AHS facility. For this reason, AHS must be part of an integrated, balanced transportation plan.

Participants discussed what they believed would be some characteristics of AHS traffic. Some thought that AHS would be characterized by long-distance commuting. This long-distance commuting might contribute to more urban sprawl. Channel growth along corridors may develop due to AHS. AHS may compete with other modes. The participants stated that not having AHS will not reduce the demand for new capacity, however, AHS and the additional capacity it could supply must be incorporated into the regional transportation and land-use policies so that its impact is to reduce congestion, not induce new traffic growth.

AHS Entry/Exit Implementation

The discussion participants identified a few additional MOEs which could be developed to evaluate entry/exit strategies. A good indication of an entry/exit strategy would be to measure the impacts of automated lanes on the manual lanes (e.g., reduced congestion, higher average speed). A measure should also be developed to contrast user delay against system safety and efficiency. The last measure, which would be used to rate strategies that compared well under the first two measures, is to measure efficiency as related to cost of the configuration infrastructure that would be needed to implement the entry/exit strategy.

The participants also discussed aspects of some of the entry/exit strategies presented. They considered the issues and risks related to a mixed-flow or dedicated-transition lane. Is a mixed-flow lane viable with the interaction of automated and non-automated vehicles? The major parameter in the development of the entry/exit configuration is how check-in will be performed and how long it will take. To mitigate the effect of the check-in procedure on entry/exit strategy and configuration, participants suggested that parts of the check-in be done at locations on local streets or maybe after the vehicle has entered the facility. Other factors that must be considered in entry/exit strategies are the need for high-capacity ramps or the use of multiple channels to and from the feeder streets.

The discussion of transition lanes raised many concerns about how to design them to maximize safety and minimize land use. A few suggested that there may not be a need for transition lanes—that accepted AHS vehicles could be pulled directly from the manual lane into the AHS lane. However, returning exiting vehicles directly to manual traffic lanes could be a problem—a buffer lane might be needed in those cases.

Participants wondered how rejected or unauthorized vehicles should be handled, and noted that an AHS must be designed to assume that a certain number of manual vehicles will breach the system, even if there are physical barriers. Most felt that TM strategies on the AHS lanes could isolate the manual vehicle so that safety is not threatened, only the efficiency of the system is reduced. Some suggested that to increase public acceptance there would need to be some sort of appeal process if a driver feels the vehicle has mistakenly been rejected.

Roadway Operational Analysis

A primary portion of the breakout session discussion concerning roadways focused on the advantages and disadvantages of privately operated AHS facilities. The participants cited the following major advantages of a privately operated AHS:

- Access to capital.
- Organizational focus.
- Competitive salaries to attract competent staff.
- Avoids equity concerns regarding the use of public funds.

However, the participants also cited these disadvantages:

- Difficulty in obtaining ROW acquisition.
- The high startup cost.
- Liability concerns.
- Profitability concerns.
- Possibility, due to cost, of limiting access to a small portion of the population.

With these advantages and disadvantages, most thought that an AHS facility would need the cooperation of both a private entity and a public entity; however, the relationship between these private and public entities may differ across the country.

C.3.8 Reporter Summary

This summarizes the materials presented by the roadway-oriented Working Group at the final Plenary session of the Workshop.

Urban/Rural Influence on AHS Design and Operations

Urban

- Entry/exit spacing.

- Capacity impacts (time of day).
- Constrained right-of-way availability.

Rural
- Safety priority.
- Higher speeds.
- Potential for lane conversion.
- Commercial vehicle operations.
- Distances for maintenance/emergency services.

Rural AHS Users

- Heavy trucks.
- Long-distance commuters.
- Tourists/recreational.
- Emergency vehicles.

Benefits:
- Safety.
- Convenience.
- Speed.
- User comfort.
- Productivity.

Transportation Agency AHS Issues

Attractive Aspects:
- Increased safety.
- Increased capacity.
- Cost-effectiveness as a capacity enhancement.
- Potential source of revenue (tolls).
- Improved mobility for older drivers.

Unattractive Aspects:
- Maintenance complexity.
  - Computers.
  - Software.
  - Access.
  - Incident severity.
- New skills.

AHS and HOV

Complementary
- Learn from HOV experiences.
- Institutional challenges.
- Restricted access.
- Potential to migrate from HOV to AHS.

AHS and Induced Traffic

- Long-distance commuting encouraged—potential for urban sprawl.
- Potential for channel growth in corridors.
- Potential competition for other modes.
- Need to couple AHS deployment with regional transportation and land-use policies.
- "... not having AHS will not reduce demand for capacity."

