APPENDIX B

HIGHLIGHTS OF CALSPAN OVERVIEW REPORT

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

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

B.1 MAJOR FINDINGS BY ACTIVITY AREA

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

B.1.1 AHS Comparable Systems Analysis Findings

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

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

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

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

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

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

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

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

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

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

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

5. Evolutionary development of AHS is recommended.

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

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

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

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

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

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

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

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

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

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

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

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

11. Potential markets for AHS should not be overlooked.

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

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

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

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

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

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

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

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

16. Public acceptance will be critical for AHS success.

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

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

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

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

    Bottlenecks can be created at popular exits if the exits cannot handle traffic demand. This could require closing an exit to avoid vehicles from backing-up onto the AHS lane(s). Approaches for mitigating this problem include proactive planning and the use of multiple parallel exits or buffer zones. Proactive planning could include placing, under system control, groups of exits in congested areas (e.g., near an activity center such as a stadium or CBD). Drivers desiring to exit could be assigned an exit by the system in a way that optimizes overall exit efficiency and flow. When there is room, an additional exit lane could be also added.

19. AHS marketability will be influenced by design and economic factors.

    AHS will be one of several options for travelers. Its design and pricing approach will affect its potential market base. Innovative approaches to AHS pricing and the sales approach used can increase the potential market achievable. For example, whether AHS systems must be purchased or leased will affect their price to consumers and impact their competitiveness within the transportation market. Also, the development of the AHS market can be facilitated by "piggybacking" on other markets (e.g., market to those using existing ETTM systems, offering commuter packages that include AHS and connecting mass transit passes).

20. There may be regions that favor AHS implementation over others.

    There may be regions in which geographic or traffic conditions favor AHS, while other areas may be less favorable. On the one hand, this will make it possible to select locations for AHS demonstration where AHS can provide significant benefits within the larger transportation system. It also will help guide the planning of AHS evolution and system expansion.

B.1.2 AHS Roadway Analysis

The AHS roadway analysis consists of these three task report summaries: (1) Urban and Rural AHS Analysis (Task A), (2) AHS Roadway Deployment Analysis and Impact of AHS on Surrounding Non-AHS Roads (Tasks H and I), and (3) AHS Roadway Operation Analysis (Task K)

B.1.2.1 Urban and Rural AHS Analysis

The following are conclusions from the analysis performed under this task:

The daily user of urban and suburban freeways wants travel time savings as a performance improvement. Acceptance of AHS equipment and traffic management costs will be based on the performance gain. A target goal for this savings is one minute per travel mile; totaling at least ten minutes on the freeway portion of the trip. This objective can, most likely, be accomplished by providing preferential lane and exit/entry provisions for AHS users, since automated control can regulate speeds above the current congested level.

Major sources of urban and suburban freeway congestion are incidents (non-recurring), bottlenecks at entry/exit points (recurring), and scheduled maintenance (non-recurring). AHS vehicle instrumentation and Traffic Management (TM) are tools to eliminate congestion, provided poor roadway geometry is corrected.
Worker commuter users of urban and suburban freeways are effective targets for early deployment of AHS. These individual users have a vested interest in making AHS a success as they gain time, reliability, and safer trips. As a daily user, they should be willing to equip their vehicles and pay for the service. HOV users and Transit are prime customers for AHS since they are currently part of the solution for urban and suburban congestion.

Optimize operational improvements on urban and suburban freeways along with introduction of AHS, as it a part of a TM package not a stand alone service. TM includes; surveillance and control systems, ramp metering, incident management, motorist information systems, HOV facilities, and low-cost geometric improvements. These TM techniques are required to supplement AHS full automation.

During early year deployments, AHS performance may not be ideal in terms of congestion relief, due to mix of manual and automated vehicles. Working with existing freeways to gain initial automation benefits, provides a wider and more immediately visible return than attempting to build new AHS guideways to serve a select few.

Understand and respect the social issues of AHS deployment. AHS deployment is not just a technical installation exercise to provide a service. Impacts on land use planning, air/noise pollution and public/political acceptance may be more important than solving mechanical/electronic/concrete problems.

Consider separated AHS lanes a high priority for suburban freeway deployment, provided equal provisions can be made for entry and exiting. A major infrastructure design issue for AHS deployment is solutions to the traffic mixing, weaving, entry and exit with non-AHS vehicles especially heavy trucks.

Assume that AHS on rural freeways will initially operate in mixed traffic lanes. When AHS use increases, and higher performance is needed, the minimum lane requirements appear to be one AHS lane and two general use lanes. This requirement will impact most of the dual two-lane freeways (outer suburban and rural). Although traffic volumes may show only a need for a single general (manual) lane, entrance/exit, passing, incidents plus operation during maintenance will probably require a minimum of two general lanes.

AHS can increase throughput during peak hours provided the supporting interchanges, feeder roads and city streets can accept this increase. At the proposed high flow rates, urban and suburban facilities now regularly fail. Only rural freeway feeders have the capacity required.

Research into AHS technology is important as this defines the "How". Equally important is research in the market to identify size and needs as this defines the "Customer". The "How" should be driven by the "Customers' Needs".

Envisioning AHS as a national system requires flexibility of design to accommodate urban, suburban, and rural needs. The urban, suburban, and rural environments cover a spectrum of needs. Therefore, a variety of configurations are required to meet each of the needs. Suburban would be more I3 driven and rural would be more I1 driven.

B.1.2.2 AHS Roadway Deployment and Surrounding Non-AHS Impact Analyses

Analyses were conducted by making certain assumptions about the AHS. These assumptions were used as constraints for the evaluation of a variety of AHS designs.

- The capacity of the AHS lane was assumed to be 5000 VPH with a usable capacity of 4500 VPH
- All AHS access and egress ramps were assumed to have a capacity of at least 1400 VPH
- The AHS access transition lane requires approximately 2500 feet.
- The AHS egress transition lane requires approximately 1600 feet.
- For the RSC I3, all AHS ramps enter and exit from and to a service road and/or a general use lane and/or a separate ramp. This eliminates the weaving movements of AHS equipped vehicles that utilize the AHS lane. Therefore, the AHS ramps can be placed closer to the traditional on and off-ramps.
- For the RSC I2, the access points to the AHS lane were placed at least 2000-3000 feet from the preceding on-ramp. Also, the egress points from the AHS lane were placed at least 2000-3000 feet from the next off-ramp. These distances were assumed to adequately facilitate weaving movements required by AHS equipped vehicles that utilize the AHS lane.

B.1.2.3 Infrastructure Design

This study concentrated on AHS infrastructure designs which provide separate lanes for AHS and non-AHS vehicles. The separate facility provides an environment which maximizes the constant speed and headway keeping capabilities of AHS vehicles. To create separate facilities, RSCs, with respect to the infrastructure, were developed. The RSCs developed were termed I2 and I3. RSC I2 provides for entry and exit to and from the AHS facility directly from the general use lanes of an expressway mainline. With the I2 design, the AHS lane can be physically separated by a barrier, a striped separation a few feet wide, or by a continuous transition lane for the length of the AHS lane. The continuous transition lane option for the RSC I2 design would require increased right-of-way as compared with the barrier option. Ingress/egress for the AHS lane would be allowed at any point. Finally, for RSC I2, both the transition lane option and the striped separation option require an impracticable level of enforcement to ensure exclusion of non-AHS vehicles. RSC I3 is achieved by providing separate ingress and egress for the AHS facility. The RSC I3 design was developed by separating the general use lanes from the AHS lane using physical barriers and providing AHS access/egress ramps that link directly to service roads or ramps.

B.1.2.4 AHS Performance Evaluation

Evaluation of the implementation of an AHS facility in urban, suburban, and rural environments provided the following results:

- AHS deployments using RSCs I2 and I3 on congested urban and suburban freeways can significantly improve speed and travel time on these facilities. Travel time improvements of up to 38 percent were obtained for the cases studied. Significant travel time improvements on the rural facility were only obtained when the AHS cruise speed was increased to 80 mph from the 62 mph speed used for the other cases.

- The selection of I2 or I3 AHS lane access techniques is best determined by the AHS access and egress volume requirements, by the general lane traffic of these locations, and by the level of service (LOS) on the general lanes.

- AHS deployments using RSCs I2 and I3 on congested urban and suburban freeways may significantly increase facility capacity to respond to future year demand. Depending on the origin-destination (OD) requirements, the capacity of the remaining general lanes rather than the AHS lanes may limit capacity.

- In areas which experience traffic congestion, such as Long Island, high levels of AHS utilization are obtained based on RSCs I2 and I3 type facilities at relatively low levels of AHS MP (15-25 percent).

- In congestion prone areas, the AHS may generate significant changes in the utilization of parallel facilities located several miles away from the AHS. However, as market penetration increases, as was evident on Long Island, the attraction of the AHS facility to distant parallel roadways decreases, and total VMT in the study area decreases.

- The need to access the AHS will, in many cases, cause saturation of surface street intersections. Geometric improvements and signal timing changes will be commonly required.

- Certain AHS control strategies call for queuing vehicles at AHS entry points (auxiliary lanes in the I2 configuration and ramps in the I3 configuration). Properly managed AHS traffic maintains queue delays and queue lengths at acceptable values.

- The attraction of the AHS facility in congestion prone areas results not only from increased capacity, but also, because of the facility's ability to sustain a constant comfortably high speed of 60 mph at increased volume.

- An AHS facility on a congested urban or suburban freeway might tend to reduce the total travel time vehicle-hours in comparison to comparable non-AHS facilities, while satisfying the trip demand. This finding, however, must be tested further using a more precise modeling technique.

B.1.2.5 AHS Roadway Operation Analysis (Task K)

Successful deployment of an AHS requires examination of all operational scenarios and associated operational elements under which an AHS will be utilized. The promise and the nature of automated highways, which involve instrumentation through electronic means, requires consideration of applications completely different from those associated with the way we operate and maintain our existing highway systems. For example, a fully instrumented infrastructure is subject to a wider range of preventive maintenance repairs and supervisory control as compared to existing highways. Assuming the evolutionary deployment of AHS, there are no show stoppers or operational barriers with

Current traffic management systems are primarily passive (and at best semi-automatic) and rely on macroscopic state variables such as density and speed to identify congestion and incidents. While traffic flow management requirements of an AHS would vary by RSC, configurations with central control will require a more discrete, microscopic orientation of traffic monitoring and management. The characteristics of traffic flow monitoring and management need to be examined and defined as AHS evolves.

Although it is the promise of the AHS to reduce the occurrence of incidents, the impacts of any incident on AHS will be catastrophic with regard to traffic operation. Therefore AHS must improve incident detection and shorten incident response time. The impact of traffic congestion and delay on an AHS lane will be much greater than current impacts to the existing highway system. Therefore, the incident response time must be reduced in order to maintain current highway levels-of-service.

For operation of an AHS, new or hybrid operating agencies and their organizational frameworks will need to be defined along with their potential operations responsibilities. The levels of association, coordination, and autonomy among the operations elements of existing highways, such as management, maintenance, police and emergency services need to be identified along with potential problems with existing arrangements of these operations elements. Each operating agency scenario and the operational impacts of a multi-jurisdictional framework need to be evaluated and studied. Evaluation criteria should include operations uniformity, effectiveness, and practicality of providing such service.

Current levels of expertise and staffing available at existing operating agencies can not support the requirements necessary for an AHS. The areas of expertise required for operation and management of an AHS need to be evaluated. Survey and review of current practices of in-house versus contracted-out functions at state DOTs and highway authorities are essential to final deployment of AHS.

AHS operations require preventive maintenance on a level similar to the airline industry. Existing levels of preventive maintenance performed by highway operating agencies, including operators of traffic management systems, will not satisfy the requirements of AHS. A target level of preventive maintenance for AHS needs to be defined through investigations of comparable systems.

It is anticipated that the AHS will need policing and involve policing tactics different from those practiced today. Dependent upon the RSC, the level of policing, police functions, and tactics will vary. Current policing practices need to be examined, including the level of policing, functions and tactics applicable to deployment of an AHS.

B.1.3 AHS SYSTEMS ANALYSIS

The AHS systems analysis consists of these five task report summaries: (1) Automated Check-In (Task B), (2) Automated Check-Out (Task C), (3) Lateral and Longitudinal Control Analysis (Task D), (4) AHS Entry/Exit Implementation (Task J), (5) Vehicle Operations (Task L).

B.1.3.1 Automated Check-In (Task B)

B.1.3.1.1 Check-in tests should be performed on the fly.

We believe all check-in tests can be made without stopping the vehicle. Status of all vehicle equipment can be tested with a series of dynamic tests. Upon receipt of a command to perform a check-in test, either generated by the roadside or by the vehicle computer, the various tests are performed. If certain tests determine that some vehicle equipment fails the test, the vehicle's computer would prevent the engagement of the automatic modes, and would also communicate to the roadside infrastructure that the vehicle is not fit to operate on the AHS.

B.1.3.1.2 Actuators for steering, throttle, and brakes will require testing in a series of dynamic tests.

In order to test for the proper operation of the various actuators, it is necessary to command the actuator to move and measure its response to the test command. These dynamic tests, which will cause a steering maneuver and changes in the vehicle's longitudinal acceleration, need not be a large or long-duration displacement. Steering tests can be a series of short pulses that may result in displacing the vehicle only a few inches. These tasks can be made on an out-ramp or in a transition lane.

B.1.3.1.3 Vehicle testing will be performed continuously during AHS operation.

The vehicle equipment test sensors and built-in test systems used during check-in will also be used as part of the malfunction management system to monitor vehicle health when engaged on the AHS. Tests of all the vehicle systems will be performed at various rates; e.g., the lateral control system will need to be monitored at a high rate. The check-in function can be considered a subset of the vehicle malfunction monitoring and management system.
With such an approach, the check-in/monitoring system must be tamper-proof, thereby preventing an unfit vehicle from operating on the AHS roadway.

B.1.3.2 Automated Check-Out (Task C)

The check-out process is a critical component for ensuring AHS safety. It concerns the process of assuring safe transfer of control from the automated driving system to manual driving. Because the driver has been out of the driving loop during AHS operation, there is concern that the driver will not be ready or capable of assuming driving control and responsibility. Check-out is the procedure for transferring vehicle control to manual operation in a way that ensures driver readiness and capability, and tests the integrity of mechanical vehicle components needed for manual driving.

The conclusions/key findings from this analysis are listed below:

- There are two types of check-out that must be considered: normal check-out and emergency check-out.
- There are two parts to check-out: the testing of vehicle components, and testing for the driver's readiness to retake manual control.
- During the process of transition from automated to manual driving, the driver must take control of the vehicle rather than having the vehicle give control back to the driver.
- The check-out "test" should be an integrated part of the larger check-out process.

- If check-out "tests" are required during the automated portion of the trip (for the purpose of maintaining an adequate level of vigilance), these "tests" should be meaningful and not artificial and extraneous.

