Precursor Systems Analyses of Automated Highway Systems

RESOURCE MATERIALS

Contract Overview

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FOREWORD

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

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

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

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

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INTRODUCTION

Program Overview

In the Intermodal Surface Transportation Act of 1991, Congress included a provision in Part B, Section 6054 (b) to proceed with the analysis, design, and prototype demonstration of an automated highway system. The Act directs that:

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

To get a quick start in meeting this aggressive program schedule, the Federal Highway Administration awarded a set of research contracts to perform a systems analysis of 16 areas of interest relating to the AHS. This work is referred to as the precursor systems analysis for the automated highway system. The research had the objective to identify the key issues and risks that needed to be addressed in meeting the 1997 milestone to have a fully automated roadway or test track in operation.

This set of reports summarizes the research performed and results obtained for eight of the sixteen areas focused on 1) deployment, operations and maintenance, 2) safety and malfunction management, and 3) institutional and societal issues.

Summary Description of Activity Areas Addressed

The team's work addressed eight activity areas.[1] A summary of the research objectives for each activity area follows:

Activity Area A - Urban and Rural AHS Analysis: The objectives of the activity area were to 1) look for the existence and nature of differences between the urban and rural environmental settings and 2) identify the issues associated with these differences that may have a significant impact on the design, deployment, and/or operation of an AHS.

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[1] Each of the 16 areas of research are referred to as activity areas and have been assigned by the FHWA an alphanumeric letter from A to P for identification.

Activity Area E - Malfunction Management and Analysis: The objective of activity area E was to identify and evaluate the management strategies that can be used to mitigate the effects of potential AHS system malfunctions.

Activity Area H - AHS Roadway Deployment Analysis: The objective of activity area H was to identify the specific issues, risks, and impacts that should be expected in the deployment of the roadways for different alternative AHS configurations.

Activity Area I - Impact of AHS on Surrounding Non-AHS Roadways: The objective of activity area I was twofold. First, the research was to analyze the likely impacts of selected types of AHS deployment on surrounding non-AHS roadways. Second, the research included the identification of candidate strategies for mitigating any adverse impacts that might be identified.

Activity Area J - AHS Entry/Exit Implementation: The objects of activity area J were to 1) identify strategies for entering and exiting an AHS roadway, 2) develop measures of effectiveness (MOE's) for evaluating the strategies, and 3) evaluate the selected AHS representative system configurations with the aid of the special entry/exit MOEs developed.

Activity Area K - AHS Roadway Operational Analysis: The objective of activity area K was to identify the operational activities, issues, and risks involved in operating an AHS. Estimates of resources for operation and maintenance are provided.

Activity Area N - AHS Safety Issues: The objective of activity area N was to identify, consolidate, and discuss the major technical, design, and implementation issues and risk to be resolved for providing AHS users with a collision-free driving environment under normal operating conditions.

Activity Area O - Institutional and Societal Aspects: The overall objective of activity area O was to develop an understanding of the institutional and societal issues likely to be important in achieving a successful AHS deployment. A secondary issue was to identify courses of action to address all of the institutional and societal issues identified.

A separate research report is included for each of the eight activity areas. In addition to the eight research reports, an overview report (this document) has been developed to provide a summary of the cross-cutting issues, overall research approach and key findings.

Specific Focus of the Research

The research performed in this AHS work focused on three primary areas as follows:

1. Activity areas A, H, I, J, and K focused on the **deployment, operation, and maintenance issues** of the AHS. The research addressed how different repre-

sentative system configurations could be implemented/integrated into the existing freeway system in both an urban and rural environment. The research looked at both building new as well as modifying existing roadways (e.g., conversion of dedicated HOV lanes) and deploying various alternative entry/exit systems. Analysis also tried to determine how the different representative system configurations impacted existing freeways and arterial roadways and how the AHS alternative configurations could be operated and maintained.

2. Activity areas E and N focused on **malfunctions and safety issues** for the AHS. The malfunctions addressed included all the potential failures that could occur in various representative system configurations. Malfunction management strategies were identified to reduce risk associated with those malfunctions to the practical absolute minimum. The safety activity area addrssed the kinds of hazards that can be encountered in the absence of a malfunction (e.g., operator errors or obstacles inadvertently appearing in the highway). The safety research focused primarily on collision avoidance issues such as establishing and maintaining adequate separation to prevent in-line and rear end collisions.

3. Activity area O addressed the **institutional and societal issues** involved in the deployment and operation of an AHS. Results of this research combined, with that of the other areas, suggest that the institutional and societal issues may be larger obstacles to deployment than the technical engineering issues.

Issues Addressed by Activity Area

A range of issues were addressed in the research performed for each of the eight activity areas. The issues addressed were discussed by the project team in early stages of the study to insure that the work focused on congruent issues and provided the information that was needed between the activity areas. For example, activity area H, roadway deployment analysis, needed input from activity area A, urban and rural AHS analysis, to determine the issues faced due to operational and physical differences between the urban and rural environments. A summary of the key issues addressed by activity area is provided in table 1.

Overall Research Approach/Methodology Across Activity Areas

The research team consisted of eight sub-teams, each of which addressed a single activity area. Each team had an assigned activity area task leader that not only was responsible for directing the sub-teams work but also was an expert in the subject matter. The approach and methodology taken by each sub-team is included and described in detail in each of the separate activity area's final report.

However, our research approach also included several cross-cutting activities that benefitted all. These key programmatic activities are summarized as follows:

- A single point of contact was designated at the beginning of the project to insure that all data inputs, memorandums, and project correspondence were collected at a project level. All key information was forwarded to activity area leaders as an "AHS Flash" document. This insured that all sub-teams received all information in a timely manner.

- A literature search was performed at a team level. The results of this search are presented in an appendix of this overview report volume. A central AHS library was established, and activity area researchers were able to access any document on an as-needed-basis.

- Weekly teleconference meetings were held to communicate progress, issues, and problems. Each activity area task leader reported on work performed and major results being obtained. Also, many cross-cutting ideas were shared and discussed at length. This helped insure that the cross-cutting issues were considered between the sub-teams.

- During the 12 month course of the research, five team meetings were held where all team members were pulled together to present assumptions, progress and any conclusions in their research. The impacts of the results on other activity areas were highlighted. This effort helped foster communications, stimulate new ideas and avoided contradictions in the research performed. Members of a special senior technical panel (STP) participated in two of these team meetings at critical stages of the program. The STP also participated in the review process of the final reports.

- At the midterm of the research, each activity area task leader formally reviewed the research proposal presented to FHWA and reported to the overall program manager how he/she was proceeding in meeting the objectives outlined in the research proposal. This approach provided a way to check that the work being performed was in the original scope of the project. This effort resulted in several midterm corrections.

- All activity area sub-teams were encouraged to interface and share information with the other AHS PSA contractors. This fostered new ideas and helped avoid going down dead-end paths in the research performed.

In general terms, the above activities focused on providing a platform for communications between the PSA research teams (both internal and external) to compare research results and to stimulate new ideas. The openness was a unique and refreshing mode of team cooperation from which the AHS PSA program will benefit.

Guiding Assumptions

The guiding assumptions made in this research work focused on developing a set of representative system configurations (RSCs) to be used by all eight activity areas. The detailed definition of the RSCs used is provided in the next section of this report volume. The research also complies with the baseline assumptions that were provided in the broad agency announcement for the PSA studies. Compliance/exceptions to these baseline assumptions are noted as follows:

1. *All vehicle types (automobiles, buses, trucks), although not necessarily inter-mixed, must be supported in the mature system. Initial deployment emphasis is expected to be on automobiles and vehicles with similar vehicle dynamics and operating characteristics.*

   Research Team Assumption: Only automobiles were considered in this research. However, the research addresses expandability to accommodate larger vehicles such as buses or trucks.

2. *The vehicles will contain instrumentation that will allow the AHS to control the vehicle when it operates on instrumented segments of the roadway.*

   Research Team Assumption: The research complies with the baseline assumption. The level of intelligence in the vehicle varies depending on the intelligence is distributed in the RSC. Note that the vehicle is assumed to be the pallet in the pallet RSC since no special instrumentation is needed in the automobile or truck being carried on the pallet.

3. *Not all vehicles will be instrumented and not all roadways will be instrumented:*

   a. *instrumented vehicles will be able to operate on non-instrumented roadways,*

   b. *only instrumented vehicles will be allowed to operate on instrumented roadways, and*

   c. *non-instrumented vehicles will be instrumentable on a retrofit basis.*

   Research Team Assumption: The research complies with the baseline assumption. However, item "c" did not affect any of the eight activity areas addressed and, therefore, no direct assumption was made.

4. *Operation in a freeway (as defined by the American Association of State Highway and Transportation Officials) type of roadway is assumed.*

   Research Team Assumption: The research complies with the baseline assumption. However, it is assumed that it might be possible to reduce the roadway/freeway lane width to as little as 8 feet in some of the RSCs used in this research.

5. *The AHS will perform better than today's roadways in all key areas including:*

a. *<u>Safety</u> -- The AHS will be significantly safer than today; in the absence of malfunctions, the system will be collision-free, and a malfunction management capability will exist that minimizes the number and severity of collisions that occur as a result of any system malfunctions.*

b. *<u>Throughput</u> -- Significant increase in vehicles per hour per lane.*

c. *<u>User comfort</u> -- Smoother ride, with less strain on users and high trust in the system.*

d. *<u>Environmental impact</u> -- Reduced fossil fuel consumption and emissions per vehicle mile.*

Research Team Assumption: All work performed complies with the above assumption. The team's research supports that the AHS throughput can be significantly better than what is achieved today. We also feel that the high level of safety and reliability that is needed to achieve high trust in the system is obtainable. Reduced emissions are also needed to obtain acceptance by some segments of the public and environmentally oriented special interest groups.

6. *The AHS will be practical, affordable, desirable, and user-friendly.*

   Research Team Assumption: All work performed complies with the above assumptions. The team's research supports that the above assumptions can be realized.

7. *The AHS will operate in a wide range of weather conditions typical to that experienced in the continental U.S.*

   Research Team Assumption: All weather conditions were considered in our research. We chose Minneapolis, Phoenix and Texas sites to analyze to obtain a range of climatic conditions. The assumption is that any AHS concept must be deployable in any part of the U.S. from Florida to Alaska.

8. *AHS primary system control and guidance will rely on non-contact electronics-based technology as opposed to mechanical or physical contact techniques. The latter might be part of a backup subsystem if the primary should degrade or fail.*

   Research Team Assumption: All research performed by this team has made the above assumption in the analyses.

Format/Content of the Full Report

This research is presented in a set of nine reports. Eight volumes provide the detailed results for each activity area A,E,H,I,J,K,N, and O. For each activity area volume, the following information is provided:

- Executive summary.
- Overview of the research objectives.
- Summary of the representative system configurations.
- Research approach and results.
- Conclusions and recommendations.

In addition to the eight topical reports, this ninth report provides an overview of the overall research and how it integrates into a coherent product. This report summarizes the results of the eight research activity areas studied and related cross-cutting issues and results. The content of this final contract overview report includes:

- Executive summaries for all eight activity areas.
- An introduction outlining the research focus and approach, assumptions made, and report content description.
- A detailed discussion of the representative system configurations used in the research.
- Significant research results, conclusions, and recommendations for each activity area.
- Overall cross-cutting conclusions/observations.
- An appendix containing a glossary of acronyms and abbreviations.

TABLE 1. KEY ISSUES ADDRESSED.

Activity Area	Issue	Scope
A	Define RSC aspects in both urban and rural	Focus on roadway characteristics.
	Define urban/rural operating characteristics	Address roadway and light vehicles; include fringe.
	Suburb as a separate environment	Address fringe environment and how it relates to urban.
E	Identification and categorization of potential malfunctions	Fault tree analysis, failure modes, and effects analysis. Iterative review by Senior Technical Panel. Classification: vehicle, operator, roadway, external.
	Establishment of safety, performance, and reliability requirements	Included.
	Estimation of collision consequences	For each combination of potential malfunction and management strategy.
	Collision type	Parameters will be developed including factors such as impact velocity and angle, sizes, and types of vehicles involved.
	Definition of MOEs	Based on mixture of subjective and objective information: reliability, safety, and cost.
	Investigation of malfunction detection techniques	Included.
	Development of malfunction management strategies	Means to detect and identify the malfunction; means to determine action; means to implement action.
	Human intervention	Only as a “last resort.”
H	Urban/Rural interface	Included.
	Conversion of lane	Included.
	Conversion of facility	
	Vertical alignment	
	Weave, merge, ramp configs.	

Table 1. (Continued)

Activity Area	Issue	Scope
H (cont.)	Use of scenarios	Apply to real life scenarios. Scenarios will portray a rural area, an urban area, a small population area, and a fringe area.
	Corridor wide operational analysis	Including spatial needs, impact on existing facilities, and construction strategies.
	Construction cost	Construction administration, input from State DOT officials.
	Land use issues	Included.
	Construction impact on traffic	Included.
	Societal issues	Included.
	Environmental issues	
	Use of plan overlays for presentation	Included.
I	Environmental, land use, and socio-economic analysis	Impact on development and development shifts.
	Capacity impacts	Loss on non-AHS roads.
	Traffic shifts	Included.
	Impact of AHS access and egress locations	
	Impact of AHS malfunction	Impact of malfunction on surrounding non-AHS lanes and roadways.
	Existing facility problems	Included.
	Impact of alternative configurations	Impacts of three alternative RSCs, and AHS placement.
	Design issues	Impacts of three alternative RSCs on existing facility redesign.
	Quantification of impacts	Maximization of benefits.
	Use of modeling scenarios	Site specific—will use Minneapolis-St. Paul for the urban investigation and a site in Minnesota for the rural investigation.
	Modeling scope	Will model AHS, surrounding parallel, and feeder roadways.
	Modeling tools	May use TRANPLAN, FREESIM, and NETSIM.

Table 1. (continued)

Activity Area	Issue	Scope
J	Effect of varying functions and strategies	Focusing on strategies.
	Integrate with other roadway tasks	Included.
	Pallet impact	Pallet impact on entry and exit plazas of the pallet RSC.
	Heavy vehicle impact	
	Use of MOEs	Evaluate candidate strategies using MOEs.
	Plazas and staging areas	Included.
	Ramp configurations	Included.
	Vehicle rejection	Included.
	Queue lengths	Included.
	Transfer of control	Included.
	Disruption of AHS lane flow	
	Length of transition lane	
	Other issues addressed	Use of barriers.
K	General operational factors	Daily traffic operations, maintenance, control strategies, communications, incident management. Will conduct literature search to identify past operational issues.
	Phasing of AHS construction	
	Evolutionary aspects of operations	
	Physical plant and staffing requirements	
	Institutional aspects of operations	
	Operational costs	Included.
	Redundancy needs	
	Automation of operations	
N	Impact on technical issues	Included.
	Impact on design issues	Included.
	Alternative actions to control risks	
	Charac. of potential AHS accidents	
	Charac. of normal operations	Included.
	Hazards vs. malfunctions	Overall analysis of hazards in AHS environment. Interaction with malfunction management.
	Safety issues database	Included.

Table 1. (continued)

Activity Area	Issue	Scope
O	Legal	Framework; general analysis with site specific inputs.
	Regulatory	Framework; general analysis.
	Funding alternatives	
	Environmental	
	Societal aspects	Stakeholder issues, public acceptance, public perceptions, social and economic effects.
	Public acceptance/education	Included.
	Interstate commerce	
	Vehicle priority	
	Organizational	
	Marketing	
	Public/private partnerships	
	Public health, safety, and welfare	
	Economic issues	Positive and negative effects.
	Other issues	Policy-making processes.

REPRESENTATIVE SYSTEM CONFIGURATIONS

Introduction

The Precursor Systems Analysis is a research activity into the issues, risks and opportunities associated with the deployment and operation of an Automated Highway System (AHS). To perform this research, this study required a defined set of AHS characteristics that could provide a framework for system analysis. AHS development is in an infant stage and the characteristics of a preferred AHS infrastructure, vehicle, or command and control structure have yet to be determined. Lacking a preferred definition, a set of definitions was created.

The definitions developed for this study were compiled from discussions and submittals from the professionals familiar with automation, roadway, societal and institutional issues. These RSC definitions are intended to provide a common framework for analysis among tasks and include a variety of competing AHS characteristics. All RSCs were considered equal in the analysis and none received preference or priority. It is understood that this analysis will be used as input by design teams responsible for developing AHS technology and applications.

Original RSC Definitions

Four primary RSCs were originally used in this analysis. These four RSCs can be defined in global operational terms independent of roadway considerations. These four RSCs are defined in table 2.

TABLE 2. PRIMARY RSC CHARACTERISTICS.

RSC		Traveling Unit	Headway Policy	Vehicle Intelligence	Guideway Intelligence
1	Average Vehicle Smart Highway	Individual Vehicle	Uniform	Average	Active
2	Smart Vehicle Average Highway	Individual Vehicle	Platoon	Autonomous	Passive
3	Smart Pallet Average Highway	Pallet	Uniform	Autonomous	Passive
4	Smart Vehicle Passive Highway	Individual Vehicle	Independent	Autonomous	Passive

The above RSC definitions describe the vehicle and command systems in very general terms. These RSCs can be further described using roadway configuration and a finer detail of vehicle, command and control descriptions. Roadway configurations will be described first and then followed by detailed descriptions.

Roadway Configuration

Each RSC used in this study requires a specific definition of the associated roadway configuration. Three of the primary RSCs were given only one roadway configuration and one of the RSCs was given three roadway configurations. This results in a total of six globally defined RSCs. The roadway configurations were described by their mainline, entry/exit and separation characteristics.

Mainline

Three different mainline roadway configurations are being considered in this study. These configurations are:

1. Two lanes in each direction with the left lane in each direction serving mixed AHS and non-AHS traffic.

2. Three lanes in each direction with the left lane in each direction serving only AHS traffic.

3. Two lanes in each direction serving non-AHS traffic and a reversible lane between the non-AHS lanes serving only AHS traffic.

Entry/Exit

Entry to and exit from the AHS lanes can be provided by a variety of means. The options considered in this study are as follows. These are only brief descriptions of the physical characteristics of the entry/exit options. Additional detail and control strategies will be provided later.

Mixed	No special provisions or access facilities are provided for the AHS vehicle to enter the AHS lane. This means that the AHS vehicle must enter the freeway via the ramp access points currently provided for non-AHS vehicles. Special AHS priority lanes could be provided at these access points but the AHS vehicles must enter the freeway via the non-AHS lanes first and then merge over to the AHS lane. No transition lane is provided in this option.
Exclusive Ramps	All entry and exit points from the AHS lanes are provided by exclusive ramps. Ramps can be to and from arterial streets, plazas, non-AHS freeways or any other roadway. This option keeps the AHS traffic segregated from the non-AHS traffic at entry and exit and therefore eliminates any need to merge with non-AHS traffic.
Transition Lane	This is similar to the mixed option where AHS vehicles enter and exit the freeway via the access ramps currently provided for non-AHS vehicles. Special AHS priority lanes could be provided at these access points but the AHS vehicles must enter the freeway via the non-AHS lanes first. This option differs from the mixed option in that AHS vehicles first merge into a special transition lane before moving into the AHS lane. The transition lane is used for vehicles entering and leaving the AHS lane and it runs the entire length of the AHS lane. The transition lane may or may not operate with mixed traffic.