AHS Sites

Promising Sites

- Long-distance corridors.
- Good metering locations.
- High demand, long trip distances (I-94 Minnesota, I-95).
- Vacation travel corridors (I-15 [Los Angeles to Las Vegas], I-75 [Michigan to Florida]).
- Monotonous rural highways (I-70 through Kansas).
- Commercial truck corridors (I-80 Chicago, I-81 Virginia).
- Others: US-101 Los Angeles, I-35 Dallas-San Antonio, I-10 Los Angeles -East.

Bad Sites

- Difficult access points.
- Snow and ice areas??

AHS Entry/Exit

MOE's

- Impacts on manual versus automated lanes.
- User delay versus system safety and efficiency.
- Efficiency versus infrastructure cost.

Strategies/Configurations

- Transition lane - dedicated or mixed flow.
- Check-in location:
  - Local streets.
  - After entry (first "x" number of miles).
- Multiple channels to and from urban street grid.
- Exclusive ramps for high capacity.
- Rejected vehicle storage.
- Appeal process for potential conflicts.
- Unauthorized vehicle access
  - Self-policing?
  - Fines for violators?
  - Accommodate violators?

AHS Operating Strategies

- Different for urban and rural.
- Heavy vehicles:
  - Incompatible with light vehicles.
  - Limited grade ability.
  - Don't mix heavy and light.
  - No trucks in platoons.
  - Time-of-day restrictions on trucks in urban areas.
  - Separate lanes complicate entry/exit.
- Expel vehicles that degrade AHS performance.

Deployment Issues

- State agencies must be brought on board.
- Rate depends on market growth.
- Consider conversion of existing lanes?
- Work is needed on operational issues for diverse applications.
- Need strategic plan for deployment.
- "Chicken-and-egg" problem.
- Need to show benefits at each stage.
- Consider incentives such as HOV lane access for AHS-equipped SOV's?

AHS Narrow Lanes

- Potential for efficient use of limited right-of-way.
- How to fit in evolutionary deployment sequence?
- Would depend on exclusive AHS lanes.
- Human factors concerns (proximity).
- Public perception/acceptance?
- How to accommodate heavy trucks?
- Snow removal?

Deployment Practicality

- Concerns about passing, merging—mixed traffic, heavy trucks.
- Exclusive truck system first?
- Concerns about merging through openings in barriers.
- Driver training needs?
- Interactions between automated and manual traffic flows?
- Need minimum standards for vehicle performance.

Special Transit AHS Access Points

- Desirable, but difficult to implement:
  - Vehicle performance limitations.
  - Concern about spacing between access points.
- Helps:
  - Schedule reliability.
  - Bus priority.

Incident Management

- Rapid response essential.
- Automatic incident detection and management.
- Special emergency vehicle locations.
- Vehicles call for help (mayday/probes).
- Needs more sophisticated strategies and service providers than today.
- Special equipment for emergency access?

Flexibility Needs

- Geographic/environmental constraints (weather, curves, grades).
- Local financing/jurisdictional/policy issues.
- Following distances for heavy vehicles.

Standards Needs

- Lane width.
- Training requirements.
- Entry/exit protocols.
- Safety, compatibility...

Privately Operated AHS Facilities

Advantages

- Access to capital.
- Organizational focus.
- Staffing and salaries.
- Avoids equity concerns about use of public funds.

Disadvantages

- Right-of-way acquisition.
- High startup investment.
- Need public shield from liability.
- Liability detracts from profitability.
- Possible limited access for lower income travelers.

Throughput Issues

- Measure people/hour, not vehicles/hour.
- Measure percent gain over existing operations.
- What throughput level is needed for each application?
- Must consider effects on throughput of:
  - Accidents.
  - Weaving.
- Consider effects on entire system, not just trunk-line throughput.

C.4 INSTITUTIONAL AND SOCIETAL OVERVIEW

This session focused on the institutional and societal issues that could potentially affect an AHS deployment. They can also impact design characteristics of an AHS system. This area encompasses a broad range of non-technical issues that affect all aspects of AHS development and operation. The major categories of issues include:

- Legal/Regulatory.
  - Tort/Product Liability.
  - Anti-Trust.
  - Intellectual Property.
  - Privacy.
- Environmental.
- User/Public Acceptance.
- Organizational.
- Jurisdictional.
- Societal Impacts.
- Financial Architecture.

C.4.1 Contractors and Areas of Research

There were five PSA contractors working on this area. The research intentionally overlapped to help ensure that critical issues were not overlooked. However, each team had a slightly different approach and there were some teams that narrowed their research to a few areas in order to obtain more depth for the issues in those categories. The research focuses were:

- Battelle - Identifying critical societal and environmental issues, including focus groups for public perception and user acceptance, applying a methodology for prioritizing critical issues.