- The driver portion of the check-out process must account for the wide variability in capabilities within the driving population.

- The requirements and approach for check-out are interdependent with the requirements for, and design of, AHS features and infrastructure.

B.1.3.2.1 Driver Readiness Issues

There is a large body of research dealing with how humans process information that can be applied to the design of an effective (driver) check-out procedure. This research deals with the way humans detect and discriminate stimuli, recognize and comprehend information and situations, make decisions, and select and execute responses. Knowledge of human strengths and limitations, within these activities, is necessary to design an effective check-out process. For example, a check-out process that focuses the driver's attention on the most critical information will help avoid selective attention and distraction problems. In addition, redundant cues can shorten and improve the process of developing driving situation awareness, (e.g., alert the driver about special road conditions). By careful human factors design, the driver readiness portion of the check-out process can be fine-tuned to perform in the most optimal fashion.

Human monitoring performance and associated vigilance decrement problems (reduction in level of alertness) have also been extensively studied. This research base can also be applied to AHS design of level of alertness and monitoring performance features. For example, knowledge of task duration has been found to affect the vigilance decrement. This can be applied to develop different approaches for maintaining vigilance on rural and urban AHS segments. One approach to ensure that the driver remains vigilant and alert is to test the driver periodically throughout the trip. However, these tests should be meaningful and related to the trip on the AHS. People generally do not respond well to meaningless tasks, and may perform poorly if they do not believe the test is important. For example, AHS could alert the driver that an exit is approaching, and could ask whether the driver desires to check-out. The act of responding to the system is an indication that the driver is awake and alert.

The driver check-out process must be designed to ensure that the driver is capable and engaged with respect to each important aspect of driving performance. Figure 4 shows a generalized model of the driving task including each important cognitive and control subtask. The check-out process must address each of these subtasks to keep the driver in-the-loop, ready, and capable of assuming driving responsibility.

Given enough time, testing for driver capability and engagement with respect to the driving subtasks, shown in the information processing model (figure 4), would be straightforward. There are substantial research and tools available to support the measuring of human performance with respect to each of these activities. However, the practicality of implementing a driver assessment procedure within the check-out process must be considered. Drivers will not tolerate a system that requires a battery of tests each time the AHS is exited. Additionally, AHS flow requirements and infrastructure limitations dictate that the tests be accomplished quickly. Our AHS check-out challenge is to accomplish the goal of a comprehensive driver assessment within the worst-case time available. Further, this must be accomplished for AHS drivers varying in age, experience, and capability.

It would be most advantageous if the driver assessment procedure is accomplished within the process of transferring control from the automated driving system to manual driving. That is, the control transfer procedure should be designed to include steps that accomplish both transferring control to the driver, and assessing the driver's readiness to accept control. Table 8 shows each component of the driving task, as illustrated in figure 4, and identifies a general approach for assessing driver capability with respect to each. This is a very general model that needs to be further developed and tested during the next AHS program phase.
It must be emphasized that this is a very skeletal description of a possible driver readiness assessment process. The specifics of this procedure need to be determined and validated on the basis of further analysis and test. This generic example of a possible approach to meeting this requirement serves to demonstrate how the steps of driver readiness assessment can be embedded within the vehicle control transfer process in a way that is practical for AHS implementation.

One critical aspect of the driver readiness assessment process is that it never fails in determining that the driver is controlling the vehicle when automated control is relinquished. Our recommendation for meeting this important requirement is that the driver be required to **take control** rather than have the vehicle give up control. The driver should be required to initiate a positive action using the vehicle's manual controls to complete the control transfer process. This is very similar to the way drivers currently take control from today's cruise control. The check-out process must ensure continuous active control of the vehicle, and has important liability implications. This is an important conclusion of this task.

In addition to verifying that the driver is ready and actively controlling the vehicle, the integrity and proper functioning of the critical vehicle control mechanisms must be ensured. Most vehicle control functions operate under both automated and manual driving conditions, and, therefore can be assumed to be working. However, the manual links to safety-critical actuators must be verified. These include actuators for steering, braking, and throttle. Three possible approaches to AHS design relevant to these tests have been identified.

In the first design approach, the manual vehicle control system or the automated vehicle system can be connected at a time. One can be connected only when the other is disconnected. The approach to verifying manual control integrity with this design may be mechanical; e.g., a mechanical switch can be engaged when manual controls are "locked-in." Automated control links can only be allowed to disengage when the mechanical engage switch is engaged.

The second approach, requires software logic and control response testing. In this approach, both control modes remain connected to the vehicle actuators at all times. An electrical switch is used to control which mode is to be recognized by the actuators at any one time. The verification of control integrity must be done through control response testing, and the switch to manual control can only occur after the automated system has been disengaged.

In the third approach manual control is always engaged. All that is needed to disengage the automated system is to provide an input to the manual system. Thus, the vehicle actuators can accept commands from both control modes simultaneously. We do not recommend this approach, since a driver who accidentally provides an input to the manual control system (e.g., bumping the steering wheel) will interfere with the automated control system. This could lead to a potentially dangerous situation.

B.1.3.2.2 AHS/Highway Design Issues

There are also issues of AHS infrastructure design that have been identified during this task. It is assumed that the check-out process will be performed while the vehicle is traveling, at regular highway speed (as determined by the automated system). It may occur on the AHS or in the transition lane. Thus, during the time required to perform the check-out tests, the vehicle will cover quite a distance. In addition, it will be necessary to allow the driver to retake the check-out test upon failure on the first attempt. This further increases the distance traveled by the vehicle. For example, a vehicle traveling at 60 mph will travel 1/4 mile in the time necessary to conduct a 15-second test, and 1/2 mile in the time necessary to conduct two 15-second tests. It is necessary to initiate the check-out process far enough in advance for all of the check-out tests, and retesting if necessary, to be conducted prior to reaching the driver's desired exit. The point where check-out must begin is determined by the speed of travel, the duration of the check-out test, and the maximum number of allowable retests. Roadway conditions may also affect where (and when) check-out is initiated. When the roadway is in less than optimal condition (e.g., rain, ice or snow), vehicles require a greater distance to decelerate, and may require additional time to perform the check-out process. Also, the check-out process may need to be modified in these situations, to reflect the increased difficulty of the driving task during non-optimal conditions.

The design of the check-out process may also affect the design of the entry/exit infrastructure, and may depend on how a check-out failure is handled by the system. AHS may either keep a driver on the system past the desired exit for further testing, or may park the vehicle at the desired exit. If a vehicle is allowed to continue to the next exit, it may be necessary to reemerge that vehicle back into AHS traffic (if the vehicle had been pulled into the transition lane for check-out testing.) If a vehicle is to be parked, it may be necessary to construct parking lots at exits, or to merge the vehicle back into traffic until a breakdown lane can be reached. Obviously, it is undesirable for vehicles that fail the check-out process to interfere with the AHS traffic.

B.1.3.3 Lateral and Longitudinal Control Analysis (Task D)

The main emphasis of the Lateral and Longitudinal Control analysis was directed toward: (1) a detailed review and study of the various technologies that may be utilized to provide sensors for lateral position measurement and longitudinal headway, and (2) a rather detailed digital simulation of a longitudinal control loop including the vehicle, engine, braking system, and control algorithms. To a lesser degree, consideration was given to communications associated with lateral and longitudinal control, obstacle detection, and a preliminary study of the cost trades between a system that employs an autonomous vehicle-follower longitudinal control and a point-follower system using an infrastructure base headway measurement system. Automatic lateral and longitudinal control is, of course, the heart of any AHS system. The studies conducted on this program barely scratch the surface of the automatic control problem. We do hope, however, that we have focused our efforts at some of the key design issues.

During the course of the studies, several results became apparent. Because these results will have significant impact on further studies and research, we have referred to them as key findings. Each of these findings is discussed below:

B.1.3.3.1 Sensors for lateral and longitudinal control must be capable of performing under severe adverse weather conditions.

An AHS system should be capable of operation during adverse weather such as very heavy rain, dense fog, and heavy falling snow. Many researchers are pursuing technologies that clearly will not function in severe weather. The argument that it is acceptable if it performs as well as a human does not make much sense to us. If, during severe weather, the lateral sensor can no longer locate the lateral position of the vehicle, or the headway sensor can no longer measure the headway, a serious safety condition exists. This is particularly true of lateral control. If a rain storm limits the performance of a headway sensor, other action can be taken, such as slowing (or stopping) all traffic. However, lateral guidance is required even if it is only used to steer the vehicle while a stopping maneuver is performed. During periods of severe weather, such as heavy rain or fog, the highway speed may be significantly reduced, provided that the sensors can continue to operate. To accommodate increased sensor errors, the gap spacing may be increased. Loss of lateral position information cannot be allowed to occur.

We must currently accept the limitations of the human sensors to function in severe weather, but we need not accept them for an AHS because sensor technology exists to provide for continued AHS operation in very dense fog, heavy rain storms, and blizzard conditions.

B.1.3.3.2 Most promising lateral control technology involves magnetic markers or overhead wires.

Of the many techniques that various researchers have explored to provide lateral position information, the magnetic markers or "nails" appear to be the most attractive. They are inexpensive and of low cost to install in a roadway. They are passive (requiring no power), extremely durable, and will provide control in all weather conditions. Component failure will occur gracefully; i.e., if a given magnet should fail, vehicle operation can continue because one missing magnet will not affect performance.

Lateral control based upon overhead wires that radiate signals, while more costly to install, also operates in all weather. The wires can also be used to provide a moving reference for point-follower type longitudinal control.

B.1.3.3.3 Headway radars will be required to provide high azimuth angle resolution.

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

B.1.3.3.4 Infrastructure-based systems may be cost effective.

An AHS system configuration which is based on the use of infrastructure-mounted sensors to obtain vehicle longitudinal position and to provide a portion of the longitudinal guidance signals and vehicle malfunction detection functions may have cost advantages over a system containing vehicle-based sensors which perform these functions. The component reliability of the infrastructure equipment can be made sufficiently high through redundancy so that component failure does not contribute significantly to the reliability of the overall system.

B.1.3.3.5 Communication between vehicles may not be required for vehicles following at gaps of 0.5 seconds, even during emergency maneuvers.

Results of simulations show that communication of the acceleration of the lead vehicle(s) is not necessary for braking maneuvers. The simulated design separated the brake controller from the throttle or accelerator controller. The accelerator controller is designed to maintain vehicle headway during normal maneuvers, while the brake controller is designed to avoid collisions. Simulation shows that no collisions occurred even with the lead vehicle braking up to 1 g. The conditions were 0.5 seconds plus 1.5 m (5 feet) nominal gap, 97 km/h (60 mph) speed, up to 15 following cars, and all cars had the capability of 1 g maximum braking. The reduction in headway as speed decreased to zero was more than enough to make up for distance lost because of sensing and braking dynamics. The acceleration of the preceding vehicle was estimated from the rate of change of the differential velocity. Up to 30 cm/sec (1 ft/sec) noise like errors on the speed measurements did not degrade the safety of the brake system. Speed and distance measurements were made at a 20 Hz rate, using an independent noise sample for each measurement. The minimum value for the gap to maintain safe braking has not been explored, but we expect it to be less than 3 m (10 feet). This finding is significant. Most researchers, ourselves included, have felt that each vehicle will need to pass its acceleration to following vehicles to prevent a collision during hard, emergency braking.

B.1.3.3.6 There is a tradeoff between longitudinal maneuver errors and noise immunity.

In the design of a longitudinal controller for an AHS, there exists a classical tradeoff between tolerable maneuver errors and noise immunity. Typically, a longitudinal controller is designed to maintain a certain headway from the preceding vehicle. When the preceding vehicle changes speed, the following vehicle's control system will generate an acceleration command to maintain the headway. During the speed change, the headway error could range from a few centimeters to meters (inches to feet) depending on the maneuver. In our simulations, an increase in speed from 80 kmph (50 mph) (73.3 ft/sec) to 97 km/h (60 mph) (88 ft/sec) at 0.1 g generated a 2 m (7 ft) distance error. The headway error gradually diminished to near zero ft/in about 25 seconds after the maneuver. If the bandwidth of the control system is increased, the headway errors can be reduced to less than 0.6 m (2 ft) with total recovery in less than 10 seconds. Although the tighter control seems more desirable, the effects of sensor errors in the system make a high bandwidth control system impractical. We believe that typical sensor errors for ranging and doppler devices are likely to be 0.3 m and 0.3 m/sec (1 ft and 1 ft/sec), respectively. When these errors are used in a high bandwidth simulation, throttle displacement is larger, causing accelerations of 0.6 m/sec/sec (±2 ft/sec/sec) during steady state cruising. The net result is an uncomfortable ride for the AHS user, not to mention reduced fuel economy. As the bandwidth of the control system is reduced, the ride may be more tolerable with accelerations for steady state cruising at 0.15 m (±0.5 ft/sec/sec). The net result is a tradeoff as shown in table B-1

Table B-1. Bandwidth Effect on Control

Control System	Steady State Accelerations	Max. Error	Recovery
High Bandwidth	±0.6 m/sec/sec	±0.6 m	10 seconds
Low Bandwidth	±0.15 m/sec/sec	±2 m	25 seconds

In order to provide a high bandwidth control system providing rider comfort, improvements in the control system could be made. Improved decisions using Kalman filters or a different controller may provide lower errors and lower accelerations, but for each design a tradeoff between noise immunity and maneuver error must be made.

It should be recognized that the simulation used on this program did not assume that lead vehicles would communicate with following vehicles. The control system derived the lead vehicle acceleration from the differential velocity measurement which contains noise-like errors. If the leading vehicle passed its acceleration data to the following vehicle, a "cleaner" acceleration signal would be available. Thus, a high gain loop could have been used with better performance.

B.1.3.4 AHS Entry/Exit Implementation (Task J)

Entry/exit is one of the major components of highway transportation service. Some might say it is the most important component since it ties directly to OD pairs, as airline service is tied to city pairs and airport capacity.

Entry/exit capacity can dictate a freeway system capacity. As we increase the freeway service lane capacity, demand increase can overload the entry/exits. Local street capacity in the vicinity will at some point reach capacity.

However, automation gives a new tool to deal with system overloads. The traffic controller can directly control sector speed and spacing analogous to a space age ramp meter. As we see in this chapter, the relationship between speed and "safe" capacity might contain an optimum, much as manual traffic achieves today, only it is higher and perhaps peaks at a higher speed. The controller can now choose to modify cruise speed, for increased capacity near an entrance region, to provide more space in the lane for a temporary increase in entry flow. Up to the capacity of the entry procedure, the need for queues or entry lane slowdowns can be reduced.