Separation

The means used to separate AHS and non-AHS traffic on the mainline is somewhat independent of the entry/exit option. The separation options being considered in this study are as follows:

None	No direct physical barriers are used to separate AHS and non-AHS traffic. Striping or signing can be used in this option to indicate separation of AHS and non-AHS traffic.
Barriers	Physical barriers are used to separate AHS and non-AHS traffic at all points along the AHS lane.

Note that standard AASHTO rules will be assumed for all other separation requirements. These means that physical barriers or wide medians will be provided to separate opposing traffic streams.

Using these characteristics, the six globally defined RSCs used in the Battelle/BRW research are presented in table 4. The RSC numbers refer to the primary characteristics presented in table 3.

TABLE 3. GLOBAL RSC DESCRIPTIONS.

RSC	Mainline Roadway Configuration	AHS Lane Access			Lane Separation	
		Mixed	Exclusive Ramps	Transition Lanes	None	Barriers
1	Three lanes each direction Exclusive AHS left lane	X		X	X	
2A	Three lanes each direction Exclusive AHS left lane	X			X	
2B	Three lanes each direction Exclusive AHS left lane		X			X
2C	Two non-AHS lanes in each direction Reversible exclusive AHS center lane		X			X
3	Three lanes each direction Exclusive AHS left lane		X			X
4	Two lanes each direction Mixed traffic left lane	X			X	

Several key points associated with the selection of these RSCs are as follows:

- All three roadway configurations are represented.
- Every combination of entry/exit and separation options are represented with the exception of transition lanes with barriers, and exclusive ramps with no barriers.
- Reversible lanes were not selected for RSC 3 because pallets could not be recirculated during the peak period.
- Two lanes in each direction were only selected for RSC 4 because mixed traffic mode was viewed as requiring the most advanced vehicle. RSC 3 was not selected because pallets are assumed to operate in exclusive lanes only.

RSC Definitions

The following sections present detailed RSC definitions in three functional groupings:

- **Vehicle.**
- **Infrastructure.**
- **Command & Control.**

These groupings have been further defined by a set of characteristics within each grouping. A set of options for each of the characteristics was developed for the Battelle/BRW analysis. The descriptions of these characteristics and a general descriptions of the options used are presented in the following section. A full description of each RSC by grouping and characteristic is then presented. RSCs 1, 3 and 4 are presented in one group and followed by RSCs 2A, 2B and 2C. RSCs 2A, 2B and 2C are similar in that they have the same technology base with varying roadway configurations.

HIGHLIGHTS OF THE TECHNICAL DISCUSSIONS OF EACH ACTIVITY AREA

This section presents highlights of the individual activity area efforts under three headings—1) key findings, 2) conclusions by issue addressed, and 3) recommendations regarding further investigation.

Key Findings

Key findings for each of this team's set of eight activity areas (i.e., activity areas A, E, H, I, J, K, N, O) are presented below in alphabetical order. The format used comprises a brief introduction followed by an enumeration of the key findings. Additional finding and supporting material is presented in the topical reports for each of the activity areas.

Task Area A—Urban and Rural AHS Analysis

Activity area A compared and contrasted the technical, operational and safety characteristics of various AHS representative system configurations in rural and urban environments. This work was accomplished through a comprehensive literature search, a series of expert workshops, and professional analysis of urban and rural travel characteristics. The key findings of this analysis are:

1. Rural AHS Deployment Benefits

   Rural freeways nationwide are generally two lanes in each direction with a wide median and interchanges spaced at 5 to 16 kilometer intervals. The average daily traffic volumes on rural freeways are between 5,000 and 20,000 vehicles per day. Rural freeways have a 104 kilometer per hour speed limit and wide rights-of-way. Rural freeways generally have good to excellent traffic operations and no recurrent daily congestion. They do experience some holiday and special event congestion.

   Rural freeways have an average accident rate of 0.7 accidents/million vehicle miles of travel. Of all rural accidents, 77 percent involve property damage only, 22 percent involve personal injury and 0.9 percent are fatal. The most common types of rural accidents are single vehicle run-off the road (35 percent) and animal hits (25 percent).

   Improved safety is expected to be the greatest benefit from implementing an AHS in a rural environment. The addition of low cost collision avoidance and lane following features would likely result in a 25 to 50 percent reduction in accidents on rural freeways. On a national basis, this would produce an annual accident cost savings between $225 and $450 million. The two types of rural accidents most desirable to correct are single vehicle run-off the road and animal hits, which are the two most common types of accidents on rural freeways. A study by the Minnesota Department of Transportation reported that the number one transportation priority of residents in greater Minnesota was the reduction of rural accidents.

2. Urban AHS Deployment Benefits

Urban freeways nationwide are generally three or more lanes in each direction with narrow, raised medians and interchanges spaced at 0.8 to 1.6 kilometer intervals. The average daily traffic volumes on urban freeways are between 50,000 and 250,000 vehicles per day. Urban freeways have a 88 kilometer per hour speed limit and narrow rights-of-way. Urban freeways generally have poor to acceptable traffic operations and recurrent daily congestion. They also have some holiday and special event congestion. The implementation of Advanced Freeway Traffic Management strategies (ramp metering, incident detection and management, etc.) have resulted in 25 percent increases in capacity and 30 percent reductions in accidents on urban freeways.

Urban freeways have an average accident rate of 1.7 accidents/million vehicle miles of travel. Of all urban accidents, 75 percent involve property damage only, 24 percent involve personal injury and 0.2 percent are fatal. The most common types of urban accidents are rear end (50 percent), single vehicle run-off the road (18 percent) and side swipes (16 percent).

Improved congestion management and safety are expected to be the greatest benefits from implementing an AHS in an urban environment. The addition of low cost improvements in freeway traffic management, incident detection and response and communications would likely increase the capacity of existing urban freeways by as much as 25 percent. The addition of low cost collision avoidance and lane following features would likely result in a 30 percent reduction in accidents on urban freeways. On a national basis, this would produce an annual accident cost savings of over $470 million. The types of accidents susceptible to correction are rear end, single vehicle run-off the road and side swipe type accidents, which are the three most common types of accidents on urban freeways.

3. Rural and Urban Deployment Differences

Rural freeway environments are characterized by low traffic levels, high speeds, infrequent interchanges and long travel distances. Urban freeway environments are characterized as high traffic levels, low speeds, frequent interchanges, and short travel distances. The largest problem on urban freeways is congestion while safety is the largest rural problem. Congestion management and improved capacity is needed for most urban freeways but would have little benefit for most rural freeways. Safety improvements would benefit both environments. Higher posted speeds might be attractive for rural freeways but not practical for urban freeways due to spatial limitations.

Task Area E—Malfunction Management and Analysis

Increasing the safety of travel is a principal goal for an Automated Highway System (AHS). Establishing the safety parameters and manner in which vehicle, highway, and human failures can be mitigated to produce the minimum harm at an affordable cost is likely to be one of the main drivers in selection of AHS architectures and system/vehicle implementations. A good understanding of the issues must be developed early in the program.

The following points highlight the findings of this task.

1. There are potentially serious malfunctions (i.e., malfunctions that could result in death or serious injury and/or which could involve large numbers of vehicles) which could occur during operation of any of the AHS RSCs investigated. However, reasonable malfunctions management strategies can be implemented to significantly mitigate the consequences of the malfunctions and/or make the serious malfunctions significantly less likely to occur for all of the examined RSCs. Considering the large number of current accidents in which human error causes or contributes to the accident, an AHS that eliminates these accidents and incorporates a well designed, tested, and maintained set of malfunction management measures should be able to offer a level of safety higher than that attained on current freeways.

2. Mixed traffic (i.e., a single lane carrying both manually driven vehicles and vehicles under AHS control) is a situation which must be addressed by a malfunction management strategy even if it is not part of the RSC's normal operational mode because the potential for a) a failure that eliminates the ability of the AHS to control a vehicle, or b) a non-AHS vehicle deliberately or accidentally penetrating the AHS-only environment will always exist. Also, a transition lane (in which a manually driven vehicle merges into the transition lane, is accepted into the automated system within the lane, and then changes lanes to a fully automated lane under AHS control) is a feature of many scenarios. This is an example of mixed traffic common to many RSCs. Therefore, mixed traffic must be accommodated.

Work done in support of IVHS has shown that vehicle systems to aid the driver avoid collisions or running off the road can be of substantial benefit. Extensions or modifications of some of these systems could be employed in an AHS to allow mixed traffic situations with reasonable levels of safety. It is the opinion of the project team that mixed traffic scenarios probably possess levels of safety intermediate between current freeways and a potential AHS based on totally separate manual and automated lanes.

3. The driver or passengers of an AHS vehicle should be able to make inputs to the AHS in certain cases, but the AHS can not be designed to rely on these inputs for safe normal operation or to counter malfunctions. The basic assumption of the AHS is that the driver can be less alert during the period that the vehicle is under automatic control; this cannot be violated. However, the driver/passenger must be able to alter the set destination to accommodate human "malfunctions" which could not be detected by the AHS (e.g., illness of a passenger). The AHS equivalent of the aircraft "pilot report" could increase safety and reliability of the AHS. In most cases, the driver should be allowed to move a malfunctioning AHS vehicle along the breakdown lane to use the next exit after the automatic systems have responded to a malfunction by stopping the vehicle in the breakdown lane. This prevents the need for an AHS response team to respond to every minor AHS vehicle failure. Other examples exist but basically, driver inputs can a) improve the capacity of the AHS, b) increase the probability of completing the trip without significant outside intervention, c) reduce AHS cost of operation, and d) increase the convenience of the AHS experience.

4. From a malfunction management viewpoint, pallets are a viable option possessing their unique advantages and disadvantages. Advantages include a) control of pallet maintenance by a central authority likely results in a better maintained pallet compared to a privately owned AHS vehicle, b) likely higher utilization of the pallet compared to a private AHS vehicle allows greater investment in each pallet (i.e., one can afford more redundancy and/or more expensive/higher reliability systems), and c) because pallets only operate on the AHS, they can be optimized for that environment. Disadvantages include a) likely higher center of gravity which likely results in a less stable vehicle, b) additional functions (e.g., vehicle load/unload and associated facilities, vehicle lockdown on the pallet, etc) that are pallet-unique provide extra opportunities for malfunctions, and c) probable need for additional response teams to recover pallets with minor malfunctions. It is the opinion of the project team that, from a malfunction management viewpoint, the advantages of pallets probably outweigh their disadvantages.

5. The Battelle Program Team believes that it is very important to minimize the possibility of a significant multi-vehicle accident because of their impact on perceived safety of the system. The occurrence of one or two 10 to 20 vehicle accidents in the early stages of AHS introduction would devastate public confidence in system safety and reliability; probably delaying widespread introduction for decades. The communications linkage of all AHS vehicles to a central authority provides the basis for minimizing the number of vehicles involved in such accidents. The basic responsibility of any vehicle involved in a collision or experiencing a malfunction which has a reasonable probability of leading to a collision is to inform the central authority of the situation immediately. The central authority can then take various actions (e.g., limiting

travel speeds, stopping potentially affected vehicles, requesting driver input, rerouting traffic, etc.) very quickly that minimizes the probability that numerous other vehicles will become involved.

6. Safety is the most important major AHS characteristic. An RSC cannot be considered viable unless it provides the public with a degree of safety at least comparable to the current freeway system. An RSC cannot be considered good unless it provides a degree of safety significantly beyond that provided on current freeway systems. In choosing components, systems, or techniques for the AHS, the predisposition of the program team is to include anything that can contribute to safety. Only if the inclusion of the item will substantially reduce system capacity, decrease convenience, or substantially increase cost will the item be excluded.

7. Capacity is important, especially in urban areas. In these urban areas, capacity and convenience are nearly synonymous. Most rural highways do not face a capacity crises, which makes increasing capacity over current levels much less important. This precursor study recognizes that the importance of increasing capacity varies between urban and rural AHS implementations, however, the project team has chosen not to explicitly evaluate any of the RSCs based on only urban or only rural implementation. Such an evaluation should be done in the future when the target RSC is better defined, however, at this point it would detract from some of the other areas that must be covered (e.g., given fixed resources, evaluating the RSCs in both urban and rural environments might result in fewer malfunctions or malfunction management strategies being considered). Therefore, this precursor study treats all examined RSCs as though they will be implemented with a single set of malfunction management strategies in both urban and rural settings.

8. The driver will need to possess an AHS driver's license to participate in the AHS system. Part of the training that will be required to obtain this license will involve the driver's responsibility in AHS safety, including the driver's responsibility in the case of vehicle or infrastructure malfunction, collision, or perceived unusual operation.

9. The introduction of AHS components or systems brings with it the potential for those systems to malfunction and cause, or contribute to, collisions or other unfavorable incidents. These malfunctions may not be limited to AHS vehicles operating under AHS control on AHS roadways, but could involve unwanted activation of AHS features or modes in inappropriate situations.

Task Area H—AHS Roadway Deployment Analysis

Activity area H identifies and analyzes the issues, risks and impacts of deploying an Automated Highway System (AHS) using various representative system configurations (RSC) in rural and urban environments. The identification of issues, risks and impacts was accomplished through a review of construction standards, interviews and a national workshop of transportation professionals. These needs were analyzed using various representative system configurations (RSC) in rural, urban, urban fringe and small population center environments. AHS lane alignments for the various RSC's were developed and overlaid on the existing roadways to determine the spatial, infrastructure and construction impacts. An analysis of the impacts was conducted to determine mitigation techniques and identify opportunities for improved AHS deployment scenarios. The key findings from this analysis are as follows:

1. Spatial Needs

   Some AHS concepts will require extensive roadway and structure reconstruction that could cost as much as upgrading a typical urban freeway—e.g., $41.0 million per mile for a 13.7-mile segment. Concepts which call for exclusive AHS lanes connected to exclusive AHS ramps, and separated from non-AHS lanes by physical barriers, offer the highest level of implementation success on existing freeways with compatible existing HOV systems because most of the space required and the associated general lane configurations are in place. However, the public reaction to “taking away” an HOV space for AHS use must be addressed by promoting the benefits of AHS. Additional lanes intended to serve AHS in a rural environment may not be cost effective for long distances, requiring consideration of a mixed flow AHS concept.

2. Deployment Evolution

   AHS deployment evolution may focus on mixed flow rural applications at first as a means of developing and field verifying the control and vehicle technology. The mixed flow concept will provide researchers and product developers an opportunity to refine mixed flow techniques as well as offer an opportunity for AHS technologies such as collision avoidance and vehicle positioning to be beneficial to off-AHS systems.

3. Transition Lanes

   Concepts which call for exclusive AHS lanes plus a transition lane may be limited in field application due to the need for additional width of the freeway. Costs are anticipated to rise dramatically in urban areas where additional right-of-way is required to satisfy additional space requirements. Elevated sections may be a viable alternative in some locations.

4. Traffic Control Devices

Traffic control devices such as variable message signs, lane indications, signaling devices, pavement markings and static signs will play a significant role in enhancing the operations and safety of any AHS concept. Application of traffic control devices must be consistent nationally among all AHS concepts to promote the highest level of driver understanding and predictive reaction.

5. Pavement Design

   Pavement for AHS lanes should be more durable and require less maintenance and repair than standard freeway pavement to allow maximum use of the lane with minimal downtime. Sensors built into the pavement would assist system monitors in evaluating surface conditions and pavement deterioration conditions.

6. Unique Environments

   The deployment of an AHS is unique to each environment. Design generalizations should be avoided. Each application should be evaluated individually for factors such as bridge and drainage structures, ramp systems, cross slopes and spatial availability.

Task Area I—Impact of AHS on Surrounding Non-AHS Roadways

Activity area I focused on the impact of deploying an AHS facility on the surrounding non-AHS roadways. Impacts to urban, urban fringe and rural environments were analyzed using expert workshops, comparable system analysis, and traffic demand modeling. Various representative system configurations were used in this system analysis. The key findings from this analysis are as follows:

1. Facility Redesign

   The introduction of an exclusive, barrier-separated AHS lane in an existing freeway facility will require conversion of an existing lane or adding a new lane. Converting an existing lane will generally require major reconstruction of the existing freeway to accommodate spacial and access requirements at costs up to $9 million per mile in urban areas. Adding a new exclusive lane will also generally require major reconstruction and land acquisition at costs up to $20 million per mile in urban areas. The redesign costs will be substantially lower for system configurations which do not require exclusive, barrier-separated lanes.

2. Travel Time Sensitivity

The selection between parallel AHS and non-AHS facilities by travelers is extremely sensitive to variations in relative trip times. For travel demand modeling, relative trip times are the aggregate of travel time, check-in/check-out time and direct user costs where costs are equated to time. The difference between these relative trip times between modes determines the use of a facility. The lower the relative trip times of an AHS facility, the higher the use of the facility compared to a parallel non-AHS facility.

The urban AHS configuration modeled included a primary freeway with three non-AHS lanes and one AHS lane in each direction. The freeway corridor had a total length of 17 kilometers. The average trip in the corridor was 16 kilometers and took 17 minutes. The corridor also had secondary parallel arterials on either side of the freeway. This urban region surrounding the AHS facility had a total of 450,000 peak hour trips. The AHS and non-AHS freeway lanes were modeled with equal access but the AHS lane had a 15 to 20 kilometer per hour higher operating speed.

The AHS lane was modeled with a range of time index penalties. A time index is defined as the combination of check-in/check-out times and user costs as represented by time. Modeled with a one minute time index penalty, approximately 45,000 peak-hour trips would be positively affected by the AHS. A positive effect is either a reduced trip time from using the AHS or a reduced trip time on other roadways due to less congestion. With a five minute time index penalty, only 500 peak-hour trips would be positively affected by the AHS. This dramatic difference in affected trips indicates the sensitivity of travelers to relative time differences. It also confirms previous studies that indicate users must perceive a time saving of approximately five minutes before a mode shift is made. This time sensitivity is independent of system configurations.

3. Market Penetration

The use of an AHS facility is directly related to the percentage of vehicles in a region that are equipped to operate on the AHS. This is also referred to as the AHS market penetration. In a scenario where the inside third lane of an existing freeway is converted to exclusive, barrier-separated AHS use, the AHS lane must attract sufficient traffic so as not to negatively impact the remaining lanes of the existing freeway. In the urban and urban fringe environments modeled for this analysis, at least 50 percent of all vehicles in the region surrounding the AHS facility must be AHS-equipped in order to prevent a level of service reduction on the remaining lanes.