- BDM (George Mason University) - Using focus groups to assess public acceptance; also addressing commercial operator regulations.

- Calspan (Parsons Brinkerhoff) - Identifying a broad spectrum of issues and their impacts on the other Calspan analyses.

- Delco (PATH) - Conducting in-depth research on environmental issues, privacy, and the potential impacts on existing transportation facilities and agencies.

- SAIC - Addressing product and tort liability, applicability of existing regulatory and financial models, and impacts of current environmental legislation.

C.4.2 Institutional and Societal-Oriented Briefings

Five briefings were presented during the Institutional/Societal Issues session:

- Types of Institutional/Societal Issues, Calspan/Parsons Brinkerhoff.
- Prioritized Issues and Report on January Focus Group, Battelle/BRW.
- Potential Implementation Frameworks and Related Legal Issues, SAIC.
- Discussion of User Acceptance, BDM/GMU.
- Discussion of Environmental Issues, Delco/PATH.

C.4.3 Breakout Group Summary

The general discussions in the breakout groups emphasized that the issues in this area are critical and could prove to be the most difficult to resolve. The discussions raised many good issues and some of the highlights are outlined below.

Legal/Regulatory Issues

The following is a subset of institutional/societal issues that were defined as part of the breakout groups; relevant comments on each is shown:

- Liability.
  - Federal protection/limitation on damages could encourage participation.
  - Establish a mediation process that could alleviate the costs of litigation.
  - Create a risk pool.
  - Involve the insurance industry in the formulation of AHS deployment configurations.

- Anti-Trust.
  - May require regulatory organization (e.g., utility company).
  - This issue is of greater importance if the private sector owns the system.
  - The model of the US CAR program could be a good model for the AHS program.

- Intellectual Property.
  - Groups felt that this is an issue, but it is not unique to AHS and it will probably be solved by the IVHS program.

- Clean Air Act.
  - AHS can manage vehicle-to-roadway gaps to allow roadway-powered EV operation.
  - More consistent speeds and reduced congestion will greatly reduce emissions.
  - AHS should increase passenger-mile traveled (PMT)-per-VMT rather than VMT.

Perceived Safety and Strategies to be Enhanced

- First impressions are extremely important, so early systems should be overly safe.
- Outreach to the public is crucial.
- Communication, starting at the check-in process, is vital for confidence building.
- False alarms should be minimized to avoid permanent disregard and nuisance.
- Mixed-vehicle traffic could potentially make people feel less safe.
- An evolutionary approach might be more publicly acceptable, but may run risks for the fully automated AHS.

Roadblocks to Public Acceptance

The public acceptance issue is probably one of the most crucial. The public needs to trust and believe in the system from the beginning or AHS will probably never be realized. Some of the roadblocks that could hinder this are uncertain costs, reliability, safety, trust, and lack of tangible benefits. There needs to be a plan that targets the early winners and a solid demonstration that AHS meets the needs.

Societal/Quality of Life

Like most new technologies that we are accustomed to, an AHS has the potential to impact the quality of life. Some possible improvements include:

- Increased driving/riding comfort and convenience.
- Efficient use of time.
- Increased mobility.
- Increased recreational travel opportunities for lower income families.
- Improved safety.
- Economic benefits (reduced insurance, job creation, etc.).

These issues are just a sampling of the extensive thought and research currently underway. Early identification of issues is essential to finding solutions before they become obstacles. The discussions also emphasized that there could be many different solutions to an issue and that lessons learned should be highly visible so that others who may be beginning to implement systems will benefit. Although not all issues will be "show stoppers," it is still imperative that they be addressed.

C.4.4 Reporter Summary

This summarizes the materials presented by the institutional and societal Working Group at the final Plenary session of the Workshop.

Legal Issues

- Liability
  - Seek Federal protection/limitation.
  - Establish mediation process.
  - Create risk pool.
  - Involve insurance industry in formulation of AHS deployment configurations.
- Antitrust
  - May require regulatory organization (e.g., utility commission).
  - More important if owned by private sector.
  - Model US CAR program.
- Intellectual Property
  - Issues exist, but not unique to AHS.

Clean Air Act

- AHS can manage gaps to allow hybrid/EV use.
- More consistent speeds on AHS may reduce emissions.
- Increase passenger-miles traveled/vehicle-miles traveled rather than vehicle-miles traveled.

Demographic Changes

- Potential for sprawl exists (depends on how development is channeled).

Perceived Safety and Strategies to Enhance

- First impressions important.
- Outreach important.