Entry/exit concept definitions are closely tied to our RSC definitions. In I2, there can be a dedicated lane from the manual lanes to the AHS lanes. In I3, this dedicated lane can originate from a local street. In I1 and I2 configurations with low participation (the fraction intending to be automated at the access point*), the lane is not dedicated to AHS vehicles exclusively.

Because low participation is associated with the early years of AHS deployment, the RSCs and their corresponding entry/exit concepts have an evolutionary interpretation. Entry/exit is also tied to the RSC communication aspect. As discussed in this chapter, the entry/exit procedures, we envision, involve predominantly the vehicle/vehicle (VV) communications link and C1 concepts in I1; the roadside/vehicle (RV) communications link and the VV link in I3; and a less complex RV link in I2, with a fully utilized VV link.

We feel confident that we can achieve higher vehicle densities with automation. However, if this brings higher person-miles traveled by attracting more and longer personal trips, real increases in travel efficiency are questionable. If, through various measures, we can keep

* Participation defined in this manner could be much different from market penetration. In particular, it could be much higher.

vehicle-miles traveled VMT unchanged and, in addition, the total flow in all cruising lanes is not changed; then maximum flows at entry/exits are not changed and existing ramps and local streets are not overloaded. The benefit to the individual user is shorter trip time, assuming that cruising lane congestion was the problem in the first place. If, indeed, entry/exit capacity is the problem, it seems that, short of building more concrete infrastructure, aspects of ITS, other than vehicle automation, must be emphasized to solve congestion problems. There are concepts such as alternate routing and departure time specification, recognizing that everyone cannot use the same portion of concrete at the same time. This line of thinking leads us to emphasize rearrangement of flow from manual to automated rather than adding high automated flows to what presently exists.

Finally, it seems reasonable to anticipate, with the increasing presence of automated vehicles, an "automation" mind set beginning to dominate all driver behavior. Perceiving automated vehicles to be a benefit to the manual vehicles in terms of decreased congestion and trip time, automated travelers would help develop the cooperation and approval needed to share the road. In what follows, the entry/exit techniques can easily be foiled by irresponsible or uncooperative manual drivers in the same lanes. Thus, just as exists today, there must be recognition that if we and our transportation systems behave intelligently, we will all get to our destinations on time.

Analyses show that we can get higher lane flow with AHS than with manual driving. Where the entry/exit capacity and the local streets can allow, this might be the choice of ATMS. Such an example is a bridge or tunnel bottleneck, where cruise and entry/exit capacity upstream and downstream are adequate, but traffic backs up from the bottleneck.

At given speed and weather conditions, how close can we space automated vehicles safely? The answer depends not only on cruise speed but also on entry/exit or ingress/egress to an AHS cruising stream. Our analysis provides a framework for determining how much space is available to add more vehicles. This analysis, used maximum braking distance, collision severity, maximum relative collision speed DV for elastic bumper behavior, deceleration system time delay, VV link time delay, the number of collisions and DVs of those collisions for a given deceleration of the vehicle ahead, the vehicle masses, and the vehicle lengths as input parameters in addition to speed.

Although not part of this task, we also consider that due to control limitations there will be a minimum allowed gap between vehicles for lane changes, mainly affecting the ingress maneuver.

Given a way to define the relationship of flow capacity (or vehicle density) and lane speed, we now proceed to the next step which is to define how we will utilize the empty space to add more vehicles to the stream. The concept of space distribution is introduced and we make the point that the merging of two flows with the spaces in one matching the vehicles in the other minimizes flow disturbances. Through a simple manual spacing strategy and a regular space distribution in the AHS lane approaching an ingress point, the final vernier adjustment is straightforward with minimal flow disturbance. Rudimentary flow analysis, with participation as a parameter, was undertaken. It leads to the definition of a reasonable boundary between the highest participation for which we still benefit by having manual vehicles in the AHS operating lane and the lowest participation appropriate for I2.

Topics related to I3 were studied. The concept of a dedicated entry ramp directly from the local streets allows a "collector" lane to be postulated that can run at high volume because it is automated. The final stage of this entry method is the merging of two automated streams at cruise velocity. This same high-speed merge appears in the interface of two AHS highways.

The use of space manipulation and entry vernier adjustments is shown to be rather primitive in I1C1, more sophisticated in I2C2 and highly refined in I3. Entry/exit pairs are discussed with exit ahead or behind entry depending on the manual highway system interface and traffic patterns. It is shown that I1, I2 and I3 entry/exit procedures and infrastructures are also interface and traffic pattern dependent.

A summary of key findings and recommendations is below:

- Entry/exits are key to AHS practicality since they dictate maximum flows throughout the system, are a big cost driver, and are a primary impact on the community.

- Participation fraction is key to entry/exit design and indeed drives overall design. It is reasonable to estimate that participation fraction will be significantly higher than market penetration. However, AHS entry/exits feasible for low participation fractions are initially the most attractive.

- Entry/exit spacing is an important design criterion in the urban environment. LIE data shows that the average OD pairing involves only a few miles of freeway use. Yet, AHS conceptually is concerned with longer freeway segments.

- The different entry/exit techniques associated with the different RSCs may well all find application on a single AHS because the specific design requirements of each street and traffic situation dictates the best technique.

- One of the highest infrastructure impacts assigned to entry/exit requirements is the merging of two AHS streams starting at right angles. This is due to the large radii required if speed is maintained, and the lack of such a requirement in today's highway geometries.

- AHS traffic controllers, according to derived capacity-versus-speed estimates applicable to automated vehicles, will have the ability to provide a tradeoff between velocity and capacity to accommodate substantial volume variations.

- The relationship between AHS entry/exit and ATMS should be tested in appropriate traffic models.

- Realistic applications that minimize expensive infrastructure modifications (I1 and I2) should be given high priority in further development. Requiring an I3 early development has less appeal since it sets up high political and social hurdles.

- The minimum space into which an automated vehicle can be safely maneuvered should be defined on the basis of realistic control capabilities and reasonable wind gusts, roadbed unevenness and other disturbances.

B.1.3.5 Vehicle Operations (Task L)

Numerous issues/risks were identified under this study. Some of the significant findings are addressed below.

B.1.3.5.1 Impact of Reliability

The addition of the required AHS components may result in a decrease of the reliability of the vehicle as a whole. It is believed that through preventive maintenance, periodic inspections, use of redundancy, and system health monitoring, a failure rate at least as low as today's experience can be maintained. Consideration must be given to the impact on reliability during the design process.

B.1.3.5.2 Impact of Redundancy

Tradeoffs will need to be made between redundancy and cost impact. To make all AHS subsystems redundant will, no doubt, result in pricing the AHS equipment out of the market. Car should be exercised during the design process to employ redundancy in areas where safety considerations dictate it, such as steering control systems. Built-in tests can be employed to detect a failure or below-specification performance, without the use of redundancy æ provided that the malfunction can be managed. For example, if a forward-looking radar system fails, the vehicle can be brought to a stop in a breakdown lane. If the radar has a low failure rate such that few failures occur, this approach of stopping the vehicle may be quite acceptable as opposed to providing redundant radar sensors.

B.1.3.5.3 Impact of the AHS Scenarios

Development and deployment of AHS components will be greatly affected by the selection of the AHS scenarios (e.g., a vehicle-based or roadway-based intelligence). Determining the feasibility of deployment of the proposed scenarios at an early stage, and selecting the appropriate scenario(s) for implementation is very crucial to the success of the project. This will provide a clear direction for research and development of the AHS components and also will speed up deployment process.

B.1.3.5.4 AHS Evolution

Progression for AHS evolution will probably be warning, control assistance, and then eventually AHS, i.e., full automated control stage. Our team does not consider the system to be AHS until the operation is hands-off, feet-off.

B.1.3.5.5 Deployment of the AHS Vehicle Components

Some of the early stage driving assist systems, such as intelligent cruise control will be entirely onboard the vehicle, without the need for involvement of any government agency or roadway facility. The addition of lateral control will probably require some additional infrastructure such as magnets or road stripes.

B.1.3.5.6 Software Cost

Software development process may become a major cost element of the system development costs of AHS systems. Software cost on a per vehicle basis will be modest due to the large number of vehicles. At a 70% market penetration (70 million vehicles) a cost of $5 per vehicle would amount to 350 million dollars of software development.

B.1.3.5.7 Software Verification and Validation

Since AHS Systems will employ sophisticated microprocessor-based systems for vehicle control, system health monitoring, and communication of signals and commands, software verification and validation monitoring will be of prime importance. Software verification must be part of the malfunction monitoring system and an integral part of the design process, rather than an after-thought, once the software is structured.

B.1.3.5.8 In-Vehicle Communications

Multiplexing of on-board communication systems has promising applications in the AHS vehicles. Some of the benefits of the system include: enhanced diagnostics, distributed control, and total wire reduction.

B.1.4 AHS MALFUNCTION MANAGEMENT AND SAFETY ANALYSIS

The AHS malfunction management and safety analysis consists of these two task report summaries: (1) Malfunction Management and Analysis (Task E), and (2) AHS Safety Issues (Task N).

B.1.4.1 Malfunction Management and Analysis (Task E)

Below, the major findings and recommendations are summarized.

- User data and analysis show that an automation failure rate of one per 2000 vehicle. hours. is feasible.

- The full answer to the cost question, both acquisition and lifetime maintenance, must remain uncertain until specific designs are considered, but we are optimistic.

- The key issues in the approach to the question of safety are the use of redundancy in vehicle equipment, and the use of a breakdown lane, entry/exit protocol, and handling communication failures. Our study suggests design approaches to deal with these issues.

- Barriers in the I2 scenario would reduce the probability of vehicles and other objects from moving into the AHS lane from the manual lanes. The ability of an automated vehicle to cope with such objects is problematical, making consideration of barrier use part of this malfunction management.

- Driver role in malfunction management remains a controversy. We examined two driver roles—one where the driver is continually alert to the vehicle's behavior and progress throughout the trip and one where the driver can turn attention to unrelated activities but can expeditiously tend to systems alerts and advisories. These two roles both find application depending on the proximity of manually-operated vehicles as dictated by RSC definition.

- Preliminary subsystem design studies should be performed and integrated into an overall system design containing life cycle cost/reliability tradeoffs.

- Redundant subsystems should be considered to obtain reliability goals with the following design questions addressed.

  - Use of dissimilar technologies as part of the redundancy
  - Failure detection availability
  - Failure identification technique
  - Transition without dynamic disturbance
  - Common mode failures

- The driver role in malfunction management should be studied in simulations and field tests.

- A target basic vehicle locomotion MTBF should be established by standards organizations and vehicle manufacturers.

- Further study is needed to resolve the issues of

  - a continuous breakdown lane
  - malfunctions during access and egress functions
  - management of communication failures

- Realistic affordable methods for managing the problem posed by an object in the lane must be developed. This study should consider the role of barriers in the AHS designs placing an automated lane contiguous to those used by manual traffic.

- A related study should address the legal implications of enforcing traffic laws addressing obstruction of AHS traffic. Such violators should be easily detectable and therefore easy to fine or at least bring to trial. The delay caused in the AHS lane is, in worst case, equivalent to stopping three or more lanes of today's congested manual traffic. There appears to be no method short of a physical gate or severe legal consequence to prevent intended or negligent obstruction.

B.1.4.2 AHS Safety Issues (Task N)

B.1.4.2.1 AHS Fault Hazard Analysis (What could go wrong?)

The fault hazard analysis of AHS operations addressed: (1) potential system failures or degradations, (2) their local and system-wide effects on the AHS, and (3) their criticality prior to any mitigating strategy. The analysis represented the individual phases of AHS operation as a time sequence of events for the six general RSCs. The main conclusions, after examining system impacts resulting from failure of AHS components, stress the need for system reliability and redundancy for a safe and successful AHS.

The key findings/conclusions stemming from the fault hazard analysis:

- Automated vehicles must have redundant steering and braking systems. The consequences of loss of vehicle control, which are detailed in the sections on individual crash types, emphasize the need for complete control at all times. Graceful degradation from an automated mode is dependent on the integrity of the basic system, and in particular, the vehicle controllers

- The question of a human driver as a participant in automated vehicle control is controversial, particularly as a malfunction management tool. As part of the fault hazard analysis, two driver roles were identified:

- Role 1: **Brain On, Hands and Feet Off**, was assumed for assessment of local and system effects of component failures. Both roles require further investigation. Role 1 does not allow the driver to completely relax, but it maintains a very capable and intelligent system component that would be extremely expensive to replace.

- Role 2: **Brain Off, Hands and Feet Off** permits the driver to be completely detached from the system. This mode eliminates the concept of manual backup, increases the requirements for malfunction management, and raises concern for AHS exit policies.

- The object/animal in the roadway problem may remain a constant between today's interstates and an AHS. The magnitude of this problem is unclearly defined. Accident statistics indicate the number of times a vehicle strikes an object or animal in the roadway, not the number of times a driver successfully maneuvers around an obstacle and still maintains control of the vehicle. The cost of preventing these elements from entering the AHS emphasizes the need for detection devices. However, even if it is possible to detect an obstacle that truly needs to be avoided, the longitudinal and lateral control systems must be capable of diverting the stream of vehicles, and they must have the room to maneuver the vehicles safely around the obstacle.

- The general RSCs were not developed as evolutionary configurations, although they can be viewed as an evolving progression from I1C1 to I3C3. However, the consequences of faults and hazards at the higher levels of automation emphasize the benefits of an evolutionary approach to an AHS. These benefits will be derived in the form of costs, implementation, and ability to gracefully degrade to lower levels of command and control as the more sophisticated designs are developed and implemented. Evolutionary designs may also turn out to be the configuration of choice for specific locations, such as rural areas, where less demand means that cost of separate automated roadways is impractical.

B.1.4.2.2 AHS Crash Analysis (If something does go wrong, what are the consequences?)

The second phase of the safety task answered the question: if something does go wrong, what are the consequences. This second phase was addressed using accident data bases and served two objectives: raise AHS safety issues and risks for AHS design considerations and estimate potential AHS benefits. The highlights of the crash analysis are discussed in this section, and the potential AHS benefits are quantified in the following section.

B.1.4.2.3 Crash Analysis for Design Guidelines

The goal of the AHS, under normal operating conditions, is a collision-free driving environment. This goal is based on assumptions of full automation and fail-safe malfunction management under any and all circumstances. To investigate the consequences of deviations from these assumptions, specific crash types were analyzed. The deviations appear in the form of mixed manual and automated vehicles for the I1C1 RSC and the transition lanes of the I2C1 and I2C2 RSCs. Deviations may also appear as holes in the mitigating strategies prescribed by malfunction management for any RSC or as degradations from safe designs due to cost, implementation or increased capacity tradeoffs.