These conditions assume an AHS lane capacity of 6000 vehicles per hour and an access frequency of 0.7 ramps per kilometer for the urban setting and 0.5 interchanges per kilometer for the fringe setting. This level of trip diversion would require a time saving of one minute per trip, which in turn requires an increase in the corridor average operating speed of 15 to 20 kilometers per hour.

These results assume that the check-in/check-out time and user cost associated with AHS is representative of one minute of travel time.

4. Parallel Arterial and Feeder Route Volumes

An AHS facility will increase the travel capacity of a corridor. The AHS facility has the potential to attract traffic from parallel arterials to the AHS and increase traffic on routes feeding the AHS. For the urban environment modeled in this analysis, the peak hour traffic on the major parallel arterials within two kilometers of the AHS decreased an average of 20 percent. For the urban fringe environment, parallel traffic decreased an average of 10 percent. These decreases were not as large as anticipated because natural equilibrium caused traffic from other congested roadways to use the excess capacity on the parallel arterials created from diversions to the AHS.

Peak hour volumes on feeder routes to the AHS increased for the urban and urban fringe environments modeled. Peak hour volumes in the urban and fringe models increased by a maximum of 14 percent, with a typical increase in the range from 5 to 6 percent. These increases did not cause the feeder routes to reach capacity as had been anticipated. This analysis assumed AHS access frequency equal to current non-AHS frequency. Decreased access will increase the volume on feeder routes.

5. Access Frequency Sensitivity

Varying the frequency of AHS entrance and exit ramps has a significant effect on the overall diversion of corridor trips to the AHS lane. Access frequency was varied in the urban environment model from a high of the current 0.7 interchanges per mile to a low of 0.4 interchanges per kilometer. The high interchange frequency resulted in a potential peak-hour AHS lane volume assignments from 4,500 to 7,100 vehicles. The upper end of the range exceeds the capacity of the AHS facility, but is reflective of the demand in the corridor. The low interchange frequency resulted in a peak-hour AHS lane volume assignments from 2,900 to 4,100 vehicles. The trip assignments assume 100 percent market penetration, an AHS lane capacity of 6,000 vehicles per hour, and an AHS average increase in the operating speed over conventional lanes of 15 to 20 kilometers per hour.

6. AHS Placement

Modeling analysis indicates that most travelers will make a mode shift to a parallel facility if the facility has at least a five minute time saving to a competing facility. For an average freeway trip length of 10 kilometers out of a total trip length of 16 kilometers, and a non-AHS average freeway speed of 64 kilometers per hour, the AHS lane would require an average speed of 137 kilometers per hour to achieve a five minute time savings. These numbers are representative of the urban corridor modeled in this analysis. If the AHS lane was limited to the current maximum speed of 88 kilometers per hour and the non-AHS freeway had an average speed of 64 kilometers per hour, the average freeway travel distance must be over 24 kilometers to achieve a five minute time savings. This indicates an AHS system will only have significant usage in corridors with average trip lengths of 24 kilometers or more if the AHS lane is limited to current speeds.

Task Area J—AHS Entry/Exit Implementation

The activities in area J, "Implementation of AHS Entry and Exit," focused on a) identifying candidate entry and exit strategies for six baseline RSCs, b) identifying measures of effectiveness (MOEs) for evaluating these strategies, and c) applying the MOEs to assess the viability and effectiveness of the strategies. The work in this area was coordinated with concurrent work by the Battelle/BRW team in areas A, H, I, and K, and to this end, concentrated on land use considerations.

A summary of key findings from the area J activities is provided below.

1. Dedicated AHS

   From a safety and performance standpoint, the most attractive entry/exit strategy involves dedicated AHS-only ramps that connect directly to dedicated AHS lanes, which in turn are separated from non-AHS lanes via barriers.

2. Transition Lanes

   Entry and exit across non-AHS lanes must involve transition lanes. The transition lanes must be capable of performing vehicle check in and/or check out, rejecting vehicles, queuing vehicles (if the transition lane is not continuous) without interfering with surrounding traffic, and releasing vehicles from rest into the AHS lanes and out of the non-AHS lanes. The use of transition lanes would not require exclusive AHS ramps.

   Without transition lanes, right-hand-side entry to and exit from inner AHS lanes would require that a) the vehicles are in manual control during some period while in the AHS lane, b) the vehicle entry speed is the non-AHS lane speed and c) the vehicle exit speed must be reduced as needed to be consistent with the non-AHS lane into which it is exiting. Requirement a) is considered unsafe, requirements b) and c) could result in severe degradation in AHS lane throughput due to "wave action" between vehicles.

3. Barriers

   As a safety device, barriers should be used wherever possible between AHS, transition and non-AHS lanes. These should be positive barriers that physically prevent intrusion to and from the AHS lanes (e.g., the Jersey barrier). Barriers themselves could create a safety hazard at entry and exit areas, and should be designed and placed to mitigate end-on collisions.

4. Metering

Traffic metering should be implemented at several levels:

a. Pre-trip—Users log-in trip requests to the system; the system in turn will evaluate the current and projected traffic conditions and approve or disapprove the request.

b. System Level—The flow of traffic on AHS and non-AHS lanes are monitored and adjusted as needed to optimize throughput while not compromising comfort, safety and environmental impact.

c. Local Level—Systems similar to current ramp meters release vehicles onto and off of the AHS lanes based on availability of space.

5. Four-Lane Highways

The application of AHS in a four-lane highway scenario (i.e., two lanes in each direction with no additional lanes) is limited to systems such as “intelligent cruise control.” Such a highway would require mixed traffic on the lanes, because without very high market penetration, dedicating two of four lanes to AHS-only would create considerable congestion on the non-AHS lanes. Thus, mixed traffic must operate on the four-lane highway; this presents significant safety and control issues. Further, the cost of such a system may be significant to achieve rather modest gains in throughput and safety. No changes would be required in the physical layout of the entry and exit areas for this configuration.

6. Lane Widths and Ramp Geometry

Standard lane widths (typically 12 feet wide) should be used for AHS lanes that involve mixed commercial, transit and automobile traffic. Smaller width lanes (e.g., 8-10 feet wide) should be considered only if use is restricted to specific “AHS class” vehicles. The geometry (lengths, curvatures) of existing ramps are based on current highway design speeds. Modifications to existing ramps should be considered if the operating speeds on the ramps are higher than the design speeds.

7. Pallets

The primary advantages of the pallet concept are a) automobiles do not have to be AHS equipped, b) ACI/ACO requirements would be reduced substantially, and c) pallets could be designed to be more energy-efficient, more reliable, and more uniform than today's fleet of automobiles. Primary disadvantages include a) cost of the pallets, b) additional space, time and facilities are needed for storage, loading, unloading and circulation and c) a "pallet authority" must be in place for operating the system. Key entry/exit issues are where and how pallets are loaded, unloaded and circulated throughout the AHS system while maintaining acceptable origin-to-destination travel times, good passenger comfort and safety.

8. Surrounding Roadways

Surrounding roadways must be evaluated and modified as needed (e.g., by changes in traffic flow patterns, signaling, AHS-only access) to assure that the flow of traffic to and from the AHS can be accommodated safely and with minimum impact on the AHS and surrounding roadways.

9. Spacing of Entry and Exit

To avoid unsafe weaving maneuvers, exit and entry should occur at different locations wherever possible.

10. Conversion of HOV Lanes

Conversion of HOV lanes to AHS would provide an effective infrastructure for AHS operation. However, it is expected that the public would resist giving up HOV lanes (as well as any other lanes). An option would be to create an AHS system that is restricted to HOV traffic. From an entry/exit standpoint, the primary advantage of converting HOV lanes to AHS is that suitable dedicated entry and exit systems, and in many cases barriers, already exist.

11. Control Transfer

Except for the four-lane highway, "intelligent cruise control" scenario, operation in AHS lanes must be restricted to vehicles under AHS control. Thus, transfer of control must occur prior to the vehicle entering the AHS lane and after the vehicle leaves the AHS lane.

12. Measures of Effectiveness (MOEs)

The following MOEs are effective in evaluating entry/exit implementation strategies for AHS:

a. Minimal need for additional land

b. Minimal need for additional facilities

c. Minimal negative impact on adjacent roadways

d. Large improvement in potential capacity over comparable non-AHS roadway systems

e. Minimal disruption of roadway traffic flow

f. Ability to mitigate safety hazards

g. Low cost and complexity

A comparative ranking of the RSCs with respect to these MOEs is provided in table 7.

Task Area K—AHS Roadway Operational Analysis

Activity area K focused on the issues and needs of operating an AHS facility. The identification of issues and needs was accomplished through a review of current freeway and automated rapid transit system operations and control centers. Staffing levels, system operation centers, response and maintenance teams, and control and communication system operations were investigated as part of this analysis. These elements were analyzed using various representative system configurations (RSC) in rural and urban environments. The key findings from this analysis are as follows:

1. Evolutionary Deployment of AHS Control Centers

   Consistent with plans for the evolutionary deployment of AHS, the first AHS operations centers will likely share facilities, staff, and field resources with current freeway traffic control centers. The functions and services required of both centers have many similarities. Examples of common functions include system monitoring, surveillance, incident management, and access control. Staff which might be shared include those performing field surveillance, maintenance, and incident management. The collocation of the two operations centers and the sharing of equipment, facilities, and staff will provide a substantial cost differential for the initial deployment of AHS over creating a separate facility. Without evidence of compelling reasons to separate the centers, the operating costs should remain low with continued sharing of resources and expenses with the freeway operations center.

2. AHS System Staffing Levels

   To operate an independent AHS control center, an estimated staff of approximately 55 system operators, programmers, incident management team members and related staff would be required to support a 400 kilometer AHS facility. This number compares to a staff of approximately the same size to provide equivalent operation of a similar freeway system. The functions of many of these staff members are already being performed by current freeway operations center personnel and would be duplicated by the addition of new AHS personnel. It is estimated that the total staffing estimate can be reduced by up to 75 percent by sharing staff between the AHS and freeway control centers. Other cost reduction measures (e.g., use of high reliability AHS systems, high

TABLE 7. COMPARATIVE RANKING OF RSCS FOR ENTRY/EXIT IMPLEMENTATION.*

MOE	RSC #1 -Smart Vehicle -Smart Hwy -6 Lanes/2 AHS -Mixed Ramp Traffic -Transition Lanes -No Barriers	RSC #2a -Smart Vehicle -Average Hwy -6 Lanes/2 AHS -Mixed Ramp Traffic -No Transition Lanes -No Barriers	RSC #2b -Smart Vehicle -Average Hwy -6 Lanes/2 AHS -Exclusive Ramps -No Transition Lanes -Barriers	RSC #2c -Smart Vehicle -Average Hwy -5 Lanes/ Reversible AHS Center Lane -Exclusive Ramps -No Transition Lanes -Barriers	RSC #3 -Smart Pallet -Average Hwy -6 Lanes/2 AHS -Exclusive Ramps -No Transition Lanes -Barriers	RSC #4 -Smart Vehicle -Passive Hwy -4 Lanes/2 Mixed AHS Lanes -Mixed Ramp Traffic -No Transition Lanes -No Barriers
Minimal need for additional land	4	3	5	2	6	1
Minimal need for additional facilities	4	3	5	2	6	1
Minimal negative impact on adjacent roadways	3	2	5	4	6	1
Large improvement in potential capacity	3	4	1	2	6	4
Minimal disruption of roadway traffic flow	5	6	1	1	1	1
Improvement in safety	5	6	1	2	3	4
Low cost & complexity	5	3	4	2	6	1

* Rankings range from 1 to 6, with 1 representing the highest rank.

durability AHS guideways, and use of driver action to handle minor AHS vehicle disability problems) would further drive to total costs of a shared center towards the cost of a current freeway control center.

3. Effect of Alternative RSCs on Daily Operations

With the exception of the pallet alternative, there would be little difference between the daily operations of an AHS system for the various RSCs under consideration. More and higher functions would be performed by the "Smart Highway, Dumb Vehicle" alternatives, but these functions would be performed by the system itself and not require a substantial increase in operations support. Since the AHS facility of all RSCs would operate automatically and virtually autonomously, it is surmised that the same number of system operators and other control center personnel would be required to operate all of the RSCs.

In the pallet alternative, there would be more mechanical equipment (the pallets themselves) which would likely be more susceptible to breakdowns than electrical equipment designed to be virtually failsafe. It is therefore expected that more maintenance staff would be required in the pallet RSC as well as new operational procedures. Additional staffing would be necessary at each access and egress point to the system where the pallets would be loaded and unloaded.

4. Incident Management for AHS Lane Blockage

Current freeway system incident management techniques and strategies will not satisfy the greater needs of an AHS facility. An incident which blocks an AHS lane serving an estimated 4,000 - 6,000 vehicles per hour would generate an immediate queue involving the entire directional facility. Alternative innovative strategies and methods need to be developed which would 1) remove an incident from the AHS facility faster than current procedures and 2) provide a relief valve from the AHS lane during the period the lane is blocked. One alternative is to provide automated incident detection and alternate routing, possibly through relief valve gates in a barrier separated facility.

The reliability of the infrastructure and vehicle hardware must be higher that what currently exists to reduce the number of incidents. On-line real time diagnostics will be required to detect problems and take corrective action prior to total breakdowns in the system.

Task Area N—AHS Safety Issues

A stated goal of this safety activity area is to provide AHS users with a collision-free driving environment under *normal operating conditions* (i.e., *in the absence of mal-*

functions). To meet this objective required initial effort to clearly define the conditions (including threats) that constitute normal operation. Once underway, this effort quickly expanded in several directions—identification of a comprehensive system concept, development of a set of normal operating rules or principles, and exploration of the physics associated with avoiding collisions (e.g., avoiding vehicle-to-obstacle and vehicle-to-vehicle collisions when one or more AHS vehicles encounter an inadvertent obstacle in the roadway). Finally, meeting the overall goal of providing AHS users with an increased level of safety over conventional highways required coordination of the two complementary activity areas of 1) safety and 2) malfunction management such that all safety risks are explicitly covered. The key activity area N findings generated by these efforts are summarized below.

1. The safety goals of an AHS should be achievable through the careful execution of a comprehensive system safety plan which encompasses not only the normal operation of the AHS (i.e., operation in the absence of malfunctions) but operation of the AHS in the presence of malfunctions.

2. A thorough analysis of the operating conditions which can or should be expected in the course of normal operation reveals that a significant number of threats to safe operation exist even in the absence of vehicle or infrastructure malfunction/loss of function. A concern of AHS designers should be that they do not fail to address all threats because of oversight or arbitrary decision. Our posture at the outset is that all threats currently faced on a highway system will be faced on an AHS and must be accommodated. This does not mean that some threats may not be controlled. Some may simply be impractical to control, e.g., the bullet, the bowling ball, and a crash landing 747. (Even these, however, might be controlled if money was not an issue). In broad categories, the range of primary threats include:

· Primary in-line collision threat agents

— Moving manually controlled vehicles operating in the AHS lane

— Moving AHS controlled vehicles

— Fixed objects (dropped load, stopped vehicle, etc.)

— Any non-vehicle - assumed fixed object (lane-fouling from adjacent lanes, animals, etc.)

· Primary in-line threat situations

— Forward
— Behind
— Merging

· Lateral control threats

— Lane departure
— Lane excursion/incursion (side-swipe situations)

- Intrinsic threats (factors that degrade the ability of a vehicle to control its trajectory (snow, ice, wind, sand, road surface changes, vehicle factors such as heavy loading and poor load distribution, etc.).

In addition to these primary types of threats, two other threat types were identified specific to AHS, partly because some AHS concepts enhance the exposure to these threats and partly because an AHS offers the opportunity to control this exposure.

- Malfunction-related threats involving control-coupled vehicles especially those malfunctions which can potentially lead to a worst-case incident.

- Transferred threats—a special case in which the threat control responsibilities of the lead vehicle in an AHS string of vehicles is suddenly transferred to the following vehicle.

3. There is a tendency to focus on the steady-state situation in which a string of AHS controlled vehicles is proceeding at a given speed and under relatively short headways. However, as is the case with commercial aircraft, the safety critical periods of operation tend to focus on the transient situations (e.g., landings and takeoffs). In the AHS environment, these key transients include entry and exit, changes in leading and following vehicle relationships, and (at some relatively small frequency) overall startup, shutdown, and restart of the AHS facility.

4. Unlike the commercial aircraft situation, the AHS on-board and off-board control systems must essentially constitute an “expert system” of a typical driver. For example, the AHS control system(s) must be able to detect and identify threats, assess road and environmental conditions, decide how much it can “trust” the leadership capabilities/behavior of the vehicle preceding it, etc.

   The variations in safety control demands and threats suggests that a “portfolio” of safety control options will be required for an AHS. This leads to the recognition of the need for a “safety management” function that directs the selection and application of a specific option as well as other responsibilities listed below. This function may be vehicle-based or central controller-based. In either event, however, it must be tasked with guarding the interest of individual vehicles. This function requires diverse capabilities and responsibilities in the following areas:

- Situation awareness—awareness of the current situation to be controlled

- Restrictive state management, including transitions—i.e., dropping back to less stringent operating conditions/engagement strategies (e.g., longer headways) in response to the current conditions

- Transferred threat management—responding to unusual behavior of the preceding/lead vehicle

- Normal malfunction management

- Transition into and out of the AHS

- Human participation management—authorizing and/or allowing selected driver inputs

- “True” exit management—extending the safety boundary of the AHS to prevent “outmerging” of an AHS vehicle into a situation which exceeds the ability of the vehicle and its driver to maintain proper control.

5. While we subscribe to the premise that normal operation of an AHS will be “hands off, feet off, brain on,” from a safety perspective, the system must function safely with the operator brain *off*. This means that, from a safety control situation, the safety manager cannot *require* operator input to resolve an unsafe situation. Furthermore, while operator inputs may be solicited and accommodated, they should be processed by the safety manager, with the results translated into vehicle motion alteration only after it is determined that this alteration will not result in an uncontrollable threat to the subject vehicle or to other vehicles in proximity. This does not preclude the possible need for an AHS initiated a “panic” stop.

6. The use of an AHS featuring pallets would cause a shift of safety management from individual vehicles to the infrastructure. There are possible benefits that could accrue:

- Design control to increase similarity/consistency of vehicles and operating characteristics.

- Maintenance control to reduce the likelihood of degraded performance.

- Reduced interruption due to ACI/ACO (i.e., ACI and ACO could be handled off-line).

- Virtual elimination of the control transfer problem to the human operator. (Transfer would be under stopped conditions. The concern for “true exit” safety problems would also be reduced.)