- Communication, starting at check-in process for confidence-building.
- Minimize false alarms.
- Mixed-vehicle traffic will make people feel less safe.
- Make safety features obvious.
- Identify the risks early.
- Evolutionary approach.

Revenue Sources

- Should be distributed among those who benefit.
- Could charge users higher fees for higher priority use.

Fees for Use

- How to achieve equity.
- Complicated taxing/fees could confuse the AHS issue.

Those Negatively Affected

- Low income.
- Immediate neighbors of AHS facility and those who live on feeder routes (who are non-users).

Roadblocks to Public Acceptance

- No major funding champion.
- Perceived safety risks, lack of trust.
- Cost (especially at start)/limited funding resources.
- Too many constraints, loss of freedom.
- Solutions:
  - Evolution could reduce roadblocks.
  - Show how features of AHS benefit users and non-users.
  - Early winners.
  - Demonstrate that AHS meets needs.

Benefits by Type of User

- SOVs - reliability, predictability, time savings, reduced cost, safety.
- HOVs - increased savings above SOVs.
- Transit - same as above and potential labor savings (no driver).
- Commercial/Trucking - same as above.

Benefits to Non-Users

- Job creation.
- Reduced congestion for manual lanes.
- Commercial/shopping and tourism industry growth.

Contributions to Quality of Life

- Lower stress.
- Comfort, convenience.
- Efficient use of time.
- Increased mobility for seniors.
- Increased recreational travel opportunities for lower income families (compared to air travel).

Research Needs

- Market research.
- How to make seamless transition between urban and inter-urban systems.
- How to maximize beneficiaries.
- How to ensure participation in AHS design and deployment process by both beneficiaries and those not benefited.
- Research to demonstrate positive relationships between quality of life/land use/environment and AHS.

APPENDIX D

PSA ISSUES/RISKS DATABASE DESCRIPTION

D.1 INTRODUCTION

Calspan was tasked to development a database to integrate the key issues and risks from all of the PSA research teams. The goal of this expansion was to standardize issues and key findings formats so that the NAHSC could resolve them more easily. The completed PSA database is seen as a tool for the NAHSC and other interested AHS researchers.

A standard format was developed from input received from all PSA teams, FHWA, and MITRE. After this standard format was developed, a form was distributed to all the PSA researchers so that their key findings could be recorded. The completed forms (in both hard copy and electronic format) were sent to Calspan who entered them into the database.

D.2 DATABASE FIELD DESCRIPTIONS

Below, a description is given for each of the fields used to describe any given database item.

The data contained in the issues database describes the major results identified by the PSA researchers. The database can be searched and queried on several different descriptors so that a user can find information of interest. The major elements for each item contained in the database is described below.

- Entry: PSA team and researcher that captured the item.
- Entry Date: Date the item was entered.
- Review: Person on PSA team that reviewed the item.
- Item Type: Identifies the item type. Four possible choices:

"Issues" refers to items where there are reasonable questions concerning how to proceed; issues may arise as concerns are addressed; they should be posed as questions; Issues are resolved.

"Risks" are conclusions that identify potentially negative situations that, if they should happen, could result in system failure or major problems; severity of risk can be indicated (High, Medium, Low); Risks are managed.

"Concerns" is for items that may be risks or issues, but sufficient analyses have not yet been done to know for sure; Concerns are addressed (perhaps through further analysis).

"Conclusions" are supportable results of analyses; they may be resolved issues; Conclusions reference supporting analysis.

- Action: This field is for use by the consortium to pursue action based on the item.

- Sources: This indicates the PSA team, the reference document in which the basis for the item can be found, and the name of the PSA researcher. This could include more than one document.

- Pertains To: The item in the database is identified as pertaining to at least one of the following categories:

    - Safety
    - Efficiency
    - User Acceptance
    - Environment
    - Legal
    - Societal
    - Concept Selection
    - '97 Demo
    - Design/Development
    - Test/Evaluation
    - Deployment
    - Maintenance/Operation
    - Transition
    - Human Interface
    - Program
    - Management
    - Funding
    - Cost
    - Benefits

- Short Description: Descriptive title for the item; no more than 10 words.

- Summary: A summary so that the reader can understand the essence of the item. Additional references may also be entered here. No more that 200 words.

