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 vehicleto 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, LADAR, 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 impacts 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. Tests performed prior at AHS entry are known as the **check-in** function (see section 5.7). 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. And it may be compulsory if 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).

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).

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.

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

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
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 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 the 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

"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. 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 relative lack of robustness, placed significant demands on the roadway. As automobiles and trucks have evolved, so have the Nation's roadways, so that today, the US 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 US 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 today's roadways; for example, pre-formed concrete sections could be formed, 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, an issue discussed 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 a 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 issue 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 effects 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 cause some redesign of them.

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 infra-structure-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 administrated.

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. Traditional administrative and managerial structures of the past may not be sufficient and new and innovative arrangements may be necessary (Calspan, Delco). Furthermore if these new arrangements are necessary, then the evolution to institute these arrangements must start now.

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 could 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 backgrounds in software engineering, communications, etc. Many administrators feel that current salary constraints may limit their ability to obtain and retain quality personnel. Also, many organizations will 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 researches 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 must be reduced compared to current response times on conventional roadways (Calspan). Fast detection and response is needed due to the operational nature of an AHS facility. 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 must be able to operate, at some level, no matter what the conditions are; an AHS would be useless if it could only be operated under ideal environmental conditions. However, 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 to mitigate 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 each deployment will not 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 the infrastructure 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 sections 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 determined 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 these trip were not inclined to use the facility.

One relationship that could not be significantly evaluated was the effects of how the extra cost of an AHS equipped vehicle would effect market penetration. Many research 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 areas transportation problems.

6.3.3 Construction Prerequisites

For any project to be funded it must meet certain requirements and be eligible for funding, for most projects this is a momentous task. 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 chosen from the candidate solutions, the chosen solution proceeds through detailed design. However, this solution has to be funded; if it is to proceed as a regular project, it has to be entered into 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, the process of the construction of the project commences.

As the preceding paragraph explains, 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 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 identified issues concerning the impacts their analyses show will occur if additional measures are not implemented on the existing roadway facilities adjacent to an AHS. The volume of AHS traffic could congest surface street intersection, 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 burden the adjacent roadway system. Many believe that AHS has to account for these impacts. Many feel 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; and some feel that AHS funding should provide for all improvements. Others feel 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 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 whom 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 it 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

When an AHS takes total control of all the vehicles on its dedicated highway lanes, "the system" must also 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 a person's 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 impact traditional transportation improvement projects. These could be regulations that have already been or will be enacted for other valid 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. One of these drawbacks is the control that states currently have over licensing and registration--one that is closely held and may be difficult to relinquish to a federal entity (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/consumer can see for themselves. (Calspan). Another researcher suggests that an important element is wining 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_X). 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 that 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. Perception is sometimes actually a preference that has discovered a rational; why people feel the way they do is an infinitely complex subject. AHS can win public acceptance if it presents the clear benefits that overwhelm risk concerns, that is, if it presents the worthwhile changes that can become preferences--that become perceived as attributes.

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). This is an image represented by the media. However, experience also supports the fact that most people hold a positive attitude toward advanced technology and automated systems as long as 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. 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 insults 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) 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

The system should be available to the entire public and not be installed just for suburbanites who can afford high tolls and expensive 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 would be subject to proper 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).