- Opportunities for incorporating reusable energy absorption techniques may lessen the demand for no collision and allow minor collisions not perceived as allowed with other RSCs.

- Controlled use of alternative propulsion systems and/or fuels.

Because of improved control over the designed-in capabilities, maintenance, and checkout of the critical on-board AHS systems—the use of pallets should result in a net increase in safety over the other candidate RSCs. These gains would, however, need to be weighed against possible losses in throughput and changes in the liability situation, financing requirements, land use requirements, etc.

Task Area O—Institutional and Societal Aspects

Activity "O" has examined a range of institutional and societal aspects of the proposed Automated Highway Systems (AHS) program, and focused on the following particularly critical issue areas:

1. Legal liability risks.

2. State and local decision processes.

3. Perspective of environmental organizations.
4. Role of the print media.

5. Public perceptions of potential risks.

6. Public involvement process.

7. Equity.

8. Sustainable transportation.

To be successful in the long-run and to have an opportunity to initiate deployment of AHS in the short-run, the concept and its various systems configurations and operations must establish a measure of stakeholder acceptance in order to be able to move forward. This analysis has examined the above significant institutional and societal component areas of the program with regard to their potential impact on public and stakeholder acceptance. Key findings include the following:

1. Liability Considerations.

- Safety—In analyzing considerations of legal liability for vehicle accidents, we have assumed that AHS as demonstrated or deployed will improve vehicle safety overall: that is, accidents will be fewer and less severe and resulting personal injuries and property damage will decline.

- Costs—To the extent AHS results in an overall improvement in vehicle safety, it should reduce the costs of motor vehicle accidents, and thus decrease liability risk in the aggregate. However, three aspects of this overall reduction in accident costs could create disincentives for vehicle manufacturers and roadway authorities to participate in AHS. First, to the extent AHS transfers control from the driver to the vehicle, the roadway authority, or a combination, the liability for the fewer and/or less severe accidents that do occur may shift to these parties. From their standpoint, the increased proportionate share of liability may more than offset the reduction in total liability and thus increase their net liability risk. Second, to the extent AHS increases uncertainty about the causes of accidents and who is responsible, it may increase the number, complexity, and parties to lawsuits, thereby raising transactions costs and the potential for reputational damage, and thus increase litigation risks. (System configurations that divide control among the driver, the vehicle, and the roadway could add complexity to determining responsibility for accidents and thus exacerbate this problem.) Third, to the extent AHS creates the possibility of accidents involving large numbers of vehicles, it likewise creates the possibility for "catastrophic liability" that could severely damage or destroy individual participants, especially smaller private firms. In principle, it should be possible to manage the legal risks of AHS accidents to overcome disincentives to participation. To the extent AHS increases highway safety and thus reduces liability for accidents in the aggregate, it creates a windfall for the liability "winners," which can be tapped if necessary to create institutional arrangements that compensate the liability "losers" so that all participants would be as well or better off as in the absence of AHS.

- Benefits—Vehicle manufacturers and roadway authorities will weigh the legal liability risks (and any other risks) against the potential benefits of participating. This calculation will largely determine whether they require some form of compensation to mange their liability risks and, if so, what level and type of assistance.

- Public voice/input—Vehicle manufacturers and roadway authorities need to be involved early in discussions with each other and other key stakeholders about the nature of liability risks, the impact of alternative system configurations, and alternative arrangements for managing the legal liability risks.

2. Regional Deployment Considerations

- Safety—Highway and driver safety are likely to be evaluated differently by individual drivers, by state and local transportation agencies and planners, by state legislatures, and by other transportation stakeholders. Individual drivers tend to rely on and trust their own driving skills more than unproven technology systems. Convenience, speed, and reliability are ranked higher by some than safety. Environmental groups tend to express concerns about low probability, high consequence safety failures, or to focus on the safety implications for secondary arterials that may experience traffic impacts from AHS. FHWA needs to understand how safety ranks among regional and local criteria, and tailor their deployment plans so that AHS addresses the priority concerns of different stakeholders in the different areas of the country.

- Costs—State legislatures, state transportation planning agencies, and local transportation planners are very cost sensitive. They operate within tight budgets, and will look for proposals that either cost less than the alternatives and still meet their needs, or they will look for cost sharing support for those proposals. A typical first reaction to AHS is that it will be very costly. Evolutionary strategies that allow AHS technologies to be incrementally added to existing, accepted programs will likely fare better than complex, stand-alone, potentially costly proposals. Many states will face serious organizational constraints on their capacity to operate and maintain an AHS with regard to such things as staffing, training, command and control capabilities, integrated facilities, and financial and manpower resources. The costs of various optional configurations of AHS must be carefully considered in discussions with recipient jurisdictions.
- Benefits—State DOTs and MPOs must be convinced of the benefits of AHS *to them* before they will be in any position to attempt to garner the public and political support that will be necessary to support decisions to deploy AHS. The benefits that different locations will likely focus upon will depend on their current experiences and problems with their transportation systems. Judgments are likely to be made in terms of the perceived equity of the distribution of AHS benefits--does everyone benefit equally or are some favored over others? Is AHS easy and convenient to use? Is the system safe and reliable? Does AHS focus on moving people more than vehicles? Are the benefits sustainable over the long-term or is this a short-term fix? These are the kinds of benefit issues likely to be faced.

- Public voice/input—There currently exists wide-spread ignorance about AHS, coupled with a dose of healthy skepticism. FHWA needs to work closely with state DOTs and encourage them to reach out to their constituencies to open a dialog about AHS. Planners need to get used to AHS concepts and to think about how AHS fits into their current transportation planning activities. Early and substantial public/stakeholder involvement is crucial. Also, involvement of local jurisdictions is critical for AHS success. This is particularly necessary to address such network effects as arterial congestion, congestion at AHS entry/exit points, the integrated management of local traffic control systems with AHS systems, and other inter-jurisdictional issues.

3. Environmental Perspectives

- Safety—Environmental groups are very concerned with the issue of safety. This concern is focused not only on the safety of drivers participating directly in AHS, but also extends to the broader population that might indirectly be impacted from a safety standpoint by AHS. This would include neighborhoods through which traffic going to and from AHS entry/exit points might pass, and safety effects on other secondary arterials due to increased AHS-generated traffic. They lobby for “traffic calming” strategies to make neighborhoods safer and more liveable for everyone. In addition, they express concern about the low probability, high consequence kind of systems accident that AHS might cause.

- Costs—Environmental groups in general are sympathetic with a least cost planning approach to address growth management, environmental impacts, and technology development issues. This calls for a comprehensive review of a full range of options for addressing particular issues that have environmental implications, and selecting those approaches or solution strategies that minimize costs. In the case of transportation congestion, or air emissions from vehicles, environmental groups place a lot of emphasis on traffic demand management strategies as less costly approaches compared with many capacity enhancement strategies. The environmentalists are generally not, at this stage, well informed about AHS, but given what they understand about it, they tend to believe that AHS reflects a very costly, and from that standpoint inappropriate, strategy for addressing congestion, safety, and mobility problems. It will be important in the early going to work with the environmental groups to jointly explore least cost implementation options for AHS.

- Benefits—Environmental groups are looking for transportation strategies that are primarily directed toward reducing air emissions, conserving non-renewable resources (particularly petroleum), and creating more liveable human environments. Their focus is on achieving long-term management of the demand for vehicle travel, in recognition of the fact that past improvements in vehicle emissions and efficiency have been outstripped by growth in VMT and numbers of trips. FHWA will want to show that AHS emphasizes the movement of people more than vehicles and is coupled with strategies to prevent latent demand for travel from offsetting the efficiency benefits that AHS achieves, that emphasizes public transportation applications, and that provides equitable access to all components of the population. On this latter point, there is a concern that a vehicle-based AHS will only advantage the well-to-do who can afford the service (“the BMW owners”). FHWA needs to work with environmentalists and others to assure the widest possible distribution of benefits from AHS.

- Public voice/input—While only a minority of the public can be described as committed environmentalists, many more are sympathetic to the broad goals of the environmental movement. Therefore, environmental perspectives and arguments pro and con with respect to AHS will play a central role in any public discussions about AHS deployment plans and strategies. While many environmentalists are skeptical of AHS technology, their current perspective's with many others is based upon limited knowledge about AHS. Additional research that can demonstrate environmental benefits and allay fears about induced demand effects may change this basic point of view. Inclusion of AHS into growth planning models, and demonstration that AHS can support growth management objectives may persuade environmentalists to be more supportive. Demonstration of economic benefit accruing from environmentally sound AHS also may help to convince some environmentalists. FHWA should seek to present AHS as a tool that can effectively help achieve environmental goals, along with economic goals and better overall traffic management goals.

4. The Role of the Print Media

- Safety—AHS is currently most often represented in the print media as a far-in-the-future technology (at least 25-30 years away), the apparent end point of the long list of ITS technologies being applied to our transportation systems. While media treatment of AHS specifically has been limited, science fiction terminology like “Buck Rogers” and “The Jetsons” is not uncommon. The media often present an image of a platoon of vehicles traveling at very high speeds (80 to 100 mph) with very close gaps (~1 yard). From the driver’s perspective AHS is characterized as a hands-off/feet-off system, with further implications that the driver will not need to pay attention to the functioning of the vehicle (brain-off). While the media have not, up to this point in time, commented very extensively on the safety of AHS, the general imagery of AHS that they offer is not likely to conjure up images of very safe travel in the minds of the public. While the media are generally supportive of the AHS concept at this early period in the conceptualization of AHS, their representation of AHS is neither accurate nor complete. FHWA needs to establish a dialog with media journalists and communicate clear images of AHS that emphasize its safety aspects along with a reasonable deployment strategy.

- Costs—The presumed high costs of AHS are included in media discussions of potential disadvantages of AHS. The media generally have very little information or basis on which to speak to the costs of AHS with any authority or accuracy. They need to better understand the range of AHS optional deployment strategies and what kinds of costs are associated with those options, and how those costs are likely to be distributed over the driver, the private developers, public agencies, or the taxpayer.

- Benefits. Some of the benefits of AHS as represented by the media include: congestion relief; driver safety; reduced air pollution; economic stimulus; improved public transit; enforcement of traffic rules; and, aid to older drivers. The majority of media articles that have been published to date represent AHS in a positive light.

- Public voice/input—The role of the media is one of interpreting AHS technology for a public readership, and the media can exert a significant impact on shaping public opinion and public acceptance. The media currently represents, and will continue to represent, the main source of information about AHS that is available to the driving public. National and regional transportation managers should establish early and close working relationships with the various journalists to assure that a balanced, accurate picture of AHS is presented to the public and that media errors or misinformation are corrected without delay. The media should be viewed as an ally and updated frequently as the program evolves.

5. Perceived Risk of AHS

- Safety—Descriptions of AHS deployment with “hands off, feet off” driving, especially when close gaps are involved, usually prompt expressions of concern about potentially catastrophic AHS system failures. Literature review shows that most people are positive about automatic controls as long as human control is possible as a back-up; automatic elevators and airport terminal trains are examples. Yet a frequent theme in science fiction horror stories is technology that has escaped control and runs out of control. Uncertainty about risk occurrence and consequences often causes people to make worst-case assumptions. As with any technology that has some measure of inherent risk associated with the possibility of catastrophic failures, it is crucial to attend both to the engineered design aspects of the system that reduce that risk, and to address the ways in which the public perceives those risks. The way that the driving public is likely to view AHS safety is every bit as important and valid as the way that engineers interpret the safety of the technology systems behind AHS. In fact, the former perceptions of safety will be more central to the success of AHS than the safety “facts” derived from engineering assessments, because the former determine how people will behave with regard to the technology. In the case of AHS, early evidence suggests that safety risks are perceived to be a greater hazard than engineers believe are likely to occur. Also, to the extent that AHS can accurately be characterized as a tightly-coupled, complex technology system, the probability of occurrence of a catastrophic system failure that will be difficult to mitigate increases. FHWA needs to seek ways to open a dialog on AHS safety that addresses this discrepancy. Systems designs that reduce the technological complexity and system couplings may also reduce risks and the perception of risk.

- Costs—The public is generally more concerned with safety than cost when considering exposure to technology risks. To the extent that “reasonable” additional costs can be shown to enhance system safety, the public can be expected to be supportive of those expenditures.

- Benefits—Among the factors working in favor of public acceptance of AHS is a generally positive attitude toward advanced technology. The way in which computers have overcome their poor reputation of 30 years ago is instructive. Phased deployment that does not require the public to place blind faith in unproved technology will be essential. Technologists and developers must be careful not to oversell AHS, and they must be careful that they are not perceived as claiming that "nothing can go wrong." Either error will provoke public distrust and lead to anger when problems do occur. One way to reduce the perceived riskiness of AHS would be to build in ways that the driver can exercise some control over the vehicle as a backup to a system failure. Another is to emphasize the safety benefits that are gained by AHS in exchange for some very small measure of risk.

- Public voice/input—A central strategy for addressing perceived risk is public involvement and education. FHWA needs to seek to understand how different components of the public perceive AHS, particularly with regard to safety risks associated with the technology. Then information can be prepared that directly addresses their questions and concerns in this regard. In this way perceived safety risk can be successfully addressed and public acceptance can be gained sufficiently to allow for AHS deployment. Another key factor is to demonstrate early success with the technology. Early failures will be picked up by the media, likely blown out of proportion, and the risks as people come to understand them will be significantly amplified. Dealing with amplified risk perceptions later in the program will be much more difficult and costly than engaging in an open dialog about the risks at the outset, with an eye to designing a system that meets peoples' expressed needs and addresses their risk concerns. An important side benefit of this approach is that it increases trust in the management of the technology system, which serves to reduce people's concerns with the risks inherent in that technology.

Conclusions by Issue Addressed

The purpose of this section is to capture the conclusions reached on the primary issues addressed in each of the eight activity areas. Of necessity there is some overlap in the material presented in this section with that presented earlier in the key findings section and subsequently in the section entitled overall cross-cutting conclusions/observations. Unlike the key findings section of this report, however, the scope of this particular section focuses on conclusions as opposed to findings of any type. And unlike the cross-cutting conclusions/observations section, this section attempts to focus as *succinctly* as possible on only the *primary or core* issues that 1) are relatively *self-contained* within each of the eight activity areas covered by this program team and 2) can be adequately presented at this point in this report without having to include extensive amounts of background material or definition of terms. The selected primary/core issues identified are presented below on an area-by-area basis. Each of the issues covered is a set of questions and answers to provide the reader with additional insight as to what answers or problem resolutions were being sought. Additional issues and supporting information are, of course, presented in the associated activity area topical reports.

Selected Core Issues for Activity Area A - Urban and Rural Analysis

The two core issues addressed by activity area A lead to the following conclusions:

1. What are the Major Differences Between the Urban, Rural, and Fringe Freeway Situations?

The differences in the urban, rural, and fringe (i.e., the urban fringe/suburban) environments can be described as elements of two major sets of characteristics—a) geometry and traffic patterns and b) accident frequency and type. Specific differences in these categories are summarized below in tables 8 and 9.

TABLE 8. GEOMETRY AND TRAFFIC PATTERNS.

Freeway Environment	No. of Lanes in Each Direction	Speed Limits (mph)	Typical Type of Median	Average Weekday Traffic (Vehicle per day)	Congestion Levels	Typical Interchange Spacing (miles)	Interchange Type(s)
Urban	³2	55	Barrier	>80,000	Recurrent Daily	1/2 to 1	System directional interchanges Std and half diamonds
Fringe	³2	55	Barrier or grass median	20,000 to 80,000	Intermediate	3/4 to 2	Partial and complete cloverleafs with collector and distributor road connections Standard and folded diamonds
Rural	2	65	Wide median	²20,000	No recurrent daily congestion	3 to 5	Cloverleaf and std. diamonds

TABLE 9. ACCIDENT FREQUENCY AND TYPE.

Accident Patterns	Accident Rate (Accidents/Million Miles of Travel)	Most Common Accident Types (% of Total)
Urban	1.7	· Rear end collisions (51%) ·Single vehicle run-off the road (18%) ·Side Swipes (17%)
Fringe	0.7	· Rear end collisions (40%) ·Single vehicle run-off road (21%) ·Side Swipe (15%)
Rural	0.7	· Single vehicle run-off road (34%) ·Collisions with animals (25%) ·Rear end (13%) ·Side Swipe (7%)

The primary (albeit unsurprising) conclusions that can be drawn from analyzing information is that a) the traffic volume, congestion, and accident problems are by far the greatest in the urban and fringe environments and b) the geometry and right-of-way conditions in which to effect a solution are greatest in the urban environment, intermediate in the fringe environment, and relatively non-existent in the urban environment.

2. What are the Major AHS Implications Associated With the Differences Between the Urban, Rural, and Fringe Freeway Situations?

The major AHS implications of the area A findings on the different candidate freeway environments are as follows:

A. The environments with the greatest needs for improved safety and reduced congestion are the urban and fringe freeway situations.

B. The environments with the greatest VMT over which to "amortize" the costs of deploying an AHS or other solution are the urban and fringe freeway situations.

C. The fringe freeways tend to be less spatially constrained than the true urban freeways.

D. Based on the above, a fringe freeway environment might be the best initial target for a real world AHS application because it would have the best combination of supportive factors—i.e., 1) strong need for expected AHS benefits, 2) large VMT over which to amortize the costs, and 3) potentially enough space in which to effect an AHS solution without incurring extreme construction costs for adding elevated or depressed grades.

E. RSCs having heavy land use requirements (e.g., pallet-based systems) would not be promising first candidates for urban areas.

F. RSCs featuring low roadway impacts and costs (e.g., mixed traffic/smart car/passive highway scenarios) could be attractive ways to provide AHS (or partial AHS) benefits to rural freeway environments.

Selected Core Issues for Activity Area E - Malfunction Management and Analysis

Conclusions for three of the top issues for area E are summarized briefly below.

1. What are the Potential Malfunctions to be Addressed?

The upper tier of potential malfunctions to be considered fall into five major categories—a) loss of vehicle lateral control, b) loss of vehicle longitudinal control, c) loss of the roadway coordination function, d) loss of correct communications between the vehicle and the roadway, and e) other (e.g., malfunctions in the vehicle status check system, driver malfunctions, and malfunction of personnel not in the subject vehicle(s). As shown through the use of Fault Trees provided in the area E topical report, there are on the order of 10 to 30 faults and subfaults which can lead to each one of the 5 upper tier major fault outcomes. These more detailed faults include things like sensors failing, faults in links connecting sensors and controls (i.e., wires or connectors), loss of power to control units, and failure in steering or brake actuator. Because the number of potential malfunctions increase with the complexity of a system (e.g., the number of components)—the number of *potential* malfunctions of AHS components and subsystems runs into the hundreds.

2. Can Individual or Sets of Malfunction Management Strategies be Developed to Achieve the Desired Stringent Safety Goals for AHS facilities?