Crash types similar to those on today's interstates will probably become the crash types that occur on an AHS under non-normal operating conditions. The causal factors will be AHS unique, the number of vehicles involved will probably be greater, and the distribution of crash types will vary from today's interstate accident picture. The emphasis must be on fail-safe designs that will be geared to the lowest injury-producing crash types

Data from the Fatal Accident Reporting System (FARS) were used to rank crash types according to risk of a fatal injury. Table B-2 lists the individual crash types in order of decreasing likelihood of producing fatal injuries. The most common crash type to result in a fatal injury is the "not a collision with a motor vehicle in transport". The collisions that do not involve another motor vehicle in transport consist of single vehicle accidents that are rollovers, barrier related, roadside departures or involve an object or animal in the roadway. Head-On and Sideswipe Opposite Direction are extremely low frequency events on interstates

Table B-2. Ranking by Occurrence of Fatalities on Interstates

Crash Type	# Fatal Injuries	% of Total
Not Collision with a Motor Vehicle in Transport	612	54.1%
Head-On	199	17.6%
Rear-End	165	14.6%
Angle	111	9.8%
Sideswipe, Same Direction	34	3.0%
Sideswipe, Opposite Direction	7	0.6%
Total	1131	100.0%

Rear-end crashes were analyzed in detail since they are likely to be the most frequently occurring AHS crash type. The Crashworthiness Data System's (CDS) algorithms (PCCRASH) to estimate DVs for vehicles involved in a collision apply to rear-end crashes. The primary measure of collision impact severity is V, defined as the change in a vehicle's velocity, taking into account vehicle mass.

Occupant injury levels and vehicle damage severities were expressed as a function of V. This analysis was performed to estimate "tolerable" Vs for collisions on an AHS. Once tolerable Vs are obtained, safe headways for travel speeds based on maximum deceleration of a lead vehicle involved in a crash can be calculated.

The highest level of medical treatment for striking vehicle occupants as a function of V. Vehicle occupants suffered injuries requiring transportation to a medical facility where they were treated and released from crashes in the 6 to 10 mph V range. Injuries requiring hospitalization resulted from crashes in the 11 to 15 mph V range. This not only implies the seriousness of the incident in terms of occupant injury, but also indicates the amount of time necessary to clear the accident scene, and its influence on the perceived safety of the AHS.

Barrier-related crashes represent another potential AHS crash type, particularly for the I2C1 and I2C2 RSCs, where automated lanes and manual lanes may be separated by barriers. CDS data show that left roadside departures account for approximately 78 percent of barrier crashes that occur on roadways with speed limits greater than 50 mph. This finding strongly supports the use of barriers on the AHS since, without a barrier between automated and manual lanes, left roadside departure vehicles from the manual lanes will intrude into the AHS.

The likelihood of a lane-blocking incident on an AHS under normal operating conditions may be viewed as the possibility of a crash with an object or animal in the roadway. Automation is capable of creating a "smart driver" that knows the state of the vehicle, and the limits of the vehicle's handling capabilities for road and weather conditions, but automation cannot control objects or animals. Therefore, automation must deal with them, particularly on the long stretches of suburban and rural highways where the problem is most significant.

Table B-3 shows the likelihood of a lane-blocking incident on an AHS under normal operating conditions. Crashes involving objects or animals represent 5.2 percent of all interstates crashes. Given the 490,336 million vehicle miles of travel on US interstates, this equates to a rate of 0.03 incidents per million VMT. Additional events, under non-normal operating conditions, that may lead to "AHS roadway obstacles" or lane-blocking incidents are:

- Loss of lateral control
- Offset rear-end crashes

- Rear-end crashes on low traction surfaces (perhaps due to fluid spills)
- Lane/change merge crashes
- Crashes related to driver impairments

Table B-3. Likelihood of Lane-Blocking Incident on an AHS

Interstate Object / Animal Rate of Vehicle Collisions per Million VMT			
Location	**Urban**	**Suburban**	**Rural**
Number of Incidents	1,678	7,496	5,802
VMT (million miles)	190,217	95,108	205,011
Rate	0.01	0.08	0.03

B.1.5 AHS Benefits Analysis

The goal of the AHS, under normal operating conditions, is a collision-free driving environment. This assumes full automation and fail-safe malfunction management under any and all circumstances. Based on these assumptions, existing studies on accident causal factor analysis provide a quantification of benefits from an AHS. Estimates of the improved accident picture for an AHS are treated separately for each crash type, where data are available. An assessment of the overall safety benefits derived from an AHS is presented as a range of percent reduction in crash frequencies in table B-4.

The lower limit is based on General Estimates System (GES) data where a vehicle defect, driver impairment, or inclement weather may have contributed to the crash. Only police-reported information is included in this estimate; there is no assessment of crash cause. This analysis resulted in a 31 percent improvement for all locations combined (table B-4).

The upper estimate of AHS safety improvement is based on data derived from a causal factor analysis of rear-end crashes (Knipling, 1993) and the Indiana Tri-Level study (Treat, 1979). This estimate is based on an assumption that the combination of automated control and vehicle system monitoring/inspection has the potential to remove human and vehicular factors and most (80 percent) of the environmental factors. This approach yields an 85 percent reduction in vehicle collisions. The data, which pertain to crashes on all roadways, are not limited to interstates.

Table B-4. Percent of Interstate Collisions where Vehicle Defects, Driver Impairment, and Inclement Weather are Involved

Percent of All Interstate Collisions by Location			
	Location		
Factor which may have contributed to cause of crash:	**Urban**	**Suburban**	**Rural**
Vehicle Defects, Driver Impairments	28,316 (11.2%)	23,191 (12.7%)	18,033 (26.6%)
Vehicle Defects, Driver Impairments, Inclement Weather	65,707 (26.0%)	59,198 (32.5%)	30,986 (45.7%)
Number of Interstate Vehicle-Collisions	252,362	182,028	67,733

*Vehicle-Collisions refer to the total number of vehicles involved in an accident as opposed to the number of accidents that may involve more than one vehicle.

Causal factor results from the Indiana Tri-Level Study are based on 420 in-depth investigated accidents where a "certain" rating was applied to the causal factor. A "certain" rating is applied when there is absolutely no doubt as to a factor's role, and is considered analogous to a 95 percent confidence level. "Certain" cause of the accident means that, assuming all else remains unchanged, there is no doubt that if the deficient factor had been removed or corrected, the accident would not have occurred.

The data in table B-5 show the rate of vehicle collisions per million VMT for today's interstates and estimates of the AHS rate when full automation is assumed. The range of improvement is shown to be 31 to 85 percent. These estimates are based on reductions in collisions; they do not include a factor for increased collision potential due to higher speeds and shorter headways. Collision numbers are from the 1992 GES. They are nationally representative estimates of police-reported interstate accidents by location. Vehicle collision rates are based on VMT on interstates, FARS, 1991.

Table B-5. AHS Safety Improvements

Interstate and AHS Rate of Vehicle Collisions per Million VMT			
Location	**Urban**	**Suburban**	**Rural**
Vehicle-Collisions*	252,362	182,028	67,733
VMT (million miles)	190,217	95,108	205,011
Interstate Rate	1.33	1.91	0.33
Percent Improvement	26.0 - 85.0	32.5 - 85.0	45.7 - 85.0
AHS Rate	0.2 - 0.98	0.29 - 1.29	0.05 - 0.18

*Vehicle-Collisions refer to the total number of vehicles involved in an accident as opposed to the number of accidents that may involve more than one vehicle.

B.1.6 AHS Alternative Propulsion System Impact (Task M)

B.1.6.1 Approach

Three types of vehicles were evaluated in this task. All of these APVs are similar in that they have batteries and electric motors. The differences lie in how power is supplied to their batteries. They are:

- Electric vehicles (EVs) - All power is supplied by rechargeable onboard batteries.
- Hybrid vehicles - There are two types of hybrids, series and parallel:
  - Series: A combustion engine is used to charge the vehicle batteries directly.
  - Parallel: The combustion engine can be used to either charge the batteries or to directly power the vehicle.
- Roadway powered electric vehicles (RPEVs) - RPEVs are electric vehicles that can be charged dynamically while moving, receiving power through induction from a powered roadway.

The technical approach used assumptions based on our estimates for APV influence in the near-term vehicle population. We assumed that APVs may only reach the levels stated in California Air Resources Board (CARB) regulations. Estimates of battery storage capacity are stated within the calculations that they are used in. No breakthrough battery that increases range by a factor of two or three times is likely. More details concerning assumptions are provided in the individual examples cited. We believe our assumptions are real world, moderate in nature; unlike many inaccurate assumptions made about APVs in previous years.

The APV goals of range, performance, refueling, and consumer acceptance have not been met.

The current and future generation of alternative propulsion vehicles (APVs) researched suffer decreased performance compared to most conventional spark ignition (SI) vehicles. These deficits encompass all aspects of vehicle performance, from acceleration and braking to vehicle range. The performance deficiencies, most notable in vehicle acceleration, result from the lack of an adequate power storage media for electricity. Current designs compromise vehicle performance for range, with battery technology the limiting factor. The present-generation batteries store only limited, and inadequate, amounts of electric charge. The range deficiency is the major drawback for APV market potential. This feature inhibits the manufacture of APVs with range and performance comparable to conventional vehicles. Therefore, because of interstate travel, AHS effectiveness will be reduced if APV battery technology is not improved.

The current and near-future APVs may encounter problems on the AHS, depending upon the system's speed limit. Although many APV designs are capable of speeds in excess of the current national speed limit, these vehicles are electronically limited to speeds in the range of 110 to 130 kmh (68 to 81 mph) to maintain battery charge. The operating speed limit will be critical to APV impact on the AHS.

The acceleration performance of most APVs are within the range of current economy class vehicles and light trucks. These values are acceptable for the acceleration and deceleration lanes of current highways under American Association of State Highway and Transportation Officials (AASHTO) guidelines. No modifications are required of the road infrastructure to incorporate APVs.

At present, a large proportion of APVs are conventional SI vehicles that have been converted to APV use. These vehicle conversions result in substantially higher design weights. This factor, along with low rolling resistance tires and a modified weight distribution, can seriously impair vehicle dynamics. Without changes to vehicle braking systems, APV braking distances are significantly longer than the original vehicle. This will cause problems for AHS platooning and emergency maneuvers. Ground-up electric vehicle designs do not suffer from these braking difficulties; at present, only one vehicle, the GM Impact, falls into this "purpose-built" category. The limited number of purpose-built vehicles illustrates the high costs involved in vehicle development. For the near-future, the APV fleet will consist predominantly of converted SI vehicles, and have a negative effect on performance.

Vehicle range is the biggest handicap facing alternative propulsion vehicles today. EV range is dependent on the battery storage system utilized. The only certainty of battery technology is that it is uncertain; it is difficult to extrapolate into the future. In the 1960s, researchers were predicting that electric vehicles would be commonplace in the seventies. This prediction was repeated in the seventies. Because current battery technologies do not provide APVs with range and performance comparable to SI vehicles, this prediction has not yet come to fruition. Research is making evolutionary progress in battery technology with no "revolutionary" breakthroughs on the horizon. The pace of battery system development will presage the closing of the performance and range gap of APVs to SI vehicles. Because of these trends, battery-powered electric vehicles will not have AHS interstate travel range.

As with battery technology, electric vehicle recharging is advancing at a slow pace. Newer, quicker ways of vehicle charging need to be developed for consumer acceptance to rise. Goals for recharging of vehicles need to be in minutes, not hours, as is currently the case. Without the installation of special charging equipment, home electric vehicle recharging cannot be performed in one to three hours. Older homes may not have the capacity to use this equipment without a complete rewiring. For apartment dwellers, the problem is magnified. The specialized charging equipment will initially require charging stations similar to gas stations to allow quick-charge of these vehicles. Electric vehicle quick-charging will have to be performed at recharging stations, possibly co-located with gas stations or AHS service areas.

If the future holds a breakthrough battery, the interim solution may be hybrid vehicles, due to their increased range capabilities and reduced emissions. Of the two types of hybrid vehicles, series and parallel, series hybrids hold the most promise since they are less complex, produce fewer emissions per distance traveled, and operate as zero emission vehicles (ZEVs) for a greater portion of their driving cycle. With the use of a small onboard SI engine, hybrids have greatly extended range capabilities as compared to EVs, and therefore provide promise as AHS vehicles.

Decreased emissions is a major goal of future transportation systems. However, APVs must represent a large share of the vehicle population, or the benefits will be insignificant. Regionally, the reduction in emissions depends directly on the different types of fuel used (the generation mix) to generate electric power. A vehicle's emissions may one day be a selling point similar to present-day features like styling, safety equipment (anti-lock brakes, airbags) and fuel consumption. APVs, especially electric vehicles, will have the lowest emissions of all vehicles. The major manufacturers' disdain for APVs is similar to their general attitude toward small cars, catalytic converters and airbags in earlier years.

Vehicle reliability will be equal to or greater than conventional SI vehicles, and electric motor reliability may be much greater. Depending on the type of APV, the need for instrumentation monitoring may decrease because of the less complex overall system. The only specialized training needed is training for AHS operation, which may be identical for all vehicles. Overall, APVs will be easier to use (less complex, no transmission, less maintenance) than comparable SI vehicles.

Fleet use is the first and best use for APVs. Even with the limited present range (approximately 100 miles), APVs can be used as many types of delivery vehicles. Initially, APVs will be developed for fleet use, independent of the AHS. With further development, they may be suitable for AHS operation. Our findings, on daily miles driven, match other surveys. The majority of fleet vehicles travel less than 70 miles per day, which is within the range of present APVs. In this regard, electric vehicles can safely operate on the AHS, but they will have limited range. Initially, EVs will be best suited for inner city travel and not for intra city or cross-country travel.

The use of roadway power as a range extender for EVs complements electric vehicle driveability. RPEVs will initially be used in transit/commercial applications where the vehicle routes are always the same. Initially, RPEV deployment will consist of public transportation operations. Roadway power presents a practical solution for eliminating emissions in densely populated areas. RPEVs are ideally suited for bus routes, shuttle services, airport shuttles, and use in pollution sensitive areas. RPEVs can play a significant role in transit applications if EV range does not improve. A battery breakthrough could render commuter RPEVs obsolete, while transit RPEVs would be modified to electric-electric vehicles. With battery advancements, RPEV status may change. Transit station recharging could be eliminated if an APV is able to recharge quickly for a entire day's use. RPEVs are still in the experimental stage but the technology is available, mature, and appropriate for present day systems. RPEVs for transit use are a deployable system. Rubber-tired RPEVs would make an excellent replacement for diesel buses, trams, and trolleys.

RPEVs can be operated on the AHS with minimal effect. The electro magnetic field (EMF) emitted by RPEVs is equivalent to household appliances or less. This is acceptable at the present known standards. No interference should occur with non-RPEVs operating on or near a powered RPEV roadway or vehicle. There does not appear to be a problem with EMF emissions from RPEV induction. But, RPEV EMF needs additional study due to the potentially serious consequences of EMF in general. The RPEV induction system is a likely candidate to be used for EV recharging, as it eliminates plugs and cables and is passive to use. If use of RPEVs is widespread in the future, it will tax power resources in New York State beginning around the year 2011.

