SECTION 2

BACKGROUND

2.1 AUTOMATED HIGHWAY SYSTEMS PROGRAM OVERVIEW

The AHS program was initiated in 1992 as part of the US 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 US highway system in order to improve mobility and transportation productivity, enhance safety, maximize the use of existing transportation facilities, conserve energy resources, and reduce adverse environmental effects.

Within ITS, the AHS is a user service that applies 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 right-of-ways.

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 US DOT role is as AHS program facilitator, supporter of longer range research, and representative of the nation's transportation and societal needs.

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

To undertake and manage the Federal aspects of the AHS program, the US DOT established the AHS program office 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 US DOT strategy is to use a public/private partnership between the US DOT and a consortium of the key AHS stakeholders to select the AHS concept and approach for operational testing and eventual national deployment in the United States. The intent is to build upon AHS research to date, and to make maximum use of state-of-the-art technologies in information systems, communications and sensors developed for 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 US 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 impacted by AHS. The US 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 US 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 US 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. It consists of: (1) a human factors study, (2) multiple PSA addressing AHS requirements and issues, and (3) collision avoidance analyses to investigate avoidance-oriented vehicle warning and control services that may someday evolve into the AHS. The **Systems Definition phase** 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 US DOT will support AHS deployment.

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

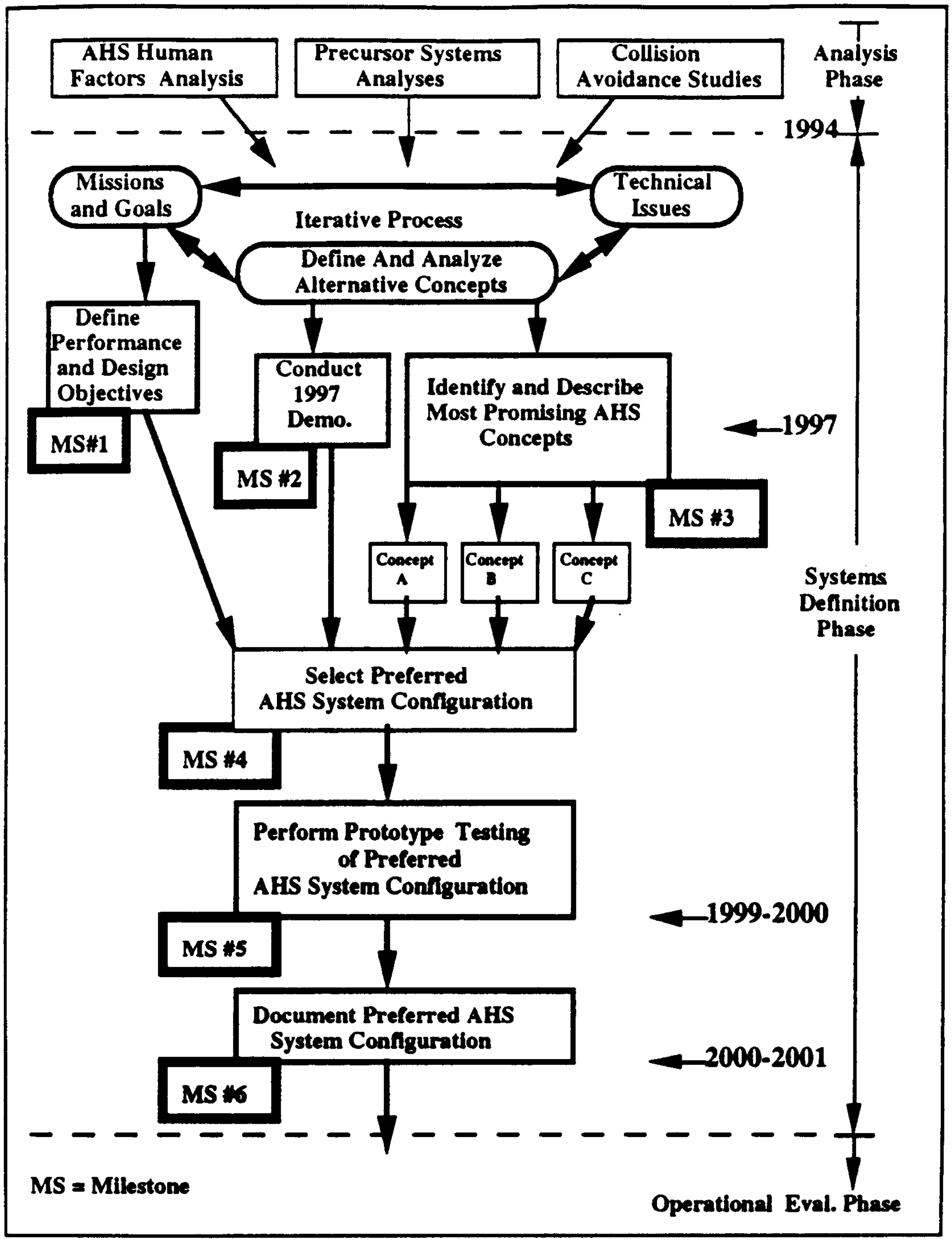

Figure 2-1. AHS Program Strategy

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 2-2. Table 2-3 provides details on the individual contractors and the activities they are addressing. Table 2-4 is a list of contractors and subcontractors for each contract team.