Area E's extensive search for potential malfunctions by means of fault trees, development of action and malfunction timelines (sequences of events), etc., was followed by an equally extensive search for and rating of candidate malfunction management strategies. Briefly stated, no significant malfunctions were identified for which potentially viable malfunction management strategies could not be identified. The “bottom line” of the area E topical report is a set of recommended malfunction management strategies (MMSs). Included are three generic types of strategic responses—vehicle system countermeasures, infrastructure countermeasures, and operational malfunction countermeasures. Specific MMSs identified got into details such as the number and type of redundant or backup devices for each of the key malfunctions identified.

3. Is Human Intervention Acceptable and/or Desirable?

A starting premise for this team's analyses of AHS safety considerations was that it was highly desirable to remove the human error and unpredictability problems from the equation. In the development of malfunction management strategies, however, it was found that there are a number of functions that the vehicle driver can provide that could improve the performance of the overall system over the duration of the trip. Examples include a) using the driver serving as a *backup* steering or braking control resource and b) having the driver provide the AHS control center with inputs on safety-related items that cannot be or may not be reasonably instrumented or otherwise observed by the center staff—i.e., inadvertent spilling or dumping of cargo from a preceding vehicle, loss of communications between a neighboring AHS vehicle and the control center, and intrusion of a non-AHS vehicle into a dedicated AHS lane.

Drivers could also provide emergency information regarding a) emergency illness of any of the vehicle occupants, b) presence of animals or ice on the roads, etc. The driver could also act as an incident management resource—e.g., changing a tire or driving his/her vehicle along a breakdown lane to the next exit or service plaza if he/she is “ejected” from the AHS lane. The current area A conclusion regarding having the driver-in-the-loop is that drivers should be able to make inputs to the AHS, but that the AHS should not be designed to rely on those inputs for safe normal operation or to counter malfunctions.

Selected Core Issues for Activity
Area H - AHS Roadway Deployment Analyses

Two of the key issues addressed by area H are described below:

1. What are the Prospects for Providing an AHS Lane by Conversion of an Existing Lane?

There is no simple conclusion for this issue, the options vary considerably depending on the specific candidate application. The primary conclusions/ options include:

(A) It can be expected that "taking away a lane" for any reason will meet with strong public resistance.

(B) "Taking away a lane" may be acceptable 1) in a four-lane rural highway environment if the inner pair of lanes are assigned to AHS use in an RSC featuring a mixed traffic scenario. In such an arrangement all four lanes are still fully available and the non-AHS vehicles can still use the left lane for passing.

(C) Conversion of an existing HOV lane to AHS use will probably work out from a space and ramp requirement basis. Expected adverse public reaction might be addressed by promoting the AHS benefits and/or giving HOVs preferential treatment in terms of facility access or facility usage charges.

(D) Converting an inner pair of lanes to AHS and replacing the converted lanes with a pair of new outer lanes may or may not be practical depending on the amount of right of way available and the potential for conflicts with overpass structure piers, abutments or slope paving. Widening could also seriously impact on/off ramp alignments.

2. What Key Considerations Are Revealed by Applying Real Life Scenarios to Considering Infrastructure Impacts Associated with AHS Deployment?

Relating generic AHS configurations to real world applications reveals and/or reinforces the need to tailor each potential AHS deployment to the actual situation. Failure to do so <u>early</u> may delay recognition of serious problems such as Item 1D above—i.e., problems with widening a road because of the constraints posed by the length and structural features of the existing overpasses. Other such real world problems include:

A. Difficulty in (or preclusion of) adding a single AHS reversible lane or a pair of new AHS lanes in the median of an existing freeway because:

· Actual or potential conflicts may be encountered with the center piers of one or more overpasses

· Widening and/or realigning the freeway section(s) approaching the center piers of overpasses may cause conflicts with the end structure of the overpasses or with "tunnel" walls if the freeway passes through a tunnel or is on a depressed grade.

B. Other real world impacts or complicating considerations include:

· Drainage modifications

· Landscaping modifications

· Needs for moving or adding noise walls
· Vertical clearance variations/reductions for lanes located near the ends of overpasses

· Needs for additional shoulder space, snow storage, etc.

C. Taken together, all of the area H items listed above indicate that it is unlikely that any AHS implementation will not require extensive construction or reconstruction.

Selected Core Issues for Activity Area I - Impact of AHS on Surrounding Non-AHS Roadways

Two of the top issues for area I are as follows:

1. What are the technical and marketing factors which will greatly affect the level of utilization of an AHS and its impacts on adjacent and/or surrounding non-AHS roadways?

Based on extensive work with the TRANPLAN and other area I activities, it has been determined that some of the key factors which impact what degree of AHS utilization will be achieved are:

A. The level of penetration of AHS-capable vehicles in the region surrounding the AHS.

B. The length of time delay, if any, associated with getting through the ACI/ACO and entry/exit ramp processes.

C. The frequency of access (i.e., interchange spacing) to the freeway.

An indication of the high level of significance of each of these key factors is given by the following three findings:

A. In the urban and fringe environments modeled, if one of three lanes of an existing freeway is dedicated to AHS use, at least 50 percent of all vehicles in the region surrounding the AHS facility must be AHS-equipped to prevent a level of service reduction on the remaining (i.e., non-AHS) lanes.

B. For a 17 kilometer freeway corridor, modeling results indicate that increasing access time delays (the combination of check-in/check-out and user costs represented by time) from one minute to five minutes would drop utilization from 45,000 peak-hour trips to only 500 peak hour trips—a 90:1 reduction.

C. Modeling results indicate that increasing the frequency of interchanges from a current rate of 0.7 interchanges per mile to only 0.4 interchanges per mile would reduce potential peak-hour AHS lane volume assignments by 37 percent.

2. What Modeling Tools are Useful and/or Needed to Facilitate the Evaluation of the Impacts of AHS on Surrounding Non-AHS Roadways?

Estimating likely shifts in traffic as a function of proposed roadway changes is so complex that a competent model or set of models is needed to support such efforts. For this team's area I effort, the TRANPLAN model was used extensively to provide a macro-level analysis of a freeway comprising one AHS lanes in each direction in combination with one or more non-AHS lanes. (A single reversible AHS lane was also modeled.) Results of this TRANPLAN modeling provided a general understanding of the shifts in traffic to the AHS lane from the non-AHS lanes and from adjacent arterials.

The TRANPLAN model does not provide micro-level results of effects such as AHS vehicle entering the freeway on standard ramps and then weaving across non-AHS lanes to merge into AHS lanes. The FRESIM model was reviewed as a potential solution to this shortcoming of the TRANPLAN model. FRESIM is not, however, ready to fill this role at this time because of deficiencies in capability, documentation, and support. It is suggested that a tailored model be developed to allow a full simulation of merging and diverging AHS vehicles into an AHS lane having no barrier restrictions.

3. What are the Approximate Costs Involved in Making Roadway Modifications Comparable to Deploying an AHS via Reconstruction?

Costs for freeway upgrades and/or expansion may be grouped into two major categories—upgrade costs and land acquisition costs. Some examples of each follow.

TABLE 10. SAMPLE OF COSTS UPGRADE OF A TYPICAL URBAN FREEWAY.

(Adding a fourth lane each direction for most of a 22 km corridor)

	~Cost (millions)	**Percent of Total**
Mainline Improvements		
Add One Lane	$46	
Widen Bridge	$20	
Subtotal	$66	12%
Upgrade five Interchanges	$322	56%
Upgrading Intersecting Arterials	19	3%
Engineering Contingencies	163	29%
Total	$570	100%

TABLE 11. SAMPLE OF COSTS FOR LAND ACQUISITION COSTS FOR FREEWAY EXPANSION.

Region Type	**Cost/Km (millions)**
Urban	$12 - $14
Fringe	$5 - $6
Rural	$0.4 - $3

Cost to convert an existing lane to HOV traffic or of adding at least one lane for HOV traffic are also useful indicators of pertinent AHS deployment cost. Some examples are provided in the following chart.

Region Type	Cost/Km (million)	
	HOV Conversion	HOV Addition
Urban	$0.6 - $6	$4 - $13
Fringe	$0 - $0.1	$0.2 - $2.5

Another significant cost to consider is the expense of deploying noise attenuation walls next to the freeway. Noise walls can cost over $1 million per kilometer to construct, not including any earth work for grading or support.

Selected Core Issues for Activity
Area J - Entry/Exit Implementation

A few of the more important issues in area J are described below:

1. What are the most important measures of effectiveness (MOEs) for evaluating the viability entry/exit strategies?

The area J team identified seven key MOEs for evaluating entry/exit strategies—they are:

A. Improvement in Safety
B. Minimal Need for Additional Land
C. Minimal Need for Addition Facilities
D. Minimal Impact on Adjacent Roadways and Environment
E. Large Improvement in Potential Capacity
F. Minimal disruption of Traffic Flow
G. Low Cost and Complexity.

2. Using the MOEs developed, which RSCs score most highly and most poorly overall?

On an overall score basis, the RSCs which scored the highest were this team's RSC-2C and RSC-4. Both involved smart vehicles—RSC-2C involved a platooning scenario using an average intelligence roadway with a reversible AHS center lane while RSC-4 utilized a four lane having the two inner lanes passive highway assigned to AHS use in a mixed traffic scenario. RSC-2C received fairly high marks relative to all of the MOEs except the one concerning “minimal impact on adjacent roadways and environment.” RSC-4 did very well relative to all the MOEs except for the ones calling for “large improvement in potential capacity” and “improvement in safety.”

The worst overall score was received by RSC-3—the smart pallet operating on an average intelligence highway. This RSC received fairly poor marks against all of the scoring except the ones having to do with “minimal disruption of traffic flow” and “low cost and complexity.” RSC-3 received the lowest marks for all of the RSCs in four of the seven categories.

3. What is the viewpoint of the area J staff regarding the use of barriers?

The area J staff views barriers as effective safety devices which should be used wherever practical between AHS, transition, and non-AHS lanes. It is recommended that the barriers a) be used in conjunction with exclusive entry/exit ramps and b) be sufficiently large that they positively prevent intrusion into (and egress from) the AHS facility other than by the exclusive ramps. A cautionary note is that the barriers could act as hazards in the entry and exit areas unless they are designed and placed to avoid and/or mitigate end-on collisions.

Selected Core Issues for Activity
Area K - Roadway Operational Issues of AHS

Two of the core issues for area K are as follows:

1. What are the primary functions of an AHS control center and is their a useful precedent for such a control center?

The major daily operations of an AHS system are fivefold—

A. System Control
B. Monitoring of System Operation
C. Incident Management
D. Maintenance
E. Reporting.

Present Freeway Management Systems (FMS) provide all of these functions/ services at some level and, therefore, could serve as a useful precedent for the design of future AHS centers. It is suggested, in fact, that future AHS control centers be collocated with regional FMS control centers so they can achieve economies of scale with regard to both staffing and facilities.

2. What precautions should be noted in planning the AHS Operations Center?

The primary precaution is that AHS operations center staffing costs could easily get out of hand if unless considerable care is exercised in sharing staffing requirements with an existing FMS facility, highly automated, high reliability and fault tolerant systems are selected, and AHS drivers are utilized wherever practical to provide their own incident management labor (e.g., changing flat tires or driving under manual control via a breakdown lane to the nearest exit if ejected from the AHS lane because of a malfunction which exceeds AHS acceptance criteria).

Several additional planning issues requiring further exploration and analysis include such questions/matters as 1) the allowability of deliberate system downtime to facilitate maintenance, 2) optimized shutdown and restart procedures following initiation of a planned or unplanned system shutdown, and 3) ability to operate in a derated mode to accommodate degraded environmental or roadway conditions (e.g., severe weather or minor flooding).

Selected Core Issues for Activity Area N - AHS Safety Issues

Two of the pervasive core issues for area N are described below:

1. Because the objective of the area N set of activities is to provide AHS users with a collision-free driving environment under normal operating conditions, how does one characterize normal what constitutes "normal operating conditions?"

To begin with, normal operating conditions refers to AHS operations in the absence of malfunctions. In the absence of malfunctions (e.g., failure of AHS equipment located on the AHS-capable vehicles or the AHS roadway/ infrastructure), there are still threats to be faced (e.g., threats posed by inclement weather). Other threats are posed by actual or potential inadequacies in the detailed design or scope of the AHS system features—possibly as a result of an oversight or arbitrary decision in anticipating all of the variables to be considered. For example, the automated braking System on an AHS vehicle may function as designed but still allow a collision to occur because the system designer did not anticipated all of the variables affecting vehicle separation and stopping distance.

Still other threats to be considered are those posed by an "acts of God or war"—e.g., a 747 crash lands on the AHS or terrorists sabotage the AHS control center. An attempt might be made to control these type threats or it may be deemed impractical to attempt such control. Deer or other animals getting on the road might fall into a category of "naturally occurring threats." Attempts to eliminate animals on the roadway (say by installation of fencing) introduces a gray type of threat—i.e., if animals get on the road despite the fence, is this a malfunction of the fence system or a deficiency or inadequacy in design of the fence system. The answer to this dilemma is to 1) integrate the safety and malfunction management analyses to assure comprehensive system safety coverage and not get overly concerned about whether a given causal factor is a malfunction or an inadequacy and 2) err on the side of overlap in planning for safety in either the presence or absence of overlap.

2. Is there any major technical issue(s) on which the safety analysts must focus?

The concept of providing a collision-free environment in a highway system populated by a multitude of vehicles traveling at moderate to reasonably high speeds presents at least one core issue—the need to establish and maintain sufficient separation of all of these potential collision partners so that reasonably attainable braking and/or steering actions can prevent collisions across the full range of normal operating events. Considering that many of the AHS deployments will provide one AHS lane in each direction and have AHS-capable vehicles traveling in line at speeds and relatively close headways consistent with increasing capacity—the area N report focuses much of its attention on separation management and vehicle braking.

Selected Core Issues for Activity
Area O - Institutional and Societal Aspects

Two of the core issues for the Institutional and Societal Aspects are presented by the following examples:

1. What are some of the leading liability considerations posed by deployment of an AHS?

Some of the leading legal considerations can be stated as follows:

· To the extent AHS transfers control from the driver to the vehicle, the roadway authority, or a combination, the liability may also shift accordingly, For any of these parties, then, even if the total liability is reduced because of the expected AHS safety improvement benefits, the increased share of liability borne by any of the parties may increase their net risk.

· To the extent that AHS deployment increases uncertainty about the causes of accidents and who is responsible, it may increase the number, complexity and parties to lawsuits, thereby raising transaction costs, the potential for reputational damage, and increasing litigation risks.

· To the extent that AHS creates the possibility of accidents involving large number of vehicles, it likewise creates the possibility for “catastrophic liability.”

2. Who are the most important stakeholders?

This is a difficult question because it depends on the nature of the AHS deployment—i.e., what type of AHS, where is to be deployed, and when. However, it is probable that one of the pivotal groups will be the State DOTs and MPOs. The results of this team's area O findings that the State DOTs and MPOs must be convinced of the benefits of AHS before they will be in any position to attempt to gain the public and political support that will be absolutely necessary to support decisions to deploy an AHS. These groups will, of course, be influenced by other stakeholders and/or influence wielders such as the public in general, the likely users, the environmentalists, and the media.

Because the key AHS deployment decisions are likely to be made at a state DOT and local MPO level, these groups are probably the best targets for early outreach by the FHWA and their AHS consortia contractors. Other early outreach efforts may well be focused on making the media an ally in building the desired perceptions, and acceptance, amongst the various public stakeholder groups.

Recommended Further Investigations

During the course of conducting these investigations and preparing this report, a number of candidate topics for further investigation were identified. Several of these candidate topics are presented below. This is a non-prioritized list; we recommend that prioritization be done after the particular types of AHS or test track target(s) are selected for implementation by 1997.

1. Further modeling is required and would be greatly facilitated by the development of a model which can provide micro-level results not possible with the current TRANPLAN model. Micro-level results of interest include the results of various merging and demerging effects such as an AHS vehicle entering the freeway on standard ramps and then weaving across non-AHS lanes to merge into an inner AHS lane.

2. A search should be undertaken of candidate sites for a test track suitable for evaluating AHS concepts, features, and malfunction scenarios. Adoption or modification of an *existing* facility (such as the 7.5 mile test track of the TRC of Ohio facilities) would be desirable from both a time and cost standpoint. Access to such a facility would help the development and evaluation of various AHS systems. Planning for a suitable facility should begin immediately. Such a facility could also be used to 1) provide demonstrations to key AHS stakeholders and 2) satisfy the need for having an operational test track by 1997.

3. A study should be made of the feasibility of *retrofitting* current or emerging transit buses to make them AHS-capable. If current and emerging transit buses are not found to be capable of such retrofit, it may be possible to incorporate upgradeability to AHS-capable status as an option in the forthcoming updating process for the transit bus “White Book”—e.g., the specification document used by transit properties to order new buses.

4. Incident management emergency services, maintenance, and snow removal, etc., for various types of RSCs may require new or modified equipment. Such needs should be identified as early as possible so work can proceed to have this modified equipment ready when it will be needed.

5. Restraint system modifications and/or enhancements may be required or desired with some of the specific RSCs. For example, it may be possible to fire air bags in an anticipation of a collision because AHS gap or lateral sensors provide an early warning not now available. It may also be required to provide special front and rear structures on pallets to assure proper restraint system performance for the occupants of the carried vehicle or to trigger the air bags based on a special pallet signal. This area needs to be explored on a basis prioritized by the RSC types selected for early deployment.

6. Further study is needed to establish the anticipated approximate trip length for early AHS deployment—if the early deployment are likely to be 15 to 30 minute rides on a fringe type freeway, this might alter the acceptability of having more than a strictly passive voluntary, or backup role for the driver.

7. More analysis, simulation, and full scale experimental work is needed to evaluate the feasibility of deploying mixed traffic based RSCs in rural applications.

8. Work on draft and final standards for AHS hardware and roadway designs should begin as soon as possible. The early availability of hardware standards could avoid conception and development of a lot of non-compatible systems. Early attention to development of AHS roadway standards could avoid public acceptance and safe use problems by motorists which would likely result if they are presented with non-uniform, unpredictable arrays of adjacent or remote AHS-roadways.

OVERALL CROSS-CUTTING CONCLUSIONS/OBSERVATIONS

Introduction/Background

This program team had the privilege of performing 8 of the 16 activity areas. The eight areas covered were:

A. Urban and Rural AHS Analyses

E. Malfunction Management and Analysis

H. AHS Roadway Deployment Analysis

I. Impact of AHS on Surrounding Non-AHS Roadways

J. AHS Entry/Exit Implementation

K. AHS Roadway Operational Analysis

N. AHS Safety Issues

O. Institutional and Societal Aspects.

The opportunity of simultaneously working areas A, H, I, J, and K provided an excellent platform for analyzing the complete range of AHS <u>Roadway-Oriented Issues</u>. Similarly, simultaneous conduct of areas E and N provided an opportunity to explore a full range of AHS safety considerations (a key subset of AHS Systems-Oriented Issues). Augmenting these analyses of primarily technical issues, the conduct of the area O set of activities provided the program team with involvement and exposure to the full range of the critical People-Oriented Issues.