The inductive coupling required in the RPEV/AHS lane could act as a lateral guidance system available to all vehicles. Many EV designs are adapting "fly-by-wire" steering to reduce weight in the vehicle. Inductive lateral guidance systems have already been adopted and proved effective.

The emissions reductions achieved using an RPEV-based AHS would be much larger than those of a non-RPEV AHS. This is an attractive alternative which promotes compliance with the 1990 Clean Air Act.

Accidents related to APV technology on the AHS will not be a major concern. Battery safety has improved such that battery spills will cause no great threat or harm to the environment and can be safely dealt with by trained emergency crews. Use of APVs will be a stimulant to the businesses created to manufacture, design, and develop these vehicles. Considerable expertise in APVs lies not only in major auto manufacturers, but in vehicle converters and small businesses. APVs are efficient in their conversion of energy to propulsive power, are as safe as a conventional vehicle, and less harmful to the environment.

The top design issues jointly affecting APVs and AHS are:

- Range/charging - If current battery and charging technology are not improved by the time of AHS implementation, APVs will experience reduced AHS capabilities. Limited vehicle range can impair AHS interstate travel.

- Top speed - Future APV designs must be capable of matching AHS design speeds. Limited top speed can negatively impact AHS throughput and increase travel time.

- Fleet/Transit use - To meet CARB mandated sales goals, designers have focused on APVs for fleet use. This feature will facilitate AHS equipment implementation.

- RPEV lane design - If RPEVs are used on the AHS, overall lane design must be standardized and power, billing, and EMF issues resolved. RPEV lanes can provide lateral guidance to all vehicles using the RPEV/AHS road.

- The major limitation is the range issue. The use of hybrid vehicles, which can extend the range of APVs, transitions the use of all the different types of APVs on the AHS. The differences in performance characteristics (acceleration, braking, and handling) between APVs and SI vehicles is decreasing and may be eliminated by the time AHS is implemented.

B.1.7 Commercial and Transit AHS Analysis (Task F)

If the implementation of AHS can result in improved highway travel time reliability, reduced delays, and lower accident rates for commercial vehicles as well as increased attractiveness of public transit for intercity as well as intra-urban travel, the potential benefits will also be accrued by passenger vehicle drivers and occupants who share these highway corridors.

This brief overview of the trucking industry has revealed its enormous contribution to the nation's economy, employment, and productivity. Its diverse types of companies, commodities carried, vehicle types, haul lengths, labor concerns, competitive pressures, and government regulations indicate that the AHS program will need to address multiple trucking industry as well as competing mode issues and concerns. The basic question will be "what's in it for us?" Issues of primary concern to the trucking industry include environmental regulations, safety and health, taxes, labor and emerging technologies.

As the tractor-trailer combination truck appears to be the "workhorse" of the trucking industry, it must be decided whether this vehicle type should be the design standard for deployment and control. The integration of mixed and separate commercial vehicles within the traffic stream must also be considered. Analyses presented within section 3.3 illustrate implications of trucks on the traffic stream for both rural and urban scenarios. If commercial vehicles are to be included, should all types, sizes, weights, and combinations be permitted, or should the AHS lane or lanes only allow smaller single unit trucks with dynamic characteristics similar to passenger vehicles?

While heavier and longer vehicles are viewed as needed by the trucking industry, what place do they have, if any, on the initial and subsequent AHSs that will be developed and constructed over the next decades? What, if any should the truck type and size restriction be? What are the cost implications for pavements and bridges? Should AHSs be designed only for passenger vehicles, vans, buses, and single unit trucks with a weight limit of 10,000 lbs, allowing the other commercial vehicles to remain on separate but non - instrumented sections of the Interstate System in both urban and rural areas? Or, should longer and heavier trucks be allowed, as is being lobbied for by the trucking industry. In theory, AHS will permit the drivers' tasks to be automated except for ingress and egress, and the risk of truck driver and / or passenger vehicle driver error leading to accidents will largely be eliminated.

The control and maintenance requirements needed for longer combination vehicles (LCVs), if they are permitted, need careful evaluation, in view of the greater accident potential of these commercial vehicles. The industry is, judging from the accident rate reductions achieved over the past decade, focusing on safety and proud of its accomplishments. It should, accordingly, be participating in the AHS efforts, to lend its expertise and experience in those vehicle and driver-related areas which will produce the most benefits in the early phases.

B.1.7.1 Transit

AHS must be seen by the Local/Express Bus and Intercity transit industries as a cost effective, significant means to maintain current patronage and encourage new ridership.

The transit industry will need to demonstrate to the American public reasons for becoming competitive with personal autos. If AHS can provide the transit industry with the technology, service, reliability, frequency, direct routing (minimal transfers), at competitive costs with personal auto, there will be a demand for it. Contrary to the trends experienced over the last few decades, the emphasis in urban and suburban transportation is towards increased transit use, particularly based upon new federal legislation mandating change in travel habits by the public. The success of these new programs in accomplishing their goals will depend on

transit's ability to provide more reliable, safe, and efficient transportation.
With AHS lanes or roadways available in high density travel corridors, buses, vans and qualifying high-occupancy vehicles will be afforded the opportunity to consistently meet on-time performance standards and schedules. Improved reliability and travel time will enhance customer service and attract 'choice' users from other modes.

AHS offers improved service and safety by reducing the potential for driver-related accidents. Removing the driver from the continuous operation of the vehicle and providing guidance and warning systems will enhance the performance of bus transit service on AHS facilities in high travel demand corridors. Continuous, predictable reliable service and well-maintained vehicles will eliminate excessive acceleration and deceleration rates which also cause numerous passenger injuries. The required increased maintenance practices would enhance vehicle operations and improve service reliability and safety.

Similar to the advantages of busways, buses and HOVs on AHS would include the following cost and service advantages:

- Relatively low initial construction is required; i.e. convert existing HOV lanes to AHS, use existing central bus terminals, and expand as bus demand increases.

- AHS transit lanes can be utilized by trucks during non-rush hour periods of the day.

- Dual service buses provide manually driven feeder service, non-transfer trunk line AHS service, and downtown manually driven distribution service.

Expected time savings for HOVs can range from 0.5 to 2.0 minutes/mile. Carpooling has increased on HOV lanes in some cases up to 100 percent, and transit ridership has increased between 10 and 20 percent. The technology inherent to AHS would allow greater travel time savings and, potentially, higher ridership. In general, HOV lanes have shown good ridership growth and proven congestion mitigation. As travel demand grows and peak period capacity requirements outstrip available HOV lane capacity, AHS offers the next solution, with at least a doubling of vehicle carrying capability, and much greater multiples of person carrying capacity.

Improvements in the design of transit vehicles, and introduction of user-friendly transit information systems through IVHS programs, as well as additional government support through the mandates of the Clean Air Act Amendments and incentives introduced in ISTEA legislation, will lead to transit's evolution to a much more attractive alternative than it has been in the past. AHS offers the potential to make transit even more reliable, safer, and less time consuming. In light of the current legislation and support of transit by government policy to move people more efficiently, transit can be an integral, if not leading, component of initial

AHS systems. Incorporation of transit into an AHS would allow transit agencies and their passengers to reap significant benefits, provided that the implementation and operating cost changes over existing conditions are viewed as worthwhile in terms of the benefits achieved. These potential benefits to the transit industry and its passengers Include:

- Increased ridership due to better customer service
- Reduced travel time: ability to compete with other, faster, modes of transportation
- Improved safety, reduced insurance costs, fewer third party claims from injuries sustained on-board buses, reduced fuel, energy consumption reduced bus down-time
- Reduced labor costs due to vehicle productivity increases
- Contribution to environmental goals of the CAAA, ISTEA.

Incorporation of AHS technologies into an existing HOV lane or roadway would provide a cost effective transition from existing infrastructure. Transit vehicles and HOVs would be among the first to benefit from AHS.

B.1.7.2 Case Studies

From the analyses conducted for the Long Island Expressway, the New York State Thruway, and the New Jersey Turnpike, it is evident that each type of interstate highway, urban or rural, exhibits varying capabilities for incorporating AHS technology.

From the analyses, based on the stated assumptions, it appears that the most efficient travel will occur with passenger vehicles in separate AHS lanes, as well as all commercial and transit vehicles in separate AHS lanes.

AHS technology would be theoretically viable to alleviate congestion. The findings in the analyses for the LIE indicate that Option A for Scenario #4, with an ultimate capacity of 8,900 pcph, would be most beneficial for people-moving efficiency. These options also exhibit favorable average vehicle occupancies for compliance with the CAAA/ECO Program goals. Along the east Spur of the New Jersey Turnpike Option A for Scenarios #1 and #4, with an ultimate capacity of 8,900 pcph, prove to be the most efficient. Option A for Scenarios #1 and #4 for the combined section of the Turnpike would also be relatively efficient in people-moving efficiency. These options would require carpools 2+ persons and aid in the effort to achieve the CAAA/ECO Program goals.

'No Build" conditions in 2024 on the New York State Thruway would not require excess capacity. An AHS could be implemented in this corridor for reasons of safety and efficiency.

Option A, with one (1) AHS lane and two (2) GULs, would be the most effective option. None of the Scenarios/Options would meet CAAA/ECO Program goals.

B.1.7.3 Analysis of Commercial and Transit Markets for AHS Services

Major Conclusions for AHS Service of Inter-City Freight

- The commercial freight inter-city market has most of its driving cycle on rural, uncongested interstate highways.

- Class 8 trucks, on average, log more than 125,000 miles per year of travel, of which 100,000 is on the interstate highway system.

- The market for class 8 trucks (over 33,000 pounds) is approximately 20,00 per year.

- Motor carriers have aggressively bought new technology that provides improved safety, comfort and convenience for the driver and advanced communication systems that improve the management of the truck fleet.

- A vehicle-borne, infrastructure-free RSC 2-type system that would be usable on much of the nations interstate and expressway highway system without any infrastructure improvement would be extremely attractive to motor carriers (and the inter-city bus industry). A good price point for these systems would be a capital outlay of about $5,000 , and a maintenance cost of less than $500 per year. At this level this adds about one cent per mile to a truck's operating costs.

- At a 50% market penetration of new sales, there is a $250 million annual market for a $5,000 vehicle-borne RSC-2 type system that is installed as optional equipment on new class-8 trucks. Conversions of existing trucks increases proportionately the size of this market.

- An infrastructure-based, RSC 8-12-type AHS has a clear evolutionary path starting with dense 1,200 mile corridor along I-80 between Chicago and Salt Lake City. Each mile of such a system could serve as many as 1.8 million truck movements per year if the economics are right. Because such a system would serve only a small portion of the driving cycle of most trucks using the system, the on-vehicle hardware costs can't be amortized over as many miles as an RSC 2, infrastructure-free system. It will be paramount to keep the on-vehicle costs extremely low so as not to stifle market entry by those trucks that could otherwise use the system.

- Future evolutions of an RSC 10-11-type AHS could grow to an 11,000 mile system that could serve roughly 50% of the current truck-served, inter-city freight market.

- Even by assuming a 100% market penetration, the 11,000 mile RSC 8-12-type AHS would only generate toll revenues of $110,000 per route mile at toll rates of $.10 per mile. This level of tolls can service the capital debt of about $1 million per mile. It is unlikely that motor carriers would be willing to pay AHS tolls that are much greater than $.10 per mile

- A driverless, SVE, RSC-8/9-type, Phase 3 AHS concept could serve a substantial amount of LTL demand. If toll charges are limited to approximately $.10 per vehicle mile, then, LTL demand patterns, shipment size, vehicle costs and existing freight rates suggest that each mile of such a system could serve as many as 600,000 of these shipments per year. Assuming a 50% market penetration, traffic densities on a Phase 3 network could generate toll revenues of about $30,000 per route-mile per year.

- Comparing the basic economics of the market for a driverless, RSC-2-type AHS with an infrastructure-intensive RSC 10-11-type AHS suggests that an RSC 2-type system is much more attractive to the inter-city freight industry. It's on-board costs can deliver benefits over much more of the driving cycle, the system has a much lower cost of entry (infrastructure does not have to be built), and even a mature RSC 10-11-type AHS does not serve enough volume, even at a large toll ($.10/mile) to service the cost of the infrastructure. This finding suggests that R&D investment focused on reducing the cost of reliable vehicle-borne, infrastructure-free RSC-2 type systems is the best way to have AHS successfully serve the inter-city freight market.

Conclusions for Intra-City Freight Movement

- Intra-city freight and the collection and distribution of inter-city freight are extremely difficult to serve with automation. The small shipment size and the multiple stop character of the operation are not conducive to automation.

- As with inter-city commercial bus operation, the driver performs more functions than simply driving the truck. The driver is the service interface with the customer.

- The geographic diffusivity of this traffic is such that much of the intra-city goods movement driving cycle takes place on road segments that are not compatible with an RSC-2 type AHS. Because each vehicle logs relative low annual mileage vehicle-borne AHS hardware can be amortized only over those few miles. An infrastructure-intensive RSC 8-12-type AHS serve even less of the driving cycle.

- AHS does not seem to be particularly attractive to this market.

Conclusions for the Commercial Inter-City Passenger Market

Table B-6 summarizes some of the major characteristics facing the commercial inter-city market.

Table B-6. Major Characteristics of the Commercial Inter-City Passenger Market

Existing Mode	1992 Market Size (billion p-m)	Opportunities for AHS	Notes
Inter-city bus	24	An RSC 2 system would be very attractive to this market	Major portion of bus fleet could covert to AHS operation
Inter-city rail	14	Little shift to private AHS vehicle, some markets could convert to inter-city AHS bus operation	AHS incursion into this market causes some public policy problems
Air passenger	340	Small opportunities for private vehicle AHS in short haul non- Northeast corridor markets	
Private air	13	No real competitive opportunity for AHS	

The major conclusions are:

- The commercial inter-city market is small in comparison with the inter-city passenger market served by the private automobile.
- The only likely short term commercial inter-city passenger market for AHS is that of inter-city bus. This is a very small market. Only 1,000 new inter-city buses are sold each year. However, the driving cycle of an inter-city bus is similar to that of an inter-city truck. Thus, it could provide a good secondary market for an RSC 2-type AHS that was designed to serve the inter-city freight market.
- The bus market is less conducive to a driverless AHS because the driver provides substantial benefits other than driving.
- An infrastructure intensive AHS has better opportunities than commercial freight to serve geographically contained sub-markets, because commercial buses can be managed to operate in constrained corridors. Such a system could better serve

geographic segments of the automobile market because the driving cycle of a particular automobile is much more geographically constrained than that of an inter-city truck.