From table 2-3, it is evident that several of the activity areas were addressed by more than one contractor. 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 (US 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. From the above, it is clear that this group of PSA researchers spanned 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 ckout	d lat long	e malf mgmt	f com trnst	g cmpr sys	h rdwy deply	i ahs impt	j ntrce exit	k rdwy anly	l vehl anly	m alt prop	n safty issu	o inst socl	p cost bnfit	q Other
Battelle	●				●			●	●	●	●			●	●		
BDM						●									●		
Calspan	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	
Delco	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	
Honeywell		●	●		●		●										
Martin Marietta				●													
Northrop		●															
PATH	●						●		●						●		
Raytheon		●	●	●	●	●				●		●		●			●
Rockwell				●	●							●					●
SAID															●		
SRI																	●
TASC																	●
TRW												●					
UC Davis										●							

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

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 application of this 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 impact would be comparable to the impact the jet engine had on aviation 40 years ago, or the impact 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

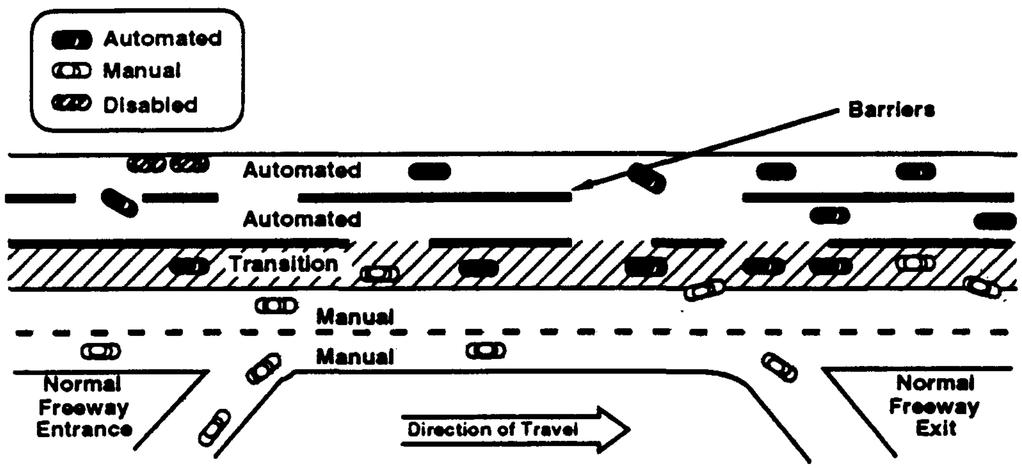

Figure 3-1. Illustration of AHS Concept of Operation (Honeywell, 1994)

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 US 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 decide 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). In off-peak periods, the system can 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 acceptability 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 US DOT goal is for the AHS to be a very safe system. It is believed that this can be accomplished by eliminating human-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 US 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 all of 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 US 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 US 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 people being killed 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 impact 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