Further augmentation of this background was provided by the program team's selection of a range of RSCs which included:

1. Various combinations of the smart highway—dumb vehicle and smart vehicle—dumb highway genre (including platoons)

2. A mixed traffic scenario

3. A pallet-based AHS.

This program team also benefited from its participation in special project and PSA-level meetings, teleconferences, workshops, etc., with a wide variety of industry specialists, actual and potential stakeholders, and other contractors. The existing and emerging literature on AHS and IVHS was, of course, also thoroughly utilized as were the personal experience and other resources of the members of the team.

Selection of Cross-Cutting Issues

The presentation of cross-cutting observations and conclusions which follows is structured around a set of 9 major topical areas. These topics were established by 1) listing the items thought to represent the team's cross-cutting observations of highest general interest and then 2) aggregating these items into the smallest practical number of categories. In this case, more than 30 items were consolidated into 9 categories as follows:

- Selection of the Initial AHS Application(s).

- Basic RSC Choices and Features.

- Timing Considerations.

- The Safety Imperative.

- The Human-in-the-Loop.

- Evolutionary versus Revolutionary Deployment.

- Costs, Risks, and Benefits.

- Technical Gaps/Needs.

- Programmatic Considerations.

Discussion

Each of the cross-cutting issue categories identified is discussed below. Where practical the contribution of the individual Activity area findings to the core observation or conclusion being presented is indicated.

Selection of the Initial AHS Application(s)

The analyses performed by this team's area A staff clearly reinforced that the need to reduce the number of accidents and to reduce congestion is greatest in the urban and urban fringe environments. While this observation will surprise no one, associated area A findings also show that 1) the concentrated need and, therefore, ability to amortize investments over large vehicle populations and VMT, is almost as great in the fringe environment and 2) the layout for the fringe freeways is more open and might better accommodate additional space needs for special ramps, ACI/ACO features, barriers, breakdown lanes, transition lanes, etc. This finding would suggest that a fringe type freeway situation might be the most attractive first choice pending (as shown by the area I analyses) sufficient penetration of AHS capable vehicles.

Another perspective on this topic is that results of the area O (Institutional and Societal Aspects) effort indicates that building public support will take significant cultivation to convince pertinent stakeholders and decision makers (e.g., the state DOTs and local MPOs). A key feature of this orientation and support building process needs to be the capability of showing the prospective stakeholders proven/successfully demonstrated results for the candidate AHS technologies. Because exposure of the pertinent stakeholders to date has been very slight—the size of this critical orientation and support building task is huge and may take more time than is available to satisfy the Congressional mandate for having an initial AHS facility in operation by 1997.

Still other factors in the equation are 1) the need to assure the public and other stake-holders that all practical measures have been taken to “guarantee” that the first AHS applications are unqualified successes and 2) a need to provide a test site to facilitate comprehensive evaluation and debugging of current and future AHS technologies and operating practices (e.g., malfunction management and incident management). Failure to prevent an early AHS implementation failure could serve as a disastrous long-term impediment against further penetration of AHSs. Most people can readily think of one or more products that were rushed to the market prematurely and wound up souring that particular market for some time.

One potentially viable suggestion which emerges from consideration of the above factors is that the initial AHS application should be a specialized AHS test site (preferably a permanent site). Planning and implementation of such a test facility could begin very shortly and was recognized as a key option in the language of the Congressional mandate for AHS development—i.e.,

> "The goal of this (automated highway) program is to have the first fully automated roadway or an automated test track in operation by 1997."

In summary, selecting the test site option rather than the actual roadway option would

(1) Assure likely compliance with both the direction and time frame of the enabling legislation

(2) Provide a proving ground to facilitate the safe and efficient *development* and *demonstration* of safe and cost effective AHS systems, methodologies, and componentry. (Access to a nationally provided AHS test track could also greatly foster the growth and international competitiveness of the fledgling AHS (and ITS) industries in the U.S.)

(3) Go a long way towards satisfying pertinent stakeholders that the candidate technologies are sufficiently proven to be implemented as safe and cost effective improvements to highways in their jurisdiction.

Ideally such a test track facility would have the built-in flexibility (or upgradeability) to accommodate/simulate a full range of RSC options (including various transit-oriented systems and pallets). The selection of the initial test track features should include consideration of not only the ultimately predominant urban and fringe needs, but also the especially promising targets for actual first real world deployment. It is suggested that the first actual deployments may, in the interest of providing 1) a highly controlled environment and 2) early application not paced by the need to accommodate a highly uncertain wait for sufficient penetration of AHS features for privately owned cars, be aimed at special niches—e.g.,

- Special mass transit corridors.
- "Conventional vehicle" alternatives to contemplated light rail applications.
- Environmentally friendly pallet systems for highly congested national parks.

Basic RSC Choices and Features

An early landmark paper on alternative AHS systems[2] identified nearly 150 unique RSC options and then narrowed this number down to 37 candidates having reasonable viability. Between them, the 15 PSA contractors explored many of these candidates, and this particular program team considered 4 basic RSC types plus 2 variations. At this juncture some might consider it desirable to report that the pool of RSC candidates can now be further narrowed. However, it this team's judgment that outright elimination of certain RSCs at this point would be premature. This does not, of course, mean that all of the candidates are equally viable/attractive. Some RSC scenarios (e.g., those involving mixed traffic, platoons, or pallets) may only be suited to particular AHS deployment life cycle stages or applications—not widespread long-term usage. For example, 1) platoons may be an excellent way of gaining capacity in certain environments but not nationwide, 2) mixed traffic scenarios might work on some rural applications but not all, and 3) pallets may make sense in early AHS applications where it is unlikely that sufficient AHS-capable vehicles will be available for a long time.

It is not practical in this overview presentation of cross-cutting observations to comment on all of the candidate RSC choices or features. Instead, comments follow for only the choices or features thought to be most interesting or surprising.

Distribution of intelligence: Of the various ways of distributing intelligence amongst the vehicle and the roadway, it became a consensus view of this team that the RSCs featuring the "smart vehicle—dumb highway" approach were the most desirable. Desirability in this case spans the gamut of technical and non-technical issues as listed below in a non-prioritized fashion:

1. Minimal impact on the roadway—thereby 1) reducing roadway construction, reconstruction and maintenance costs, and 2) improving the equity of funding AHSs.

2. Increased potential for using advanced AHS supported features (e.g., intelligent cruise control and accident avoidance systems) on non-AHS roads—thereby greatly increasing the benefits and salability of AHS features.

3. Spreading of the liability responsibilities in a manner more consistent with the present highway and highway user institutional and societal systems—thereby reducing the daunting prospect of a single entity (roadway commission, transit authority, etc.) being responsible for everything.

4. Keeping the door open for a large number of organizations to conceive and introduce new AHS products in a constructively competitive environment.

5. Minimal dependence on a central controller 1) which must continuously provide sophisticated control and guidance to a whole AHS system full of vehicles and

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[2] Stevens, W. B., "The Automotive Highway System (AHS) Concepts Analysis," MITRE Report MTR93W000123 (August 1993)

2) whose loss or malfunction could conceivably lead to a very serious multi-vehicle accident.

Many may resist the introduction of still more sophisticated features into the U.S. fleet of vehicles. However, the wave of increased sophistication is already in motion as evidenced by the introduction and large penetration of such features as multi-point sequential fuel injection, antilock brake systems, air bags, etc. The level of complexity is likely to continue to increase anyhow—adding AHS capability could be viewed as essentially just the introduction of a new plateau of increased safety and convenience. Given appropriate direction, it might also serve as a valuable aid to a population having increasing numbers of aged and impaired drivers.

Matching RSCs to the application/environment: Extensive effort has been applied to introduce and implement standards in the design and deployment of highways across the country. Despite these efforts, there is considerable variety and, therefore, RSCs will have to be selected and deployed on a tailored basis, unique to each environment and/or locale. Such tailoring must, however, be done in a manner sufficiently consistent/uniform nationally that driver safety and public acceptance problems will not result.

At the outset, it seems likely that some RSCs would match given applications better than others—e.g.,

1. For long distance rural highways (which, according to the area A Analyses, generally tend not to be congested), the first choice would seem to be an RSC featuring minimal infrastructure work (e.g., a dumb highway—smart vehicle scenario). A pallet based RSC might be attractive in this application if/when 1) few RSC-capable vehicles are likely to be available to utilize it for a long interval of time, 2) a particularly boring, tedious, or congested drive is involved, and/or 3) there are highly restrictive local conditions (e.g., dense fog or narrow roads) that make it desirable to completely remove the driver from the control of the vehicle/traveling unit.

   Because this team's area I efforts indicated a very strong inverse relationship between potential AHS usage and any time delays in accessing the AHS, this factor would suggest that long routes would be better targets for pallet based systems because the loading and unloading delays would be short *relative* to the total duration of the trip.

2. For short to medium length urban and fringe freeway environments, any of the RSCs that are not high in land use requirements would be likely candidates. Some versions which require additional ramp space, ACI/ACO space, transition, lanes, etc., might be accommodated by using relatively expensive elevated or depressed grades to effect a solution.

3. Special applications may well prompt RSC selections which are suitable for niche markets rather than nationwide use. For example, certain highly congested corridors might seem to be good applications for the potential capacity gains of a platoon based system. However, detailed analyses for some of those applications might show that such factors as 1) the space and infrastructure investment requirements for providing breakdown lanes, special entry or exit ramps or ACI/ACO features, etc., 2) the time delay before sufficient AHS-capable small/private vehicles exist to make the necessary investments cost-effective, and/or 3) the need for extensive development and demonstration of safety features sufficient to satisfy pertinent stakeholders might make an alternative transit or HOV (e.g., bus or van pool) based RSC look much more attractive.

Our area O efforts emphasized the need to demonstrate/prove safe reliable performance for any AHS candidate. It did not identify the platoon based RSC specifically as having a more challenging safety demonstration requirement. However our area J and N efforts indicated that the short headway and close lateral separation aspects of the platoon concept would be especially challenging.

A transit or van pooling choice would support the goal to 1) safely and effectively *move people*, not necessarily vehicles and 2) provide broad system access. Such a choice might also provide an attractive means of incentivizing/achieving environmental gains via reduced VMT and/or use of alternative fuels.

Certain regions might select a particular RSC to promote or incentivize the use of electric powered vehicles and/or pallets to satisfy especially stringent environmental needs. It should be noted, however, that while pallets could be selected which use electricity (or another environmentally friendly alternative fuel), a pallet capable of carrying a full size passenger car or van (and providing reasonable acceleration rates) will consume more energy doing so then would the vehicle carried operating on its own.

Lane width and associated reconstruction: At the outset it was generally thought that a key benefit of deploying an AHS would be to capitalize on the precise control expected via AHS systems to provide an increased number of lanes (albeit significantly narrower lanes) on a given size facility. Further examination suggests this is unlikely for several reasons.

1. Work in areas E, N, and O suggest that drivers and operators must occasionally expect some non-trivial number of manually controlled vehicles in the AHS lanes. Even though a particular AHS is designed to preclude the entry of manually controlled vehicles to the AHS lane(s)—some such operation will occur as a result of a) inadvertent or deliberate breaching of the prevented entry countermeasure, b) reversion to manual control is a likely fallback safety measure should the AHS control systems (e.g., automatic steering) malfunction, c) some emergency vehicles or maintenance vehicles (e.g.,

snow plows) not being fitted for and/or operated under AHS automation, and d) some finite (albeit relatively rare) amount of AHS system downtime necessitated by maintenance or unusual emergencies (e.g., earthquakes or floods).

2. Even if the selected AHS configuration is restricted to cars, some use by larger vehicles (e.g., emergency and maintenance vehicles) should be anticipated.

3. It is expected that shoulders and/or breakdown lanes will have to be provided alongside the AHS lanes. Provision of barriers next to the AHS lanes would further complicate the lane width issue.

4. Converting an HOV lane to serve as an AHS might satisfy many of the dimensional requirements for an AHS lane, however, work in areas H and O indicate it will be very difficult from a public acceptance standpoint to “take away any lane” (HOV or other) to provide an AHS lane.

5. The upshot of the above is that AHS lanes (and in some cases breakdown lanes, transition lanes, barriers, modified entry/exit ramps, etc.) will probably have to be *added*, not just provided by “simple” conversion of existing lanes. If this observation holds up, it will have significant implications on the selection of AHS type, the active width of the resultant thoroughfare, and the extent and cost of reconstruction based deployments.

Vehicle Features: At a minimum an AHS-capable vehicle/traveling unit will require special on-board systems to provide such functions as lane following, remotely actuated variable throttle/speed control, vehicle-to-vehicle gap sensing and maintenance, and sophisticated crash avoidance systems. Some of these particular systems might be retrofittable. However, means of providing automated steering and braking functions which cannot be overridden by the driver without AHS permission are unlikely to be retrofittable from a technical standpoint, much less a liability standpoint. Accordingly, the notion of having AHS retrofit kits or vehicles does not seem viable on *present* cars, trucks, and buses. Retrofits might, however, be possible in the future if there is 1) a significant movement towards “fly-by-wire” type steering and braking systems and 2) upgradeability to AHS-capability is a designed-in feature. In the very near term the only obvious approach to making existing vehicles compatible with use on an AHS would be to load them onto an AHS-capable pallet. This approach would, in fact, require no retrofitting whatsoever with the possible exception of the pallet user temporarily taking on board a portable communication/interface control box. The basic function of this interface device would be to provide a communications link between the vehicle occupants and AHS zone controller for the duration of the AHS trip.

Other details regarding potential vehicle features are covered in the area E report. In trying to identify potentially necessary malfunction management strategies, the area E team had to identify all of the functions to be performed, what kinds of equipment would perform them, and what kinds of strategies (e.g., redundant sensors, redundant or high reliability actuators, run flat tires, etc.) would be necessary to provide the desired high levels of safety and reliability.

Pallets: This contractor was the only one to explore pallets. Accordingly, it is appropriate that the pallet based RSC be reviewed in this Cross-Cutting Issue section. This review is probably achieved most concisely by presenting 1) a brief definition and 2) a list of pros and cons. For purposes of this study, a pallet was defined as being a completely AHS-capable, self-propelled vehicle (essentially a cab-less, flat bed truck upon which a conventional full sized car could be readily loaded (and unloaded) and safely and efficiently carried under AHS control from Point A to Point B.

Some preliminary thought was given to a “partial pallet” upon which just the front portion of the AHS user's vehicle would be driven. It was envisioned that a partial pallet would eliminate much of the full pallets' cost (e.g., its engine and transmission). It would also require much less space for storage and recirculation. Consideration of the partial pallet was dropped because of anticipated problems in 1) effectively using the vehicle's powerplant to drive the pallet/vehicle combination, 2) providing adequate steering and braking, 3) adjusting to a variety of vehicles (e.g., different vehicle sizes and driving arrangements such as front wheel drive versus rear wheel drive).

Basic pros and cons of the full pallet concept which emerged from this team's efforts are as follows.

TABLE 12. PROS AND CONS OF PALLET-BASED RSC.

Pros	
1.	Could be one of the safest RSC types available because it could provide the best equipped and maintained traveling unit having the most uniform characteristics.
2.	Universal access - all potential AHS users can access a pallet based system with their existing vehicles.
3.	There would immediately be a high number of “AHS-capable” vehicles—no need to wait for uncertain rates of penetration.
4.	Pallets would provide a “portable” AHS technology, the pallets could be moved from one location to another.
5.	A high utilization factor should justify better and more robust AHS features than an occasionally used, private AHS vehicle.
6.	Use of “system” owned and maintained pallets should yield safer, better maintained AHS vehicles/traveling units.
7.	A pallet based RSC could be dedicated to using an environmentally friendly alternative fuel(s)—e.g., electricity.
8.	Pallet RSCs could be especially valuable in applications where it is highly desirable to prevent potential driver intervention, tampering, etc.
Cons	
1.	A pallet based system will be a heavy consumer of land space for storage and for achieving the entry and exit functions.
2.	Storing and maintaining a large inventory of pallets will be a major undertaking as will “recirculating empty pallets.”
3.	A pallet based approach would concentrate equipment investment costs and liability onto the system entity's shoulders.
4.	Pallets will probably use more energy for a given trip than the vehicle being carried. They may also have to make a significant amount of the return trips (i.e., the recirculation trip) empty.
5.	The vehicle/pallet combination traveling unit will be heavier (probably on the order of twice the weight of the passenger vehicle itself) and have a higher center of gravity. Its higher center of gravity will make it somewhat less stable in lateral maneuvers.

Timing Considerations

Several key timing considerations must be addressed in planning the work to be done at the conclusion of the PSA contracts. As noted earlier, 1) the enabling legislation calls for an initial AHS facility to be in operation in 1997 and 2) the results of this team's area O efforts indicate that building public support for deployment of an actual AHS in a given locale will take significant cultivation and time. It is this team's view that the amount of time to cultivate and convince the necessary stakeholders will be measured in years, not months, even if much of the total cost of deployment will be borne by the government. A compounding factor is that much of the serious cultivation cannot be done until all of the necessary systems have been developed and successfully demonstrated. A reasonable sequence of events for an expeditious program, therefore, might be as follows:

1. Identification of the most promising RSC(s) for early pursuit.
2. Identification and prioritization of the technical and non-technical gaps associated with launching that particular type of RSC(s) (preferably with one or a few candidate sites in mind).
3. Simultaneous attack on the technical and non-technical gaps and the preparation of an existing or new proving ground facility to conduct development and convincing demonstration of the key AHS technologies.
4. Expeditious test track based demonstration of the selected technologies to the critical stakeholders.

Another timing consideration which should be addressed as early as possible is that of developing national and/or international standards for the key hardware involved. Done properly, the early existence of draft and final standards could help to prevent the very troublesome non-compatibility and non-supportability problems encountered in recent years with products such as personal computers and VCRs. The Society of Automotive Engineers (SAE) a large, international organization, well known for its standards work would probably be an excellent choice for handling this need.

The Safety Imperative

The many internal and outreach discussions conducted by this program team came to a strong consensus on the matter of safety—i.e., any viable AHS concept *must* offer significantly improved safety over competing conventional roadway. The only debate on this finding is how much safer and what are the appropriate safety measures or yardsticks.

One starting point for these deliberations was the notion that an AHS would be at least as safe as present properly executed freeway systems while offering significant improvements in other benefit categories such as increased efficiency/throughput and convenience. It was decided that this level of safety was clearly not enough. At the other end of the spectrum is the notion that when the public is taken out of a control role in a transportation system—the system operator (e.g., commercial airlines or rail systems) must provide levels of safety which are orders of magnitude better than the privately operated alternatives (e.g., privately driven cars). The current team consensus regarding AHS facility safety falls somewhere between these two extremes.

