APPENDIX A

HIGHLIGHTS OF DELCO OVERVIEW REPORT

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

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

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

A.1 CROSS-CUTTING CONCLUSIONS/OBSERVATIONS

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

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

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

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

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

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

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

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

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

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

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

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

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

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

A.2 FOCUS OF THE INDIVIDUAL ACTIVITY AREA ANALYSES

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

A.3 HIGHLIGHTS OF THE ACTIVITY AREA TECHNICAL ANALYSES

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

A.3.1 Activity A - Urban And Rural AHS Comparison

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

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

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

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

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

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

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

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

A.3.2 Activity B - Automated Check-In

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

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

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

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

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

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

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

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

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

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

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

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

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

A.3.3 Activity C - Automated Check-Out

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

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

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

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

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

The issue of driver readiness to resume manual control is related to issues of privacy and liability. There is a broad range of tests available to verify driver capabilities, including sensors to detect the presence of substances in the driver's blood, prompts to gauge reaction times, or scanning of eye movement to evaluate alertness. The invasiveness of certain tests may cause concerns among privacy advocates and have an adverse effect on user acceptance.

The assignment of liability in the event of an incident following the transition to manual control is a concern as well. Extensive tests may create the impression that the AHS is responsible for ensuring that no impaired drivers are allowed to have manual control. It is recommended that the driver check-out consist of a simplified routine that places the responsibility for assuming manual control completely with the driver. The check-out process might follow a screening of manual brake and steering functionality with a prompt to the driver. The driver will then respond with a positive action such as pressing a push-button to indicate readiness to assume control. Legislation may be required to clearly delineate the responsibility for accidents following transition from the automated lanes.

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

A.3.4 Activity D - Lateral And Longitudinal Control Analysis

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

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

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

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

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

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

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

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

A.3.5 Activity E - Malfunction Management And Analysis

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

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

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

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

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

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

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

The management strategy for each malfunction can be divided into two parts: a set of immediate actions to contain the malfunction and a set of actions to restore AHS operation.

Five sets of immediate actions were defined that cover all of the malfunctions and five sets of actions to recover from the effects of these immediate actions were also defined.

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

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

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

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

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

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

A.3.6 Activity F - Commercial And Transit AHS Analysis

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

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

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

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

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

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

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

A.3.7 Activity G - Comparable Systems Analysis

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

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

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

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

Technical systems specifications:

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

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

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

Verification of system performance:

- A comprehensive set of performance parameters along with reasonable evaluation methods must be established. In some aspect, it proved very difficult to establish measurable performance parameters for parts of TravTek. For instance, a measurable parameter was never established for the quality of traffic data from the Traffic

Management Center. It turned out that the poor quality of this traffic data was the most serious performance flaw in TravTek. Local users, familiar with Orlando traffic, preferred not to receive the TMC data. The lesson here is that performance parameters must be established and tested for all parts of the system

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

Initial pre-deployment testing:

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

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

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

Provide quality assurance:

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

System safety:

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

Reliability:

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

Maintenance:

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

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

To minimize political pressure:

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

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

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

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

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

To increase public confidence:

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

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

Management/funding philosophy:

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

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

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

Privacy issue:

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

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

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

To mitigate liability concerns:

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

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

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

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

A.3.8 Activity H - AHS Roadway Deployment Analysis

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

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

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

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

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

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

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

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

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

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

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

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

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

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

A.3.10 Activity J - AHS Entry / Exit Implementation

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

A.3.11 Activity K - AHS Roadway Operational Analysis

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

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

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

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

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

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

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

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

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

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

A.3.12 Activity L - Vehicle Operational Analysis

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

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

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

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

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

A.3.13 Activity M - Alternative Propulsion System Impact

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

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

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

- Fuel economy regulations and fuel taxes will exert pressures on standard propulsion vehicles to not extend their present performance.
- AHS must be compatible with light duty trucks and sport utility vehicles exhibiting performance lower than standard vehicles because they are a large part of the fleet.

- Consumer pressures will force alternative propulsion system vehicles to improve performance until they fall at least into the lower portion of the continuum which includes the above categories of vehicles.

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

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

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

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

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

A.3.14 Activity N - AHS Safety Issues

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

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

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

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

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

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

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

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

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

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

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

A.3.15 Activity O - Institutional And Societal Aspects

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

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

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

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

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

Beyond PSA, it is strongly recommended that more definitive risk assessment(s) be made once a baseline AHS approach has been chosen from the RSC(s). For example, prior to a bid award, a detailed risk analysis should be performed to determine risk rating tradeoffs of, probability of occurrence vs. severity of impact (in dollars). Information and conclusions derived from Activity P - Preliminary Cost / Benefit Factors Analysis could be used as additional inputs in further quantifying, controlling, and re-evaluating risks during long-term AHS implementation.

Of all the design issues discussed and summarized, funding is a major issue which can lead to a number of other issues and accompanying risks. For example, inadequate institutionalized funding resulting in substandard AHS designs and inadequate system safety designed into AHS (e.g. design for minimum risk concept-fail/safe, hazard analyses, hazard mitigation, systems assurance, etc.) causing AHS-related fatalities is unacceptable.

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

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

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

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

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

Table A-1. Risk Assessment Rank Areas and Prioritization

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

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

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

Primary suggestions for resolving these issues include:

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

- The ongoing development of an AHS roadway network in Phoenix and other metropolitan areas.

- Continued public funding of AHS development.

- Implementation of multimodal planning and investment to relieve arterial congestion.

- Technological development and market acceptance keeps pace with scheduled deployment.

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

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

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

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

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

Table A-2. Continued

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

Table A-2. Continued

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

Table A-2. Continued

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

Table A-2. Continued

Item #	Act.	Database Topic	Item Type	Contract Overview Report Section				
				Sys Ch	Op/Mt	Imp	Dep	Fnd
H06	H,F	What operating speed should be used for AHS design?	issue	x				
H07	H	A physical barrier should separate AHS and non-AHS traffic in both the urban and rural scenarios	concern	x		x	x	
I01	I,J	AHS volumes on local streets will negatively impact neighborhoods	conclusion	x		x		
J01	J	What is the desirable minimum distance along the cross street from the AHS to nearest parallel street?	issue	x		x		
J02	J	In an urban setting, existing interchanges cannot be retrofitted for AHS entry/exit	conclusion	x		x		
J03	J	On-site check-in is not feasible	conclusion	x				
J04	J	Demand must be managed at AHS entry points	conclusion	x		x		
J05	J	Entry/exit ramps for dedicated facilities must be separated	conclusion	x		x		
K01	K	Can AHS operating agencies attract and retain quality personnel?	issue		x			
K02	K	Who should operate the AHS?	issue		x			
K03	K	Will the States (or other operating agencies) accept the added tort liability AHS may bring?	issue				x	
L01	L	What AHS research should consider about RF communications	risk	x				
L02	L	Will AHS vehicle components be produceable at an acceptable cost?	issue	x				x

Table A-2. Continued

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

Table A-2. Concluded

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