- The large inter-city market is served by the private automobile. Unfortunately, on average, the private automobile travels too few miles on inter-city expressways to justify spending even a modest amount for an RSC 1/2 type system. However, there may exist some significant sub-markets, such as traveling salesmen, that could easily justify investment in an RSC 1/2 type system. Such systems also become more attractive if they could be used for the daily commute portion of the automobile's driving cycle.

Conclusions for the Intra-City Passenger Transit Market

- Urban transit, that is, for-hire, intra-city passenger transportation is only a small fraction of intra-city person transportation which is dominated by the private automobile. Nationally, transit serves only 3% of intra-city person trips.

- Only the express bus sub-market of transit is conducive to the early stages of AHS. A particularly attractive example of such a system is the exclusive counter-flow bus lane leading to the Lincoln Tunnel. This is the busiest bus corridor in the US

- There are several fundamental characteristics that make the Lincoln Tunnel XBL a particularly good application for AHS. First, there is a monumental problem on the horizon if a substantial capacity improvement is need in this facility. There is no place to put another access lane and the cost of boring another tube is enormous. Thus, capacity through automation would surely be the most cost effective solution. Even without need for capacity improvement, automation would smooth out the flow of buses and improve the travel time reliability of the buses. The application is on a very short corridor, less than five (5) miles, and the same busses use the facilities repeatedly. The institutional challenges are "minimal". All buses are the property of NJ DOT and were purchased with PA/NY/NJ money. NJ DOT and PA/NY/NJ have authority over all operations and construction in the corridor. For these major reasons, this is an excellent candidate "early winner" for AHS

- A Dual-mode service over a 750 mile NJ AHS network could provide auto-like service 780,759 passengers (71 %) out of NJ's 1,116,985 daily auto-based work trips that are greater than 5 miles in length. A \$.10 per passenger mile fare would generate annual revenues of about \$800 million. It may well be that fares would need to be more like \$.20 -\$.25 per mile for such a system to begin to contribute to the debt service payments for the AHSway.

- The average vehicle occupancy is 4.68 passengers per dual-mode vehicle. This is an enormous average vehicle occupancy, especially when compared with that of the current automobile's value of 1.1 for work trips. Because of this high average vehicle occupancy, the densest link on the network needs to serve a maximum of only 2,000 VPH.

- Dual-mode is an interesting transit concept for a mature AHS. It needs to have access to an rather extensive network of AHSways in order to serve a significant portion of urban/suburban travel demand.

- A driverless AHS transit application could piggy-back onto the economies of scale associated with private vehicle development and the AHSway construction.

- A driverless AHS transit system could serve metropolitan trip demand nearly as well as dual-mode without the need of drivers and with less confusion in the collection and distribution. This concept make more sense as the size of the network of AHSways grows, thus, reducing the access problem.

B.1.8 AHS Institutional, Societal, and Cost Benefit Analysis

The AHS institutional, societal, and cost benefit analysis consists of these two task report summaries: (1) Institutional and Societal Issues (Task O), and (2) Preliminary Costs/Benefit Factors Analysis (Task P).

B.1.8.1 Institutional and Societal Issues (Task O)

Key findings of this activity area are as follows:

- Perhaps, the most important finding of this task is that there are ***likely to be no insurmountable institutional and societal barriers – show stoppers – to the evolutionary deployment of AHS.*** This does not mean that surmounting some barriers will necessarily be easy. There is much to do before AHS deployments – beyond initial test sites – is feasible.

This finding itself rests on two of the earliest conclusions of this research effort:

- ***Institutional and societal issues and risks vary enormously depending on the RSC to be deployed***; and an important conclusion that seemed a bit daring when we first stated it early in the year, but which came be accepted with a surprising near-unanimity as of the conclusion of the April 1994 Interim Results Workshop, that

- Based on an analysis of the history of the introduction and acceptance of comparable, earlier technologies; the likely availability of funding, and the need to resolve some institutional and societal barriers incrementally as part of the process of deploying ITS technologies – even before AHS – ***AHS must develop evolutionarily from less infrastructure and outside-the-driver command and control technologies to more infrastructure dependent/greater outside command and control technologies.***

Additional findings include:

- Beyond confirming early (pre-PSA) predictions that AHS would be expected to provide air quality benefits – based on the assumption that carbon monoxide would be reduced simply because vehicles would move more consistently at higher speeds – ***it is likely that AHS will provide air quality benefits not only by reducing CO emissions, but also by reducing both the hydrocarbons and nitrogen oxides that create the more serious air quality problem of ground-level ozone.***

- ***Many institutional/societal issues that arise in connection with AHS are not unique to AHS, but rather, related to any plans to build roads today or in the future.*** The AHS effort cannot be expected to address, let alone resolve, all of these larger societal and historical issues. On the other hand, these issues can become barriers to the deployment of AHS. And to the extent that AHS may accentuate the effects of how some of these issues are perceived, for example, urban sprawl, the AHS effort must be aware of its place in this larger context of institutional and societal issues and be prepared to address such issues in its deployments.

- ***The awareness that AHS is likely to evolve evolutionarily from ITS technologies and that the ITS effort is addressing many of the same institutional and societal issues does not mean that all of these issues will be resolved through the ITS deployment process prior to the time when it is technologically feasible to deploy AHS.*** Nor can the AHS effort expect that even those institutional and societal issues that are "resolved" in the process of deploying ITS will necessarily simply "go away" for AHS. Moreover, there are institutional and societal issues that are likely to arise specifically with AHS, as opposed to ITS, technologies.

- ***If the AHS technology is not generally available at modest cost, there are important equity issues involved in reserving or constructing a lane for the use of relatively wealthy private vehicle owners.***

- The AHS effort must play "catch-up" with the long-term state and regional transportation planning already well underway in response to previous state and federal mandates and the more recent 1990 amendments to the Clean Air Act and

1991 ISTEA. ***Transportation plans for the next 20 years in congested areas in many cases are looking to rail projects to address many of the same transportation issues that an AHS might conceivably address.***

- Application of the technology to a mode of transportation that serves moderate-income commuters in an existing, heavily used corridor under the institutional jurisdiction of relatively few actors provides the kind of setting that could allow an early AHS success. AHS proponents must focus on both short-term and long-term opportunities by being aware that it is the institutional and societal milieu that determines if, when and where new technologies such as AHS will be deployed and being prepared to: (1) maximize the use or imminent improvement of existing facilities to demonstrate the benefits of AHS, even, or perhaps particularly, when the technology is used exclusively for non-personal vehicles, and that **such an early win opportunity may be represented by the desirability of automating the existing Lincoln Tunnel exclusive bus lane in New Jersey;** and (2) support the development of non-AHS facilities where there may be a good opportunity for later conversion to automation.

B.1.8.2 Preliminary Costs/Benefit Factors Analysis (Task P)

Formulating the expected costs and benefits of an AHS requires the use of a conceptual framework for determining types of costs and benefits, measures of cost and benefits, and an understanding of the uncertainty involved in the range of estimates derived as a result of the framework. We have developed an analytical matrix that accomplishes this task. We have also evaluated the major factors affecting the incremental costs of an AHS system, from initial research, to early deployment, through ongoing operations. Similarly, we have identified the most important benefit measures to be travel time savings, from the point of view of AHS road users themselves; accident avoidance and congestion avoidance benefits, from the societal point of view; and traffic throughput from the road operator's point of view. In addition, there are significant construction and ongoing operations and maintenance benefits to be gained as a result of secondary or "multiplier" effects of spending resources in deploying such systems regionally, or even nationally. Other benefits, such as productivity improvements at the workplace, will have to be an area for further research. It is conceivable that these may be significant, but quantifying such benefits, when little is known or predicted about the share of (say) commuting trips that are taken on AHS roadways the produce travel time savings or other user comforts/conveniences, is difficult if at all possible.

On the cost side, AHS roadways will incur substantial infrastructure construction, operating and maintenance costs. In addition, there are the costs of on-board electronics, as well as the added costs of the system infrastructure. A proper evaluation of AHS systems will thus have to consider these cost components.

We also examined traffic data for several actual roadways that could implement candidate AHS systems. Considering estimates of both benefits and incremental costs for these actual roadway scenarios, we found that, on the whole, AHS roadways do not produce sufficient economic gains to outweigh potential costs. Only in one of our roadway scenarios did we find that AHS roadways would pass a numerical cost-benefit test. However, we cautioned against over-interpreting these results. Our estimated performance gains were just that: estimated. Our cost estimates could be subject to wide variation when real systems would be actually deployed. But this exercise provided us with some useful insights into some of the more prominent relationships between benefits and costs when considering AHS.

Our research focused on the major benefit and cost factors that should enter into proper evaluations of candidate AHS systems. We first defined the economic rationale behind cost-benefit analysis. The strongest principle of a sound investment in a project is its internal rate of return, which is the discounted present value of its projected income stream net of its initial investment and all other costs to be incurred during its projected lifetime. A project with a projected rate of return that is both large and positive is indeed a project that should be undertaken. Alternatively, we reviewed the net present value appraisal method. A project should be undertaken if its net present value, or its net discounted stream of future income minus costs, is positive. For example, we found that travel time savings will accrue to some roadway users after implementing an AHS system. These savings, expressed in dollars, constitute one component of the annual stream of expected benefits. On the other hand, annual periodic payments need to be made for the upkeep of the roadway, to take another example. These payments are counted in the future stream of costs.

Following our discussion of cost-benefit principles, we discussed the importance of considering cost-benefit analysis for the policy context. There will be many goals expected from future AHS systems. Roadway operators will be concerned with performance gains, such as increased vehicular throughput and gains in operational efficiency, particularly in inclement conditions. Users will be concerned with increased in comfort and convenience and reductions in operating costs, delay and congestion, as well as better schedule reliability. To society as a whole, AHS roadways will have to deal with the roadway safety issue, with traffic congestion, with better personal mobility, with trip and schedule reliability, and so on. Concurrent with such benefit categories, AHS roadways will have to accomplish such gains while keeping deployment, operation, maintenance and renewal costs to a minimum. The importance of cost-benefit analysis, then, in this policy context, is to outline these categories of expected system benefits and costs so that AHS can be evaluated effectively, or even tailored so that it can achieve the maximum gain for the least amount of cost in general.

Our next objective was to ensure that we could capture the major components of system benefits and costs. To do this, we research several possible evolutionary deployment scenarios for representative AHS roadways. At each step in the evolutionary process, the costs of deploying systems would generally increase, with often either a corresponding or a less than corresponding increase in expected benefits. We took care in distinguishing between performance gains themselves, and the perceived value to users or others of such gains. We included at first all of the major components of benefits and costs, and then judged several distinct components to be more than significant than the others using currently accepted standards of evaluation.

In particular, we judged travel time savings, accident cost savings, and the secondary economic effects of ongoing operations and maintenance activities on societal output and employment to be among the most important categories of economic benefits that are the most easily quantifiable. Other benefit measures, such as general increased in workplace productivity or better schedule reliability are certainly important, but do not readily lend themselves to reasonable quantification. On the cost side, we found that the major component of system costs is the actual construction cost of the AHS roadway. Other important costs include system infrastructure costs, vehicle electronic costs, and the costs of ongoing operations and maintenance.

To apply our general principles, we then considered four candidate real roadways where deploying some form of AHS would be possible and even desirable. We looked at New York's Long Island Expressway and the New York State Thruway, Baltimore's section of Interstate 495 and Boston's Interstate 93. Our analysis of these roadways suggested that, at least conceptually, AHS deployment would pass a numerical cost-benefit test on only one roadway scenario, New York's Long Island Expressway, a particularly congested roadway with parked peak hours of congestion, and a roadway with significant commercial vehicle access as well as transit (bus) use. However, that is not to suggest that AHS as currently configured does not make economic sense anywhere else. There are several reasons for this. One, our current evaluation methods are relatively crude, and cannot capture the major societal effects of general improvements in living standards or in workplace productivity as a result of reducing the stress, fatigue and accidents involved with major commuting patterns. Two, our analysis is preliminary and is entirely limited by the many assumptions used in our traffic analysis, cost estimates, and roadway deployment scenarios. It is entirely possible that as we refine our work in these and other areas, we will derive performance gains that are much more substantive. Three, there are too many uncertainties with regards to the possible makeup of future AHS systems that concluding at this stage that AHS has only limited economic applicability would be too premature. Clearly, AHS displays a considerable amount of promise with regards to potential economic gain, and this needs to be carefully developed further. Particularly since AHS will undoubtedly involve a significant commitment of public resources, its justification will hinge on the ability to develop and achieve such gains.

B.2 CROSS-CUTTING ANALYSIS FINDINGS

The conclusions and key findings in the individual tasks reports, presented above, already identify a number of cross-cutting conclusions. The cross-cutting conclusions in this section represent the major findings, but more importantly, are organized in a manner that consolidates the results.

One major difficulty in effectively synthesizing the task results is the extent to which the individual tasks are based on common assumptions. The definitions of the RSCs provide one level of common assumptions; however, it is possible that some task conclusions arise from different and possibly contradictory assumptions. Therefore, we have been careful to only combine conclusions that come from similar assumptions.

It is important to state at this time five major themes associated with our study approach. They are:

- The AHS analysis was performed with a priority towards **breadth of research** rather than depth of research. For example, the comparable systems task, the lateral and longitudinal guidance task, the institutional and societal task, and others all were very broad in scope.
- A **conservative approach to safety** impacted most all design analysis. For example, the costing of the infrastructure included the cost of a breakdown lane for malfunction management purposes.
- **Detailed infrastructure analysis** was performed. Since the infrastructure is such a costly component, the costing exercise utilized actual scale drawings of the roadway design to provide greater accuracy.
- **Travel time benefits for four representative roadway scenarios** were carefully calculated. Most benefits models are driven by time reduction calculations. Therefore, the INTEGRATION model was exercised to supply estimates of travel time savings.
- A comprehensive study was performed of the **market potential of commercial and transit applications of AHS.**

This section is organized into the four topics: (1) AHS Configuration and Deployment, (2) Technical System, (3) Benefits and Costs, and (4) Institutional and Societal System Impacts. These topics were chosen to represent a high level systems view of AHS design, implementation, and operation issues. They are the researchers own choice and are not the only system level view available. However, they are a convenient structure to frame the major conclusions. The major element of the synthesis approach was to organize, analyze, and combine the individual task key findings into this new structure.

B.2.1 AHS Deployment

B.2.1.1 Deployment Strategy

The deployment strategy analysis consisted of three separate parts. Initially, the various RSCs were analyzed for applicability to generalized deployment scenarios that cover the full spectrum of AHS applicable roadway environments (i.e., urban, suburban, and rural). The results of this general analysis were then used to guide studies of specific roadway deployments, with both SVE-only and mixed SVE and MVE AHS use. A third area of analysis then focused on the issues associated with the evolutionary aspects of deployment.