A frequently used yardstick of highway safety is the number of injuries and fatalities per vehicle mile traveled (VMT). It was thought by the team that this measure was probably still appropriate but insufficient. The insufficiency aspect comes about by considering that (as discussed in the area N and O reports) safety has two major impacts—actual and perceived. Based on the work and experience of the staff who conducted the area A, E, H, K, N, and O tasks, in order for an AHS to be perceived as safe, the thoroughness of the identification, preparation, and maintenance of provisions to assure a high level of safety must be obvious and continuously communicated. An additional related thought is that in the early days and years of introduction, “extreme” measures must be taken to avoid occurrence of any multi-vehicle accidents. Even 1) without a number of serious or fatal injuries or 2) a better overall safety record, the occurrence of a multi-vehicle accident would contribute to perceptions of poor safety that would be hard to erase.

The Human-in-the-Loop

One of the more controversial issues addressed by this program's team members as individuals and as a group was the issue of the human-in-the-loop—i.e., what should be the role of the driver. The “going-in position” was that once a driver had become fully accepted and engaged into an AHS stream of traffic that the vehicle driver go into a hands-off, feet-off, brain-off mode. This hands-off, feet-off, brain-off mode would persist until it became necessary for the AHS system to transfer control back to the driver at or near the end of the trip. As the program progressed, however, a number of arguments surfaced to support various non-passive responsibilities for the driver. Those arguments (most of which are presented in the area E and O reports) are provided below:

1. As one of the candidate malfunction management strategies, the driver could serve as a very capable and versatile fallback control system in the event that an automated control system such as automated steering (and any of its built-in mechanical or electronic safety countermeasures) should fail.

2. Capitalizing on the sophisticated observation and control system skills embedded in the driver as an additional source of input information to the zone controller could be very helpful to the overall system (just as pilot reported information is helpful to current air-traffic control center personnel).

3. Maintaining some active role(s) for the driver during entry and exit and other stages of AHS operation could help minimize the extent and cost of infrastructure modifications.

4. Using the driver to handle certain malfunctions (e.g., to change a flat tire while in the breakdown lane or driving an ejected car on the breakdown lane from the point of “ejection” to the nearest exit) could greatly reduce the incident management costs discussed in the area O report.

5. Maintaining some meaningful role for the driver (especially some control or input to control in emergency situations) could (as discussed in the area O report) counter possible resistance of many potential AHS users to totally giving up control of their vehicles to an automated system.

In general the team now feels that AHS should be developed to *accept* inputs from the driver (e.g., a panic button type signal or a verbal communication regarding an observed hazard (e.g., an obstacle on the roadway, etc.) *but not expect driver inputs*.

Evolutionary Versus Revolutionary Deployment

Consideration of various approaches to the design *and deployment* of AHS prompted this program team to add a fourth RSC featuring a two lane mixed traffic scenario. This concept seems somewhat out of step with the initial thought that an AHS should provide the driver with hands-off, feet-off, *and brain-off* operation. However, it seemed to make imminent good sense for four lane rural highways where it is inconceivable that it would be generally cost effective and publicly acceptable to either 1) dedicate one of the two lanes in each direction to AHS use or 2) add a whole third lane in each direction dedicated to AHS use. The former would tend to turn four lane highways into two lane highways. It would also either complicate entry, exit and passing, or eliminate passing depending on which lane was assigned to be the AHS lane. The latter approach of adding a whole third lane in each direction would provide a non-interfering AHS capability but at enormous expense.

A tentative conclusion might, therefore, be to not consider AHS deployment for four lane divided highway applications. To do so, however, would give up 1) the potentially large gains in safety that might accrue from using AHS features such as lane following and crash avoidance to reduce run-off road and various on-road collision accidents in rural situations and 2) a means of greatly increasing the potential attractiveness and market pull of such AHS features by making them quickly available on more of the country's roadways.

One immediate reaction to such a concept is that a mixed traffic scenario will introduce undesired safety problems and/or lose appeal to a market which favors a revolutionary new generation approach to guideway design which essentially eliminates any need for driver attention once AHS control has been activated. Subsequent analysis in area E indicated that mixed traffic type operation could be structured to provide levels of safety between that offered by present freeways and that offered by a fully implemented AHS having a dedicated AHS lane(s). It was also envisioned that such hybrid or partial AHS deployment would not necessarily be restricted to rural type applications.

Subsequent analyses in area O would tend to support that many potential AHS users would feel more comfortable with an AHS that they had a chance to grow into. A mixed traffic scenario would also tend to mesh with area K findings that show some synergism and significant economies by combining a current Freeway Management System Control Center (FMS) with a new AHS control center.

Costs, Risks, and Benefits

This program team was not assigned to work on activity area P, Preliminary Cost/Benefit Factors Analysis. Nonetheless, several cross-cutting type observations were made by the team and are discussed briefly below.

With regard to costs, it was found through the work on areas A and H that the approximate costs to add an AHS lane in some environments could be on the order of $41.0 million per mile. It was also found in the work on areas H and O that it was likely that few opportunities would exist to create an AHS system by “taking away” a conventional or HOV lane. The implication of these combined findings (along with other findings of areas A, H, I, and O) is that the deployment of an AHS lane is likely to be very costly unless it can be “piggybacked” onto other highly needed construction or reconstruction.

Some of the more pervasive risks identified by this program team include the following:

1. Failure to allow sufficient time for maturing and demonstrating the key technologies before committing to the first real world installation.

2. Failure to correctly assess the likely rate of penetration of AHS capability into cars in a given region(s) to justify the costs of a) deploying a *new* full fledged AHS system or b) *retrofitting* two or more AHS lanes onto an existing freeway system.

3. Failure to correctly assess the importance of safety (both actual and perceived) to public acceptance of AHSs.

4. Focusing too much attention on the technical issues and not enough on the institutional and societal issues.

5. Focusing too much attention on the steady-state behavior of the system(s) to the detriment of sufficiently looking at the transient conditions (analogous to looking at the long term cruise situation for aircraft as opposed to the critical landing and takeoff intervals).

6. Ignoring the potential impact of a lack of standards/guidelines on the generation of a range of non-compatible systems and subsystems which cannot be utilized in optimal combinations and/or subsequently inhibits widespread penetration of AHSs and foreign sales.

As potential benefits, a list beginning with improved safety follows:

1. Improved safety.

2. Increased efficiency and capacity in moving people (and cargo)—not necessarily vehicles.

3. Increased reliability of trip times between two or more points served by the AHS.

4. Increased convenience.

5. A marketable export item for the U.S. and/or an American-produced product that keep jobs and dollars at home.

6. A special way of switching an appreciable portion of transportation energy consumption to alternative fuels.

Technical Gaps/Needs

Technical gaps/needs identified during the conduct of this particular program range from a) products known to be for sale or under development to b) functional concepts not known to be under development. A starter listing of such products/features/or technical gaps follows:

1. Fly-by-wire steering systems and/or high reliability, low cost decoupling units for mechanically based systems.

2. Fly-by-wire brakes and/or high reliability, low cost decoupling units for mechanically based systems.

3. Collision avoidance systems (radar, IR, etc.).

4. ACI/ACO systems for vehicles *and* driver.

5. Special collision energy absorbers for pallets.

6. Special passenger restraints and/or air bag triggers for pallet mounted vehicles.

7. Special emergency and maintenance vehicles for AHS facilities (including remote location pallet unloading and pallet/vehicle combination retrieval).

8. Low cost high reliability vehicle separation/ranging sensors.

9. High reliability, low cost run flat tires.

10. Draft standards for emerging AHS/IVHS systems and subsystems.

Programmatic Considerations

Based on the experience of this program team, there are several programmatic observations that should be considered by future AHS teams. Included are the following:

1. Critical near term development and demonstration of AHS systems will be greatly impeded by the lack of general access to a test track/proving ground especially equipped to facilitate such testing, development, and demonstration.

2. Long-term development and internationally competitive growth of AHS (and ITS) based systems and industries will be hampered if work is not expedited to create appropriate draft and final standards.

3. Work on topics equivalent to areas E and N should be closely coordinated and/or done by the same qualified staff to assure complete and comprehensive coverage of these related safety issues.

4. Work on topics equivalent to areas B, C, and J should be closely coordinated and/or done by the same staff to assure proper synergy.

APPENDIX A

ACRONYMS/ABBREVIATIONS

AARP American Association of Retired Persons

AASHTO American Association of State Highway and Transportation Officials

ABS Antilock Braking System

ADT Average Daily Traffic

AE Architectural Engineer

AHMCT Advanced Highway Maintenance and Construction Technology Program

AHS National Automated Highway System

AICC Autonomous Intelligent Cruise Control

ANSI American National Standards Institute

APTS Automated Public Transportation System

ARPA Advanced Research Project Agency

ARTS Automated Rural Transportation System

ASTM American Society for Testing Materials

ATIS Automated Traffic Information System

ATMS Advanced Traffic Management System

AVCS Automatic Vehicle Control System

AVI Automatic Vehicle Identification

AVLS Automatic Vehicle Location System

BBS Bulletin Board System

CASA Computer and Automated System Association

CE Civil Engineering

CI Configuration Items

CVO Commercial Vehicle Operation

DC Direct Current

DCAA Defense Contract Audit Agency

DOT Department of Transportation

DVI Driver Vehicle Interface

EPS Electric Power Steering

FAA Federal Aviation Administration

FCC Federal Communications Commission

FHWA Federal Highway Administration

FMEA Failure Modes Effects Analyses

FMVSS Federal Motor Vehicle Safety Standard

FOT Field Operational Test

FREE-SIM Freeway Simulation

FTA Federal Transit Authority

FY Fiscal Year

GIS Geographic Information System

GPS Global Positioning System

HOV High Occupancy Vehicle

HW Hardware

IAVD International Association of Vehicle Dynamics

IEEE Institute of Electrical and Electronic Engineers

IR Infrared

IR&D Independent Research and Development

ISO International Standards Organization

ISTEA Intermodal Surface Transportation Efficiency Act

IVHS Intelligent Vehicle Highway Systems

MOE Measure of Effectiveness

MOP Measure of Performance

MPR Mean Personal Rating

MTBCF Mean-Time Between Critical Failure

MTBF Mean-Time Between Failures

MVMT Million Vehicle Miles Traveled

NADS National Advanced Driving Simulator

NAHTSA National Automotive Highway Transportation Society of America

NDS National Driving Simulator

NES National Energy Strategy

NHTSA National Highway Traffic Safety Administration

NSC National Safety Council

OEM Original Equipment Manufacturer

PC Personal Computer

PBMS Performance Based Measurement System

PSA Precursor Systems Analysis

QFD Quality Function Deployment

R&D Research and Development

SAE Society of Automotive Engineers

TMC Traffic Management Center

TRB Transportation Research Board

TRAF-NET Traffic Network Simulation

UL Underwriters Laboratories

USG United States Government

V&V Validation and Verification

VMT Vehicle Miles Traveled

APPENDIX B

SUMMARIES OF ALL ACTIVITY AREAS

In August 1993, the Federal Highway Administration (FHWA) awarded 15 contracts to perform a precursor systems analysis (PSA) for the automated highway system (AHS) in sixteen activity areas. This research team was awarded and analyzed the following eight activity areas:

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

Below are the executive summaries for each of the eight activity areas, each of which includes an overview of research objectives, approach, results, and conclusions.

Activity Area A. Urban and Rural AHS Analysis

Objective and Scope

At the outset of this program it was anticipated that implementation and daily operations of an AHS system would be significantly different depending on the generic type of environmental setting—i.e., rural or urban. The objectives of this activity area, therefore, were to 1) look for the existence and nature of such differences and 2) identify the issues associated with these differences that would be likely to have a significant impact on the design, deployment, and/or operation of an AHS.

This activity area was one of eight activity areas analyzed by this program team. As such, the scope of this effort not only required achieving the basic objectives outlined above, but played a major role in providing the urban and rural information cornerstone for the other seven activity areas. This secondary role included providing ongoing input and collaboration on the development of both 1) the team's set of representative system configurations (RSCs) and 2) the team's integrated contract overview report.

The scope of this work was broadened somewhat to explore a third freeway area type referred to as *fringe*—i.e., a freeway situation intermediate between the urban and rural environments. Much of the background information for this effort was obtained from the State of Minnesota, but the scope of this activity included a literature search and outreach work to show that the Minnesota situation was not atypical for other States likely to be candidates for AHS deployment.

Methodology

The identification of technical, operational, and safety issues was accomplished primarily through a comprehensive literature search and a series of expert workshops. The literature search included identification and review of a broad range of previous AHS, IVHS, and related topic research and findings. This work supported a preliminary identification and/or confirmation and detailed description of major technical features; for example, 1) geometric design characteristics such as interchange design, lane width, and median configuration and 2) vehicle characteristics such as braking and acceleration capabilities. Accident type and severity data were also obtained and analyzed for various roadway categories and roadway improvements. Considering improved safety as a primary driver for the implementation of AHSs, current accident statistics were examined carefully to assess their potential utility as an indicator of likely AHS benefits.

A summary of freeway design and operating characteristic information was developed not only to guide the ongoing work in this activity area, but to serve as a key point of reference for the team's other seven activity areas throughout the remainder of the program.

Several workshops were held at different locations across the country and were attended by a range of transportation experts (e.g., representatives of FHWA, FTA, State transportation agencies, auto makers, and academia). These workshops helped to identify issues and promote a working dialogue of AHS within the industry. Results from the literature search and expert workshops were synthesized to develop a matrix of technical, operations, and safety issues by locale (e.g., urban, rural, and fringe). Included in this matrix were elements such as:

- Geometric design.
- Vehicle characteristics.
- Trip characteristics.
- Traffic flow behavior.
- Accident statistics.

Once this matrix was in hand, it was used as a basis for reviewing the team's set of RSCs—with special emphasis on comparing and contrasting the technical, operation, and safety characteristics in urban, rural, and fringe environments.

Results

Highlights of the results for activity area A are summarized in the following several paragraphs. Additional findings and supporting material are presented in the main topical report for area A.

Geometric and operational differences: There are significant geometric and operational differences in the three freeway environments reviewed, as characterized below.

TABLE 13. GEOMETRY AND TRAFFIC PATTERNS.

Freeway Environment	No. of Lanes in Each Direction	Speed Limits (mph)	Typical Type of Median	Average Weekday Traffic (Vehicle per day)	Congestion Levels	Typical Interchange Spacing (miles)	Interchange Type(s)
Urban	^{3}2	55	Barrier	>80,000	Recurrent Daily	1/2 to 1	System directional interchanges Std and half diamonds
Fringe	^{3}2	55	Barrier or grass median	20,000 to 80,000	Intermediate	3/4 to 2	Partial and complete cloverleafs with collector and distributor road connections Standard and folded diamonds
Rural	2	65	Wide median	^{2}20,000	No recurrent daily congestion	3 to 5	Cloverleaf and std. diamonds

From an aerial perspective, the fringe freeways more closely resemble the rural freeways. However, from a traffic pattern standpoint, the fringe freeways are more similar to urban systems in being highly loaded and frequently congested.

TABLE 14. ACCIDENT FREQUENCY AND TYPE.

Accident Patterns	Accident Rate (Accidents/Million Miles of Travel)	Most Common Accident Types (% of Total)
Urban	1.7	· Rear end collisions (51%) ·Single vehicle run-off the road (18%) ·Side Swipes (17%)
Fringe	0.7	· Rear end collisions (40%) ·Single vehicle run-off road (21%) ·Side Swipe (15%)
Rural	0.7	· Single vehicle run-off road (34%) ·Collisions with animals (25%) ·Rear end (13%) ·Side Swipe (7%)

From an accident pattern standpoint, the fringe environment freeways tend to track the urban patterns, while the rural freeway situation differs greatly from fringe and urban situations in both accident rate and type.

Potential benefits: From a highway engineering standpoint, the primary potential benefits of AHS deployment are the anticipated reduction of accidents. Considering the primary modes of accidents enumerated in Item 1 above, the planned capability for AHS to provide *collision avoidance* and *road following* features could eliminate or greatly reduce the majority of accidents that cost billions of dollars on U.S. urban, rural, and fringe freeways. Improved congestion management in the urban and fringe environments might yield capacity increases of 25 percent or more and would, of course, be another key anticipated benefit.

Implications of the activity area A findings, in addition to reinforcing the need for and potential benefits of the AHS, are as follows:

- The urban and fringe freeway environments offer similar concentrated needs for improvement where the investments in AHS technology can be amortized over a much larger number of vehicles. Of the two, the more open geometry of fringe freeways would better lend itself to incorporating any changes in ramps, barriers, etc., than the true urban freeway.

- Carefully selecting and developing the on-board and roadway-installed AHS subsystems might permit use of a significant portion of the safety features of an urban or fringe AHS in a semi-AHS or standard rural freeway and, therefore, greatly increase their acceptance.

Conclusions: Reviewing the team's specific set of RSCs in light of the generic findings of activity area A suggests the following considerations and conclusions.

- RSC 1 is characterized as having vehicles with “average intelligence” operating on a “smart highway.” Because this RSC and the pallet based RSC (RSC 3) are nominally the most infrastructure intensive AHS types—the associated large investment requirements suggest that consideration of these AHS types should probably be restricted to the urban and fringe applications. As noted above, the urban and fringe freeways have much higher traffic volumes over which to amortize the expenses. Furthermore, the urban and fringe freeways account for only a small fraction of the total freeway mileage. Based on State of Minnesota data, for example, the distribution of total interstate freeway mileage across the three types is as follows:

Freeway Type	Portion of Mileage
· Rural	76.6%
· Fringe	18.2%
· Urban	5.2%

A corollary is that RSC #4, which features a basically passive guideway (therefore, relatively small infrastructure investment), is probably a good type of AHS for initial consideration for rural applications.

- RSC 2 may be characterized as a platooning based concept—it features intelligent/autonomous vehicles operating on a “dumb”/passive highway. Because a primary motivation for considering platooning based systems is increased capacity, the initial applications for consideration would probably be the urban and fringe freeway situation where 1) the traffic volumes and congestion problems are the most stringent and 2) the ability to add additional lanes is very limited and/or expensive. This latter consideration, however, could cease to be a favorable factor for platoons if 1) the actual means of implementing a platoon based AHS calls for exclusive ramps, breakdown lanes, or additional barriers that require appreciable space to incorporate and/or 2) it would take too long to make enough AHS vehicles available to increase the roadway's capacity. Unfortunately, it is likely that most if not all fully developed platoon based AHSs (such as this team's RSC 2 variations—2A, 2B, and 2C) will call for one or more of the space requiring features just mentioned—i.e., exclusive ramps, breakdown lanes, and/or additional barriers.