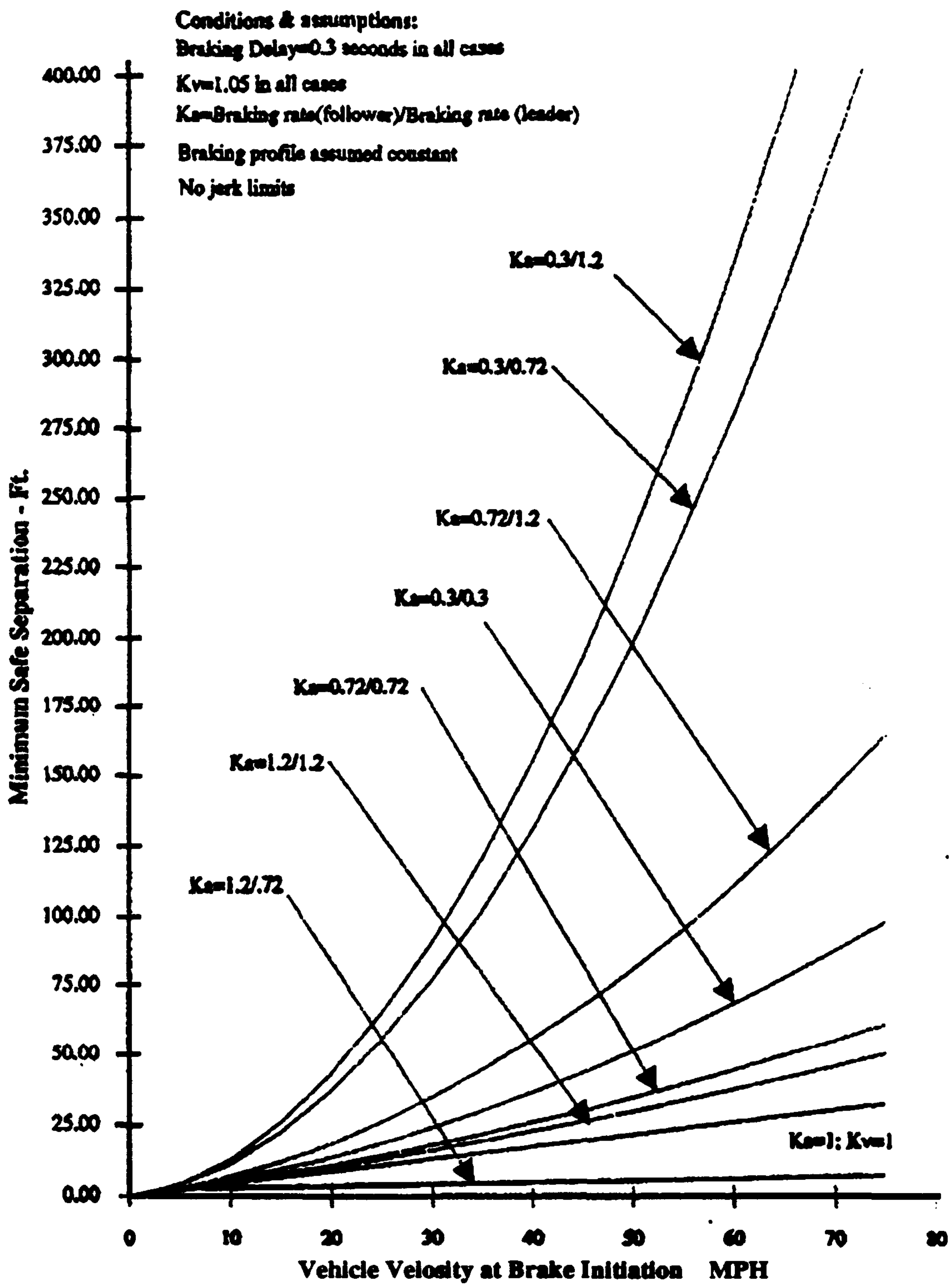

Figure 3-2. Minimum Separation Requirements Between Vehicles with Different Stopping Capabilities (Battelle)

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.

3.3.4 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 malfunctions (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 (LADAR) 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 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 seemed to imply 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 US 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 US 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 breaking the system 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. A current example may be the Denver International Airport's baggage handling system where a new technology was apparently allowed to become the critical path of the development.
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-ORIENTED FINDINGS

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

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 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 US 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 US 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 spacing 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.