B.2.1.2 Urban, Rural, and Suburban Environment Analysis

The target for AHS deployment is our national freeways, the backbone for worker commuter, inter- and inter-city travel and the major roadway choice of America. Freeways, pressured to carry more traffic, are experiencing crippling and prolonged congestion. The remedy for congested freeways is not to build more of them but to make them work more efficiently. AHS analysis is based on this premise.

Experienced transportation engineers recognize the fact that freeway problems are not the same for urban, suburban and rural environments. They were not built for the same purposes, were not engineered the same, and do not operate the same. Therefore, the three environments provide different market potential, different design problems, and different operational considerations.

Our **major conclusion** in this area is that envisioning AHS as a national system requires flexibility of design to accommodate urban, suburban, and rural needs. The urban, suburban, and rural environments cover a spectrum of needs. Therefore, a variety of configurations are required to meet each of the needs. Suburban would be more I3 driven and rural would be more I1 driven. As discussed above, the I1 configuration would be more compatible with C1 control. The I2, I3 or mixed I2/I3 configurations would be more appropriate with C2 or C3 control. (UR11)

This study centered around deployments in the northeast US. Within this region, sufficient roadway diversity exists to support the requirement for a flexible implementation strategy.

Other major infrastructure related conclusions involve (1) minimum AHS and general use lane requirements, (2) use of manual lanes for access to the AHS lanes, and (3) the impact of increased throughput on surrounding roads.

The key findings in these areas are:

- If one assumes that rural AHS will initially operate in mixed traffic lanes, when AHS use increases, and higher throughput performance is required, the minimum lane requirements appear to be one AHS lane and two general use lanes. This requirement will impact most of the dual two-lane freeways (outer suburban and rural). Although traffic volumes may show only a need for a single general (manual) lane, entrance/exit, passing, incidents and operation during maintenance will probably require a minimum of two general lanes. This step in the evolutionary process is the most costly and the greatest risk to evolutionary advances of AHS. More detailed discussions about evolution of AHS is presented in section 5.2.2.4. (UR8)

- Suburban freeway deployment is a prime candidate for initial implementation of separate AHS, since the increased throughput is required and the right-of-way may be available. However, equal provisions need to be made for entry and exiting. A major infrastructure design issue for AHS deployment is finding solutions to the traffic mixing, weaving, entry and exit with non-AHS vehicles especially heavy trucks. (UR7)

- One of the highest infrastructure impacts assigned to entry/exit requirements is the merging of two AHS streams starting at right angles. This is due to the large radii required if speed is maintained, and the lack of such a requirement in today's highway geometries. (EE5)

- Infrastructure design issues, including exit and entry location and techniques, are not easily generalized. The four separate freeway case studies concluded that the placement of entries and exits significantly impact the traffic flow. Depending on the OD requirements, the capacity of the remaining general lanes rather than the AHS lanes may limit overall capacity. Likewise, the specific street and traffic situations dictate requirements on exit and entry techniques.(RDPE3, EE3, EE4)

- AHS can increase throughput during peak hours provided the supporting interchanges, feeder roads and city streets can accept this increase. At the proposed high flow rates, urban and suburban facilities now regularly fail. Only rural freeway feeders have the capacity required. (UR9)

B.2.1.3 Specific Deployment Case Studies

Four case studies were developed to assess the performance and potential benefits of AHS within these representative roadways. The four scenarios included one urban, two suburban, and one rural freeway. Traffic loading for AHS and general lane configurations were developed for each case study. The INTEGRATION traffic model was adapted for AHS evaluation purposes, and the performance of each AHS design was evaluated relative to a baseline or no build case. The effects on nearby surface street intersections were evaluated in some cases.

B.2.1.4 Urban and Suburban Case Studies

Three of the studies were performed using roadways that are characterized as either urban or suburban. They are segments of: the Maryland Beltway (I495) near Washington DC, the Long Island Expressway (I495), and the Southeast Expressway in Boston (I93). Six conclusions from these studies are:

- Deployments on congested urban and suburban freeways can significantly improve speed and travel time on these facilities. Travel time improvements of up to 38 percent were obtained for the cases studied.

- The selection of access techniques is best determined by the AHS access and egress volume requirements, by the general lane traffic of these locations, and by the LOS on the general lanes.

- In areas which experience high levels of traffic congestion, such as Long Island, high levels of AHS utilization are obtained based on relatively low levels of AHS Market Penetration (15-25 percent).

- In congestion prone areas, the AHS may generate significant changes in the utilization of parallel facilities located several miles away from the AHS. However, as market penetration increases, as was evident on Long Island, the attraction of the AHS facility to distant parallel roadways decreases, and total VMT in the study area decreases.

- The need to access the AHS will, in many cases, cause saturation of surface street intersections. Geometric improvements and signal timing changes will be commonly required.

B.2.1.5 Rural Case Study

The rural case study was for a segment of the New York State Thruway (I87) north of New York City.

One conclusion from this study is that significant travel time improvements on the rural facility were only obtained when the AHS cruise speed was increased to 80 mph from the 62 mph speed used for the urban and suburban case because the roadway runs at the speed limit with no recurring delay.

B.2.1.6 Commercial and Transit Case Studies

The deployment results presented above are based on only passenger vehicle types. The assumptions used vehicle headways, and associated capacities, that were based on passenger vehicle characteristics. Three separate case studies were used to study the effects of mixing commercial and transit vehicles with passenger vehicles. These case studies were for the Long Island Expressway, the New York State Thruway, and the New Jersey Turnpike. The results indicated that each type of interstate highway, urban or rural, exhibited varying capabilities for incorporating AHS technology over a mix of vehicle types. Four of the more significant conclusions are:

- The most efficient travel occurs with passenger vehicles and large commercial and transit vehicles separated, either both in AHS lanes or one type in AHS lanes and the other in the manual lanes.

- AHS technology is viable to alleviate congestion. The findings for the LIE indicate that an exclusive AHS lane for all commercial and transit vehicles and all passenger cars distributed evenly between two general use lanes, with an ultimate capacity of 8,900 pcph, would be the most beneficial case for people-moving efficiency. These options also exhibit favorable average vehicle occupancies for compliance with the CAAA/ECO Program goals.

- Along the east spur of the New Jersey Turnpike an exclusive AHS lane for only passenger vehicles and two general use lanes for all vehicle types or an exclusive AHS lane for all commercial and transit vehicles and all passenger cars distributed evenly between two general use lanes, with ultimate capacities of 8,900 pcph, prove to be the most efficient. These options for the combined section of the Turnpike would also be relatively efficient in people-moving efficiency. These options would require carpools of two or more persons and aid in the effort to achieve the CAAA/ECO Program goals.

- 'No Build" conditions in 2024 on the New York State Thruway would not require excess capacity. An AHS could be implemented in this corridor for reasons of safety and efficiency. One AHS lane and two general use lanes would be the most effective option. None of the Options would meet CAAA/ECO Program goals.

B.2.1.7 Evolution versus Revolution

The question continually surfaces as to the extent, cost and associated benefits of the initial implementation. Simply stated, the question is one of evolutionary deployment versus revolutionary deployment. The evolutionary approach would entail simpler, less costly systems that provide compatible benefits. It would then grow incrementally, with appropriately scaled costs and benefits, to a more complete system. Each stage would be driven by the market. The revolutionary approach is much different from this strategy. It is driven by the need to implement a complete system in order to generate sufficient benefits to outweigh the costs. The assumption is that the market will not drive the incremental growth; it needs to be orchestrated in one collective effort.

B.2.1.8 AHS Operations

Deployment strategies must include operational issues along with the more visible design and development issues. The long term viability of the system depends heavily on the effectiveness of systems operation, which is highly focused on organizations and procedures. Key findings follow:

- For operation of an AHS, new or hybrid operating agencies and their organizational frameworks will need to be defined along with their potential operations responsibilities. The levels of association, coordination, and autonomy among the operations elements of existing highways, such as management, maintenance, police and emergency services need to be identified along with potential problems with existing arrangements of these operations elements. Each operating agency scenario and the operational impacts of a multi-jurisdictional framework need to be evaluated and studied. Evaluation criteria should include operations uniformity, effectiveness, and practicality of providing such service.

- Current levels of expertise and staffing available at existing operating agencies can not support the requirements necessary for an AHS. The areas of expertise required for operation and management of an AHS need to be evaluated. Survey and review of current practices of in-house versus contracted-out functions at state DOTs and highway authorities are essential to final deployment of AHS.

- AHS operations require preventive maintenance on a level similar to the airline industry. Existing levels of preventive maintenance performed by highway operating agencies, including operators of traffic management systems, will not satisfy the requirements of AHS. A target level of preventive maintenance for AHS needs to be defined through investigations of comparable systems.

- It is anticipated that the AHS will need policing and involve policing tactics different from those practiced today. Dependent upon the RSC, the level of policing, police functions, and tactics will vary. Current policing practices need to be examined, including the level of policing, functions and tactics applicable to deployment of an AHS

- AHS should be designed with system upgrades in mind. System upgrades and expansion need to be accomplished with only minimal disruptions of service. System upgrades should accommodate earlier AHS users after it is upgraded.

B.2.2 Market Potential

The specific AHS system configurations and the various deployment strategies should be driven by the market need. **That is a clear result of this study and a mandate for any follow-on program.** The market has many facets however and all need to be included. It includes the public and private system operators, who are responsible for building, operating and maintaining the roadways that serve potential AHS customers. It also includes the various private vehicle operators that use the roadways for work commutes, inter-city business travel, vacation travel, etc. It includes the private and public commercial and transit industry. It also covers the various manufacturing elements of the system; vehicle manufactures, roadway electronics, etc. that will be driven to find cost effective methods to supply products.

Our study offers a broad base of results as to the potential of enticing these various elements of the market to invest in the future of an AHS. We have organized our findings into: (1) the overall market potential of the system; and (2) the market strategies that are required to demonstrate the potential.

Our research into overall market potential of the system focused more on the quantifiable traffic related benefits of the system rather than the more subtle benefits of user comfort and convenience and increased productivity.

Our key findings in this area follow:

- Research into AHS technology is important as this defines the "How". Equally important is research in the market to identify size and needs as this defines the "Customer". The "How" should be driven by the "Customers' Needs".

- The daily user of urban and suburban freeways wants travel time savings as a performance improvement. Acceptance of AHS equipment and traffic management costs will be based on the performance gain. A target goal for this savings is one minute per travel mile; totaling at least ten minutes on the freeway portion of the trip. This objective can be accomplished by providing preferential lane and exit/entry provisions for AHS users, since automated control can regulate speeds above the current congested level.

- Worker commuter users of urban and suburban freeways are effective targets for early deployment of AHS. These individual users have a vested interest in making AHS a success as they gain time, reliability, and safer trips. As a daily user, they should be willing to equip their vehicles and pay for the service. HOV users and Transit providers are prime customers for AHS since they are currently part of the solution for urban and suburban congestion.

- In areas which experience significant traffic congestion, such as Long Island, high levels of AHS utilization are obtained based on RSCs I2 and I3 type facilities at relatively low levels of AHS Market Penetration (15-25 percent).
- A large AHS benefit can be achieved with transit vehicles. AHS when combined with transit and/or HOV treatments can provide very significant improvements to the people-moving capacity of our highways. These treatments are especially applicable to (and perhaps limited to) AHS applications in urban areas and along congested corridors. When considering the AHS goal of congestion mitigation, the potential of these treatments cannot be overlooked. For example, an AHS implemented in the Lincoln Tunnel Express Bus Lane could potentially provide people-moving capacity greatly exceeding that possible with heavy rail mass transit (although this would require expanded terminal capacity). Even HOV treatments on AHS could potentially provide service comparable to existing light rail systems.

B.2.3 Technical Aspects

The RSCs are generalized approaches to specific AHS technology implementations. They served a useful purpose for supporting the generalized deployment studies, reported in section 5.2 above. However, all of the analysis assumed: (1) the technology was available to safely and reliably deliver the level of automation required by the market, and (2) the system design appropriately accounted for driver capabilities. This section reports on our research findings relating to these two broad assumptions.

It is organized into three major subsections. The first subsection, entitled Automation Capability, covers the areas of automated control, driver role, and safety, reliability, and malfunction management. The next subsection covers the more global automation issue of traffic management. Lastly, a subsection is included that reports on AHS vehicle propulsion system alternatives to the conventional SI engine.

B.2.4 Automation Capability

Automation of manual operations has been an ever increasing element of our society over the last few decades. A few examples are unmanned elevators, robots for manufacturing, aircraft automation, and ATMs. The surface transportation industry's experience with automation is not as extensive as other aspects of society. It is mostly relegated to transit vehicles operating on fixed guideways. Therefore, the automation of rubber tired vehicles using interstate highways is a very significant and challenging technology initiative.

Our key findings are:

- The most promising lateral control technology involves magnetic markers or overhead wires.

- Headway radars will be required to provide high azimuth angle resolution.

- Infrastructure-based systems may be cost effective.

- There is a tradeoff between longitudinal maneuver errors and noise immunity.

- Sensors for lateral and longitudinal control must be capable of performing under severe adverse weather conditions.

- Communication between vehicles may not be required for vehicles following at gaps of 0.5 seconds, even during emergency maneuvers.

- Entry and exit techniques are key to the derivation of traffic flow related benefits since they dictate maximum flows throughout the system.

- The different entry/exit techniques associated with the different RSCs may well all find application on a single AHS because the specific design requirements of each street and traffic situation dictates the best technique.

- The check-out "test", associated with exit from the AHS lane, should be an integrated part of the larger check-out process that has the driver take control of the system rather than the system give control to the driver.

B.2.4.1 Driver Role

The manual driver is a very significant component of the existing interstate transportation system. He or she performs a variety of tasks that are critical to the safe operation, trip reliability, and overall system performance. He or she will have a new role in the AHS. By definition it will be less time consuming but it will still require retention of some of the old skills and, importantly, development of new skills.
Some key driver-role related findings in the check-out area are:

- During the process of transition from automated to manual driving, the driver must take control of the vehicle rather than having the vehicle give control back to the driver.

- The check-out "test" should be an integrated part of the larger check-out process.

- If check-out "tests" are required during the automated portion of the trip (for the purpose of maintaining an adequate level of vigilance), these "tests" should be meaningful and not artificial and extraneous.

- The driver portion of the check-out process must account for the wide variability in capabilities within the driving population.

One, often discussed, driver role associated with AHS travel is "Brain Off as well as Hands and Feet Off". This is in contrast to a "Brain On, Hands and Feet Off" role. We studied both roles as part of our fault hazard analysis work in the safety and malfunction management tasks. Both roles require further investigation but our preliminary conclusions are:

- Not allowing the driver to completely relax maintains a very capable and intelligent system component that would be extremely expensive to replace.