- System Function: Identifies those functions that are related or most closely related to the item (several may be identified):

    - ALL
    - Check-In
    - Enter/Merge
    - Driver Interface
    - Longitudinal Control
    - Lateral Control
    - Maneuver Coordination
    - Check-Out
    - Exit/Merge
    - Incident Management

- Zone Flow Management
- Regional Management
- Environmental Sensing
- Maintenance/Operation
- Operational Mode

- Infrastructure and Vehicle System: Identifies those elements of AHS that the item impacts (several may be identified):

  Infrastructure System:

  - ALL
  - Entry/Exit Configuration
  - Lane Configuration
  - Roadside Sensors, Communication/Processors
  - Region Command Centers
  - Barriers
  - Surface Materials
  - Bridges/Tunnels
  - Roadway Maintenance Equipment

  Vehicle System:

  - ALL
  - Steering Actions
  - Braking Actions
  - Throttle Control
  - Power Train Control
  - Lights
  - Suspension
  - Vehicle Electronics
  - Sensors
  - Chassis
  - AHS Controller

  Communications:

  - Intra-vehicle
  - Road-road
  - Road-vehicle
  - Vehicle-vehicle

- Concept Impact: Identifies those characteristics of an AHS concept that may be affected by the item (several may be identified):

  Concept Impact:

  - ALL

  Vehicle Type:

- Light
- Heavy
- Transit
- Pallet
- Special
- Maintenance

Infrastructure Type:

- Dedicated
- Shared with Manual
- Barrier
- No Barrier

Entry/Exit Type:

- Dedicated
- Transition Lanes
  - Periodic
  - Unrestricted

Power Source:

- On-Board Internal Combustion Engine
- On-Board Alternative Propulsion System
- Roadway Powered Electric

Longitudinal Control:

- Autonomous Vehicle
- Platooned Vehicle
- Point Following

Lateral Control:

- Passive Road (e.g., magnets, paint)
- Barriers
- Active Road

Control Location:

- Mostly Vehicle
- Mostly Infrastructure
- Balanced

D.3 ACCESS TO THE PSA DATABASE

Any AHS researcher can have access to the PSA database. The database is contained on a single floppy disk in either Personal Computer (PC) or Mac format. Access to the database requires the use of the Access Database Management System, which is available for either the p.c. or the Mac. Detailed instructions on how to use the PSA implementation are also available. Both the database and the instructions are available from the FHWA, AHS Program Manager.

There are currently 599 items in the PSA issues database. The breakdown of items is as follows:

140	Issues
53	Risks
135	Concerns
253	Conclusions
18	Unknown

599	TOTAL

GLOSSARY

AASHTO	American Association of State Highway and Transportation Officials
ABS	Anti-lock Braking Systems
ACC	Adaptive Cruise Control
AHS	Automated Highway Systems
APV	Alternative Propulsion Vehicle
ATM	Automated Teller Machine
AVCS	Advanced Vehicle Control Systems
BAA	Broad Agency Announcement
BART	Bay Area Rapid Transit
BIT	Built-In-Test
CARB	California Air Resources Board
CBA	Cost/Benefit Analysis
CDS	Crashworthiness Data Systems
CO	Carbon Monoxide
EIS	Environmental Impact Statement
EMF	Electro Magnetic Field
EMI	Electromagnetic Interference
ETTM	Electronic Toll and Traffic Management
EV	Electric Vehicle
FARS	Fatal Accident Reporting System
FCC	Federal Communications Commission
FHWA	Federal Highway Administration
FTA	Federal Transit Administration
GES	General Estimate Systems
GPS	Global Positioning System
HOV	High Occupancy Vehicle
ISTEA	Intermodal Surface Transportation Efficiency Act
ITS	Intelligent Transportation Systems
IVHS	Intelligent Vehicle Highway Systems
KM/H	Kilometers Per Hour

LADAR	Laser Based Radar
LCV	Longer Combination Vehicle
LIE	Long Island Expressway
LOS	Level of Service
NAHSC	National Automated Highway Systems Consortium
NHTSA	National Highway Traffic Safety Administration
NO_2	Nitrogen Oxide
NTIS	National Technical Information Service
OD	Origin-Destination
PC	Personal Computer
PSA	Precursor Systems Analyses
ROW	Right of Way
RPEV	Roadway Powered Electric Vehicle
RSC	Representative System Configurations
RV	Roadside/Vehicle
SI	Spark Ignition
SIP	State Implementation Plans
SIR	Supplemental Inflatable Restraint
SOV	Single Occupant Vehicle
SST	Supersonic Transport
TIP	Transportation Implementation Plans
TM	Traffic Management
TOS	Traffic Operation Systems
U.S. DOT	United States Department of Transportation
U.S. DOD	United States Department of Defense
USC	University of California
VMT	Vehicle Miles Traveled
VPH	Vehicles Per Hour
VPHPL	Vehicles Per Hour Per Lane
VV	Vehicle/Vehicle
ZEV	Zero Emission Vehicle