- Allowing the driver to be completely detached from the system eliminates the concept of manual backup, increases the requirements for malfunction management, and raises concern for AHS exit policies.

B.2.4.2 Reliability, Malfunction Management and Safety

The reliability, safety and malfunction management aspects of the system are critical to the AHS market driven strategy. These characteristics are not products of the system design. They are drivers of the design. Therefore, a number of issues relating to reliability, safety, and malfunction management need to be addressed as the AHS system design moves forward.

One comparable systems study conclusion clearly states the compelling case for designing a safe and reliable AHS system: "The safety and reliability of AHS must be clearly demonstrated".

The major key findings are:

- **Check-in tests should be performed on the fly.**

- **Actuators for steering, throttle, and brakes will require testing in a series of dynamic tests.**
- **Vehicle testing will be performed continuously during AHS operation.**

- User data and analysis show that an automation failure rate of one per 2000 vehicle. hours. is feasible. This would provide acceptable levels of service for an AHS.

- The full answer to the cost impacts associated with delivering a specific failure rate performance, both acquisition and lifetime maintenance, must remain uncertain until specific designs are considered, but we are optimistic in terms of realistic market costs.

- The key issues in the approach to the question of safety are the use of redundancy in vehicle equipment, and the use of a breakdown lane, entry/exit protocol, and handling communication failures. Our study suggests design approaches to deal with these issues.

- Barriers in the I2 scenario would reduce the probability of vehicles and other objects from moving into the AHS lane from the manual lanes. The ability of an automated vehicle to cope with such objects is problematical, making consideration of barrier use part of a realistic malfunction management strategy.

- The check-out process needs to check vehicle components not utilized during the AHS travel.

- Crash types similar to those on today's interstates will probably become the crash types that occur on an AHS under **non-normal operating conditions**. The causal factors will be AHS unique, the number of vehicles involved will probably be greater, and the distribution of crash types will vary from today's interstate accident picture.

- The most common crash types to result in a fatal injury are the single vehicle accidents that are rollovers, barrier related, roadside departures or involve an object or animal in the roadway. Head-on and Sideswipe Opposite Direction are extremely low frequency events on interstates.

- Rear-end crashes are likely to be the most frequently occurring AHS crash type, especially under some very small headway concepts. The primary measure of collision impact severity is V, defined as the change in a vehicle's velocity, taking into account vehicle mass. Occupant injury levels and vehicle damage severity's were expressed as a function of V. This analysis was performed to estimate "tolerable" Vs for collisions on an AHS. Once tolerable Vs are obtained, safe headways for travel speeds based on maximum deceleration of a lead vehicle involved in a crash can be calculated.

- Vehicle occupants suffered injuries requiring transportation to a medical facility where they were treated and released from crashes in the 6 to 10 mph V range. Injuries requiring hospitalization resulted from crashes in the 11 to 15 mph V range.

This not only implies the seriousness of the incident in terms of occupant injury, but also indicates the amount of time necessary to clear the accident scene, and its influence on the perceived safety of the AHS.

- Barrier-related crashes represent another potential AHS crash type. CDS data show that left roadside departures account for approximately 78 percent of barrier crashes that occur on roadways with speed limits greater than 50 mph. This finding strongly supports the use of barriers on the AHS since, without a barrier between automated and manual lanes, left roadside departure vehicles from the manual lanes will intrude into the AHS.

- The likelihood of a lane-blocking incident on an AHS under normal operating conditions may be viewed as the possibility of a crash with an object or animal in the roadway. Automation is capable of creating a "smart driver" that knows the state of the vehicle, and the limits of the vehicle's handling capabilities for road and weather conditions, but automation cannot control objects or animals. Therefore, automation must deal with them, particularly on the long stretches of suburban and rural highways where the problem is most significant.

- The magnitude of the object in the road problem is not clearly defined. Accident statistics indicate the number of times a vehicle strikes an object or animal in the roadway, not the number of times a driver successfully maneuvers around an obstacle and still maintains control of the vehicle. The cost of preventing these elements from entering the AHS emphasizes the need for detection devices. However, even if it is possible to detect an obstacle that truly needs to be avoided, the longitudinal and lateral control systems must be capable of diverting the stream of vehicles, and they must have the room to maneuver the vehicles safely around the obstacle. (SI3)

- Crashes involving objects or animals represent 5.2 percent of all interstates crashes. Given the 490,336 million vehicle miles of travel on US interstates, this equates to a rate of 0.03 incidents per million VMT. However, this does not account for the situations where the driver encountered an object and successfully avoided the crash. Additional events, under non-normal operating conditions, that may lead to "AHS roadway obstacles" or lane-blocking incidents are:

  - Loss of lateral control
  - Offset rear-end crashes
  - Rear-end crashes on low traction surfaces (perhaps due to fluid spills)
  - Lane/change merge crashes
  - Crashes related to driver impairments

B.2.5 Traffic Management Aspects of AHS

Full automation of vehicles operating on an AHS roadway, when viewed collectively, is a form of traffic management. It is a natural extension of the initiatives that are taking place in ITS research and deployments nationwide. These advances in Advanced Traffic Management Systems will be directly applicable to aspects of AHS operation as well be required as a seamless interface to the manual system. Therefore, lessons learned from these initiatives are useful for current and future AHS research.

One key finding from the comparable system study involves the desirability of designing for fully centralized control. "The degree of centralized control and human decision making can slow system response".

B.2.5.1 Traffic Management Impacts related to Exit and Entry

- Entry/exits are key to AHS practicality since they dictate maximum flows throughout the system, are a big cost driver, and are a primary impact on the community.

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

- Certain AHS control strategies call for queuing vehicles at AHS entry points. Properly managed AHS traffic maintains queue delays and queue lengths at acceptable values.

- Major sources of urban and suburban freeway congestion are incidents (non-recurring), bottlenecks at entry/exit points (recurring), and scheduled maintenance (non-recurring). AHS vehicle instrumentation and TM are tools to eliminate congestion, provided poor roadway geometry is corrected.

B.2.5.2 Traffic Management Benefits for AHS

- The attraction of the AHS facility in congestion prone areas results not only from increased capacity, but also, because of the facility's ability to sustain a constant comfortably high speed of 60 mph at increased volume.

- An AHS facility on a congested urban or suburban freeway might tend to reduce the total travel time vehicle-hours in comparison to comparable non-AHS facilities, while satisfying the trip demand. This finding, however, must be tested further using a more precise modeling technique.

- AHS traffic controllers, according to derived capacity-versus-speed estimates applicable to automated vehicles, will have the ability to provide a tradeoff between velocity and capacity to accommodate substantial volume variations.

- Optimize operational improvements on urban and suburban freeways along with introduction of AHS, as it a part of a TM package not a stand alone service. TM includes; surveillance and control systems, ramp metering, incident management, motorist information systems, HOV facilities, and low-cost geometric improvements. These TM techniques are required to supplement AHS full automation.

B.2.5.3 Traffic Management Operations

Current TM systems are primarily passive (and at best semi-automatic) and rely on macroscopic state variables such as density and speed to identify congestion and incidents. While traffic flow management requirements of an AHS would vary by RSC, configurations with central control will require a more discrete, microscopic orientation of traffic monitoring and management. The characteristics of traffic flow monitoring and management need to be examined and defined as AHS evolves.

Although it is the promise of the AHS to reduce the occurrence of incidents, the impacts of any incident on AHS could be more severe, due to the higher capacities, with regard to traffic operation. Therefore AHS must improve incident detection and shorten incident response time. The impact of traffic congestion and delay on an AHS lane will be much greater than current impacts to the existing highway system. Therefore, the incident response time must be reduced in order to maintain current highway levels-of-service.

B.2.6 Benefits and Costs

There economic goals (potential benefits) and potential costs of an AHS system program are many. To roadway operators, who are concerned with operational parameters, AHS should increase vehicular throughput and operational efficiency, particularly in inclement conditions such as adverse weather. To society as a whole, an AHS corridor should reduce trip times, improve trip and schedule reliability, improve safety, and enhance personal mobility. An AHS system should accomplish these and other goals while reducing vehicle operating costs, reducing societal insurance costs, and perhaps reducing the cost of making an individual trip by automobile. Achieving these very broad goals through implementation of such an advanced technological system is an extremely challenging task.

The cost benefits task, conducted within this study, was only able to begin to determine economic feasibility for a system at this stage of development. This task was not designed as a final say in whether to proceed with any particular AHS program. Rather it only sheds light on methods to properly evaluate and appraise an AHS.

Our specific charge was to develop a conceptual framework for analyzing costs and benefits; determine cost and benefit measures; list and rank by importance of impact such measures;

examine how such measures are affected by the evolutionary deployment of AHS systems; and, finally, examine the critical threshold points of incremental costs and benefits across various system configurations. Also, we were to examine four specific roadway deployment scenarios and report on benefit and cost measures to support the more generalized analysis.

Four candidate real roadways where deploying some form of AHS would be possible and even desirable were analyzed. We looked at New York's Long Island Expressway and the New York State Thruway, Baltimore's section of Interstate 495 and Boston's Interstate 93. Our analysis of these roadways suggested that, at least conceptually, AHS deployment would pass a numerical cost-benefit test on only one roadway scenario, New York's Long Island Expressway, a particularly congested roadway with parked peak hours of congestion, and a roadway with significant commercial vehicle access as well as transit (bus) use. However, that is not to suggest that AHS as currently configured does not make economic sense anywhere else.

There are several reasons for this. One, our current evaluation methods are relatively crude, and cannot capture the major societal effects of general improvements in living standards or in workplace productivity as a result of reducing the stress, fatigue and accidents involved with major commuting patterns. Two, our analysis is preliminary and is entirely limited by the many assumptions used in our traffic analysis, cost estimates, and roadway deployment scenarios. It is entirely possible that as we refine our work in these and other areas, we will derive performance gains that are much more substantive. Three, there are too many uncertainties with regards to the possible makeup of future AHS systems that concluding at this stage that AHS has only limited economic applicability would be too premature. Clearly, AHS displays a considerable amount of promise with regards to potential economic gain, and this needs to be carefully developed further. Particularly since AHS will undoubtedly involve a significant commitment of public resources, its justification will hinge on the ability to develop and achieve such gains.

B.2.7 Institutional and Societal System Impacts

All of the preceding analysis hinges, to a very large degree, on the view of AHS by transportation related institutions and society as a whole. The importance of the institutional and societal aspects of AHS design, development and deployment cannot be understated. AHS deployment is not just a technical installation exercise to provide a service. **Impacts on land use planning, air/noise pollution and public/political acceptance are probably more important than solving mechanical, electronic, and concrete problems.** If the development of the system is to be market driven, it must earn support from the myriad of associated transportation institutions. Since transportation is so pervasive in our society, these institutions are numerous. The support must also be enduring and that is why it is characterized as "earned" support. It will take work to earn the required support and the work must begin now.

During this study we documented the panoply of institutional and societal issues and risks that confront the effort to deploy AHS. The methodology involved a multi-stage process of reviewing all available literature regarding the subject of automated vehicles and highways and of ITS. The initial research lead to a categorization of AHS-specific issues and risks that was later modified to conform with commonly accepted categories being used by the ITS community.

Perhaps, the most important finding of this task is that there are likely to be no insurmountable institutional and societal barriers – show stoppers – to the evolutionary deployment of AHS.

Other key findings in the areas of air quality, land use, ITS versus AHS issues, social equity, transportation planning and liability:

- Beyond confirming early (pre-PSA) predictions that AHS would be expected to provide air quality benefits – based on the assumption that carbon monoxide would be reduced simply because vehicles would move more consistently at higher speeds – it is likely that AHS will provide air quality benefits not only by reducing CO emissions, but also by reducing both the hydrocarbons and nitrogen oxides that create the more serious air quality problem of ground-level ozone.

- Many institutional/societal issues that arise in connection with AHS are not unique to AHS, but rather, related to any plans to build roads today or in the future. The AHS effort cannot be expected to address, let alone resolve, all of these larger societal and historical issues. On the other hand, these issues can become barriers to the deployment of AHS. And to the extent that AHS may accentuate the effects of how some of these issues are perceived, for example, urban sprawl, the AHS effort must be aware of its place in this larger context of institutional and societal issues and be prepared to address such issues in its deployments.

- The awareness that AHS is likely to evolve evolutionary from ITS technologies and that the ITS effort is addressing many of the same institutional and societal issues does not mean that all of these issues will be resolved through the ITS deployment process prior to the time when it is technologically feasible to deploy AHS. Nor can the AHS effort expect that even those institutional and societal issues that are "resolved" in the process of deploying ITS will necessarily simply "go away" for AHS. Moreover, there are institutional and societal issues that are likely to arise specifically with AHS, as opposed to ITS, technologies.

- If the AHS technology is not generally available at modest cost, there are important equity issues involved in reserving or constructing a lane for the use of relatively wealthy private vehicle owners.

- The AHS effort must play "catch-up" with the long-term state and regional transportation planning already well underway in response to previous state and federal mandates and the more recent 1990 amendments to the Clean Air Act and 1991 ISTEA. Transportation plans for the next 20 years in congested areas in many cases are looking to rail projects to address many of the same transportation issues that an AHS might conceivably address.

- Application of the technology to a mode of transportation that serves moderate-income commuters in an existing, heavily used corridor under the institutional jurisdiction of relatively few actors provides the kind of setting that could allow an early AHS success. AHS proponents must focus on both short-term and long-term opportunities by being aware that it is the institutional and societal milieu that determines if, when and where new technologies such as AHS will be deployed and being prepared to maximize the use or imminent improvement of existing facilities to demonstrate the benefits of AHS, even, or perhaps particularly, when the technology is used exclusively for non-personal vehicles. **Such an early win opportunity may be represented by the desirability of automating the existing Lincoln Tunnel exclusive bus lane in New Jersey.**

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

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

- Support from influential persons in Government and industry is important for large programs. The success of many large-scale projects has been facilitated through the commitment of high ranking officials from Government or industry who were willing to work hard to ensure the success of the projects. AHS will benefit from such an individual (or group) to help secure the necessary financing and support, and to help maintain enthusiasm for the project during all stages of design and implementation..

- Cost and time estimates for developing AHS must be carefully and accurately determined. Budget overruns and schedule slippage can lead to negative publicity, poor public acceptance, and reduced political support for the system. System design, testing, and implementation must remain within budgetary guidelines and time constraints for the project to ensure continued support. Cost and schedule "bad news" can reduce public acceptance of AHS, even when the shortfalls are due to estimation errors, rather than the more serious system problems. Also, it is important to plan for schedule and cost contingencies. AHS developers must carefully make realistic estimates concerning the amount of time the system will take to implement, and the amount of money it will cost to complete. Overly optimistic budget and schedule estimates look good at planning time but lead to almost certain failure, at least as measured against budget and schedule.

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