- Many potential safety, initial capacity, environmental impact reduction, and system control advantages can be seen for the use of a pallet based system. However, pallet based systems are likely (as is RSC 3) to pose offsetting impacts regarding 1) the amount of land required for storing and maintaining the pallets, 2) lane space for “recirculating” empty pallets, 3) energy use for “recirculating” empty pallets and moving *both* a pallet and a vehicle from point A to point B, and 4) access/egress delays.

- The implementation of AHS presents the opportunity to positively affect the single most important transportation issue identified in the course of this study—

traffic safety. The effect of even a partially automated system, with collision avoidance and lane following features, would be to reduce urban and rural freeway accidents by a minimum of 30 and 25 percent respectively. Accident reductions of this magnitude would eliminate approximately 1,300 accidents per year in Minnesota and 71,000 accidents per year nationally and save $13 million per year nationally.

Activity Area E. Malfunction Management and Analysis

Objective and Scope

Increasing the safety of travel is a principal goal for an AHS. Accordingly, the objective and scope of this team's activity area E efforts were coordinated with those of its activity area N efforts (i.e., AHS safety issues) to assure comprehensive coverage of this critical pair of issues. Briefly stated, the overall objective for activity area E was to identify and evaluate the management strategies that can be used to *mitigate the effects of potential AHS system malfunctions*. By way of contrast, activity area N efforts were directed at providing AHS users with a *collision-free driving environment in the absence of malfunctions*. The scope of this activity area E search for pertinent malfunction management strategies was restricted to looking for malfunctions that might occur with the various subsystems and human participants anticipated in the team's selected group of RSCs.

In addition to coordination with area N, the activity area E staff coordinated at differing levels with project staff for all of the six other activity areas analyzed by this same program team. One of the focal points for collaboration and discussion was the development of the team's set of RSCs. In general it was found that the area E subteam had to describe the RSCs in much more detail than was required by the other subteams. Some subteams could consider an entire AHS vehicle/traveling unit as essentially a “black box.” To do a meaningful job of anticipating and mitigating potential malfunctions, however, the area E subteam had to visualize what *sorts* of systems and subsystems would accomplish the required AHS functions, maneuvers, etc. In pursuing relative depth, the area E subteam did not, of course, get into design details, just “functional concepts.”

The scope of those efforts included potential malfunctions for the human elements (e.g., vehicle drivers and AHS operational staff) as well as the hardware/equipment in the vehicles and the roadway infrastructure. In general, the analyses were restricted to the representative systems within the program team's selected set of RSCs. One exception to the scoping consideration was that some thought was given to potential malfunctions of AHS systems while the AHS vehicles were intended to be under manual control (e.g., while being operated on non-AHS roadways).

Methodology

While participating in formulation of the program team's RSCs, the area E subteam simultaneously fleshed out its intended approach to systematically:

- Identify and analyze major malfunctions.
- Identify requirements and strategies to manage malfunctions.
- Assess consequences of collisions.
- Develop and utilize measures of effectiveness to select the more promising malfunction strategies.

An initial step in this process was to search for relative precedental information in the relatively sparse existing and emerging literature for AHS and IVHS systems. With this background and the program team's RSCs as a point of departure, the area E subteam formulated a functional block diagram to begin its visualization of the specific AHS systems which might be selected and which might malfunction. Many of the systems so identified shared a basic structure as follows:

- A sensor which receives or detects vital input information for the control of the AHS vehicle (or AHS facility).
- One or more communication links which carry this information to the control elements in the vehicle (or AHS facility).
- A control unit, driver or controller which/who must interpret and/or process this information and generate or send appropriate command signals or actions.
- One or more actuators to execute the AHS commands.

Obviously each of these elements is a node in the system and potential failures can occur at any of the nodes or the interfaces between them.

The initial analyses of the functional AHS elements was performed using the well known system safety technique known as fault tree analysis (FTA). This technique is graphical in nature. It begins with the identification of a major undesirable outcome (e.g., a serious fault) at the top of what will become a tree-shaped figure. The expanding triangular base of the tree is comprised of the possible subfaults that could lead to the main fault and, in turn, the sub-sub faults which might cause the sub-faults in the tier above them, and so on. While FTA is a comprehensive form of analysis, to develop a more comprehensive/thorough understanding of the various systems, their interactions, when their actions and interactions occur, etc., the area E subteam also developed action timelines, which provided an organized means of describing (for each RSC) a series of functions or events needed to be performed by the driver, the vehicle, the infrastructure, and any intervening communication links during each phase of a hypothetical trip on the subject RSC.

Once the action timelines were developed, the required functions in the action timelines were then analyzed to develop the potential operational malfunctions that would occur given the negation of the required function. The results from this effort was organized as a set of malfunction timelines.

The efforts described above provided a foundation for understanding what systems were likely to be involved, what their key intended interactions were, and how they might fail to perform their intended functions. The area E tasks which followed were then aimed at identifying and assessing appropriate countermeasures (i.e., malfunction management strategies for the identified malfunctions. Some of the key steps involved in this phase of the work included development and use of scoring techniques to assess the probability and severity of the identified malfunctions in the *absence* of any malfunction management strategies. Specific malfunction management strategies (e.g., use of higher reliability components, use of redundancy, and use of adaptive type controls) were then conceived to mitigate each of the identified malfunctions (with emphasis on the malfunctions which had scored as being the most critical). (In this context criticality refers to the product of probability and severity.) Re-scoring the probability and severity of the likely malfunctions in the *presence* of the identified malfunction management strategies (MMS) then provided an indication of the viability of the MMSs identified. By structuring this scoring process to include such measures of effectiveness as cost, convenience, and capacity as well as safety, it was possible to begin the process of rank ordering the various MMSs. The scoring and rescoring activities in area E were performed independently by three area E staff members having extensive experience in automotive and/or hydromechanical control systems.

Synthesizing the results of the above activities yielded final activity area products in the form of recommended AHS vehicle system countermeasures, recommended AHS infrastructure countermeasures, and recommended AHS operational malfunction countermeasures.

Results

The following points highlight the findings for activity area E. Additional findings and supporting material are presented in the main topical report for area E.

Malfunction management strategy needs and adequacy: Potentially serious malfunctions (i.e., malfunctions that could result in death or serious injury and/or could involve 13 or more vehicles) could occur during operation of any of the four AHS RSCs investigated. However, reasonable malfunction management strategies were identified to significantly mitigate the consequences of the malfunctions and/or make the serious malfunctions significantly less likely to occur for all of the RSCs examined. The recommended malfunction management strategies (MMSs) are based on a “defense-in-depth” approach to achieving a desired level of safety—i.e., the likelihood of a potentially serious malfunction is minimized by use of reliable components and one or more levels of redundancy. For the specific RSCs studied, the MMSs selected called for one or more levels of redundancy on 11 of the 26 major vehicle and infrastructure elements. One element, the zone control element, was judged sufficiently critical to warrant the use of three levels of redundancy. Considering the large number of current accidents in which human error causes or contributes to the accident (i.e., approximately 80 percent of current highway accidents are attributed to improper driving), an AHS that eliminates these accidents and incorporates a well designed, tested, and maintained set of malfunction management measures should be able to offer a level of safety higher than that attained on current freeways.

Mixed traffic: Mixed traffic (i.e., a single lane carrying both manually driven vehicles and vehicles under AHS control) is a situation which must be addressed by a malfunction management strategy even if it is not part of the RSC's normal operational mode. This is true because the potential for a) a failure that eliminates the ability of the AHS to control a vehicle or b) a non-AHS vehicle deliberately or accidentally penetrating the AHS-only environment will always exist. Also, a transition lane (in which a manually driven vehicle merges into the transition lane, is accepted into the automated system within the lane, and then changes lanes to a fully automated lane under AHS control) is a feature of many scenarios. This is an example of mixed traffic common to many RSCs. Therefore, mixed traffic must be accommodated.

Work done in support of IVHS has shown that vehicle systems to aid the driver avoid collisions or running off the road can be of substantial benefit. Extensions or modifications of some of these systems could be employed in an AHS to allow mixed traffic situations with reasonable levels of safety. It is the opinion of the area E team that mixed traffic scenarios probably possess levels of safety intermediate between current freeways and a potential AHS based on totally separate manual and automated lanes.

Driver-in-the-loop: The driver or passengers of an AHS vehicle should be able to make inputs to the AHS in certain cases, but the AHS cannot be designed to rely on these inputs for safe normal operation or to counter malfunctions. A basic assumption of the AHS is that the driver can be less alert (e.g., to read a newspaper) during the period that the vehicle is under automatic control; this cannot be violated. However, the driver/passenger must be able to alter some AHS processes such as altering the originally set destination to accommodate human “malfunctions” which could not be detected by the AHS (e.g., illness of a passenger). The AHS equivalent of the aircraft “pilot report” could increase safety and reliability of the AHS. In most cases, the driver should be allowed to move a malfunctioning AHS vehicle along the breakdown lane to use the next exit after the automatic systems have responded to a malfunction by stopping the vehicle in the breakdown lane. This prevents the need for an AHS response team to respond to every minor AHS vehicle failure. Other examples exist but basically, drive inputs can a) improve the capacity of the AHS, b) increase the probability of completing the trip without significant outside intervention, c) reduce AHS cost of operation, and d) increase the convenience of the AHS experience.

Pallet based AHSs: From a malfunction management viewpoint, pallets are a viable option possessing their unique advantages and disadvantages. Advantages include

a) control of pallet maintenance by a central authority results in a better maintained pallet compared to a privately owned AHS vehicle, b) higher utilization of the pallet compared to a private AHS vehicle allows greater investment in each pallet (i.e., one can afford more redundancy and/or more expensive/higher reliability systems), and c) because pallets only operate on the AHS, they can be optimized for that environment. Disadvantages include a) higher center of gravity which likely results in a less stable vehicle, b) additional functions (e.g., vehicle load/unload and associated facilities, vehicle lockdown on the pallet, etc.) that are pallet-unique provide additional opportunities for malfunctions, and c) probable need for additional response teams to recover pallets with minor malfunctions. It is the opinion of the project team that, from a malfunction management viewpoint, the advantages of pallets probably outweigh their disadvantages.

Multi-vehicle incidents: The team believes that it is very important to minimize the possibility of a significant multi-vehicle accident because of the impact on perceived safety of the system. The occurrence of one or more 10- to 20-vehicle accidents in the early stages of AHS introduction would tend to devastate public confidence in system safety and reliability; probably delaying widespread introduction for decades. The communications linkage of all AHS vehicles to a central authority provides the basis for minimizing the number of vehicles involved in such accidents. The basic responsibility of any vehicle a) involved in a collision or b) experiencing a malfunction which has a reasonable probability of leading to a collision is to inform the central authority of the situation immediately. The central authority can then take various actions (e.g., limiting travel speeds, stopping potentially affected vehicles, requesting driver input, rerouting traffic, etc.) very quickly that minimize the probability that numerous other vehicles will become involved.

Safety is an imperative: Safety is the most important major AHS attribute. An RSC cannot be considered viable unless it provides the public with a degree of safety at least comparable to the current freeway system. An RSC cannot be considered good unless it provides a degree of safety significantly beyond that provided on current freeway systems. In choosing components, systems, or techniques for the AHS, the predisposition of the program team is to include anything that can contribute to safety. Only if the inclusion of the item will substantially reduce system capacity, decrease convenience, or substantially increase cost should the item be excluded.

Capacity: Capacity is important, especially in urban areas. In urban areas, capacity and convenience are nearly synonymous. Most rural highways do not face a capacity crises, which makes increasing capacity over current levels much less important. This precursor study recognizes that the importance of increasing capacity varies between urban and rural AHS implementations, however, the project team has chosen not to explicitly evaluate any of the RSCs based on only urban or only rural implementation. Such an evaluation should be done in the future when the target RSCs are better defined, however, at this point it would detract from some of the other areas that must be covered (e.g., given fixed resources, evaluating each of the RSCs in both urban and rural environments might result in less consideration being given to identifying and assessing potential malfunctions or malfunction management strategies). Therefore, this precursor study treats all examined RSCs as though they will be implemented with a single set of malfunction management strategies in both urban and rural settings.

Driver training: The driver needs to possess an AHS driver's license to participate in the AHS system. It is this team's view that the driver will not inherently know how to do the basic driver functions—i.e., how to get on the system, enter the desired destination, relinquish control to the system, resume control at the end of the automated AHS ride, and exit the system. Still further training is anticipated with regard to the driver's responsibilities for vehicle maintenance and procedures/requirements appropriate in the event of an infrastructure malfunction or shut down or collision with another vehicle. It is expected that drivers will also need instruction on how to respond to perceived unusual operation of their vehicle or the system—e.g., serious degradation of their vehicle, illness of a passenger, observation of deer or other animals in the median, etc.

Extracurricular AHS system malfunctions: The introduction of AHS components or systems brings with it the potential for those systems to malfunction and cause, or contribute to, collisions or other unfavorable incidents. These malfunctions may not be limited to AHS vehicles operating under AHS control on AHS roadways, but could be induced by unwanted activation of AHS features or modes in “extracurricular” situations (e.g., normal manual operation of an AHS vehicle on residential streets).

Activity Area H. AHS Roadway Deployment Analysis

Objective and Scope

Depending on the particular AHS concept/configuration selected, it was anticipated that the roadway deployment impacts could range from moderately extensive to practically prohibitive. The objective of the efforts of this activity area was to identify the specific issues, risks, and impacts that should be expected in the deployment of representative AHSs. The goal of the effort was to use the results of this analysis as the basis for formulating recommendations for mitigating any negative impacts identified and maximize the opportunity for successful AHS deployment.

The scope of this analysis included looking at the program team's selected set of RSCs primarily in the urban and rural environments. Some consideration was also given to urban fringe and small population centers in rural areas. Aspects of special interest included highway construction impacts, spatial/geometric issues pertinent to freeway design, and infrastructure impacts.

Activity area H was one of eight activity areas analyzed by the program team. Results of activity area H, along with those from activity area A, provided the highway design foundation/perspective for the overall effort. The basis for the area H input included not only the extensive pertinent expertise of the area H team, but input obtained from 1) engineers and planners from the Department of Transportation in Arizona, Texas, and

Minnesota, and a national workshop of transportation professionals; and 2) other interested parties and stakeholders.

Methodology

The two major tasks utilized in reaching the objectives of activity area H were to 1) initially define and analyze candidate urban and rural linkages on a *generic* roadway and then 2) review the candidate RSCs against *actual* field sites. The overall approach involved five steps as follows:

1. Identification of issues.
2. Generic analysis.
3. State DOT input.
4. Specific site analysis.
5. Evolution of strategies.

The identification of issues focused on three categories of the physical roadway and its associated characteristics.

1. Spatial requirements—e.g.,

- AHS lane locations and dimension.
- Shoulders.
- Right of way.
- Entry/exit facilities.
- Frontage roads.
- Barriers.

2. Infrastructure—e.g.,

- Instrumentation.
- Pavement.
- Drainage.
- Communications plant.
- Traffic operations centers.

3. Construction

- Constructability.
- Cost.
- Conversion strategies.
- Connectivity with other facilities.
- Termination of AHS facilities.

The details considered included preferred locations of AHS lanes (e.g., on the inside of the freeway), possible conversion of existing high occupancy vehicle (HOV) lanes, grading separated lanes where spatial restrictions are severe, using different types of barriers, special requirements (e.g., use of shoulders to facilitate maintenance and snow storage), and drainage requirements. AHS application to generic roadways was considered to determine if typical roadway features would be likely to dictate compromises in AHS design concepts and/or to impact negatively on the safety and capacity goals for AHS facilities. Subsequent evaluation of selected AHS concepts against actual field sites was performed to look for *real world* impacts of a proposed deployment that might escape exposure when reviewed only in relation to generic settings.

The culmination of these efforts was 1) formulation of findings regarding the potential deployment impacts of selected RSCs (i.e., AHS configurations) and 2) generation of recommendations for ways to enhance the AHS deployment process.

Results

Activity area H identified and analyzed the issues, risks, and impacts of deploying an AHS using various RSCs in rural and urban environments. The key findings from this analysis follow. Additional findings and supporting material are presented in the main topical report for area H.

Spatial needs: Some AHS concepts will require extensive roadway and structure reconstruction. Costs to deploy an AHS vary widely depending on whether it's simply a matter of converting an existing lane or doing a massive upgrade to add lanes and require widening bridges, upgrading interchanges, and upgrading intersecting arterials. Examples of both these approaches are presented in the area H report. One of the relatively straightforward lane conversion type examples identified involved costs on the order of $3.6 million per mile. One of the relatively complex examples (i.e., adding lanes to a 22 km section of I-94) costs $41.0 million per mile. Concepts that call for exclusive AHS lanes, connected to exclusive AHS ramps, and separated from non-AHS lanes by physical barriers, might find the highest level of implementation success on existing freeways with compatible existing HOV systems. This is true because most of the space required and the associated general lane configurations would already be in place. Likely adverse public reaction to taking away HOV space for AHS use might be addressed by promoting the benefits of AHS and/or giving HOV preferential treatment in access or usage charges. Additional lanes intended to serve AHS in a rural environment may not be cost effective for long distances, requiring consideration of a mixed flow AHS concept.

Deployment evolution: AHS deployment evolution may consider a limited focus on mixed flow rural applications at first as a means of developing and field verifying the control and vehicle technology. The mixed flow concept will provide researchers and product developers an opportunity to refine mixed flow techniques, as well as offer an opportunity for AHS technologies such as collision avoidance and vehicle positioning to be beneficial to off-AHS systems. Urban areas have the most to gain from successful AHS deployment. It would be desirable for early successful deployment sites to be identified from feasible urban sites as a means of testing and promoting exclusive-lane AHS configurations.

Transition lanes: Concepts that call for exclusive AHS lanes plus a transition lane must be carefully reviewed on a case-by-case basis due to the need for additional width of the freeway. Costs are anticipated to rise dramatically in urban areas where additional right-of-way is required to satisfy additional space requirements. Elevated sections may be a viable, albeit costly, alternative in some locations.

Traffic control devices: Traffic control devices should play a significant role in AHS deployment, as a means of 1) clarifying right-of-way assignment, (e.g., who has priority to move, enter a ramp, etc.), 2) providing information regarding status of special operating procedures, and 3) indicating to drivers which lanes are available for AHS use. Application of traffic control devices must be consistent nationally among all AHS concepts to promote the highest level of driver understanding and predictive reaction.

Pavement design: Pavement for AHS lanes and shoulders should be more durable and require less maintenance and repair than standard freeway pavement to allow maximum use of the lane with minimal downtime. Sensors built into the pavement would assist system monitors in evaluating surface conditions and pavement deterioration conditions.

Unique environments: The deployment of an AHS is unique to each environment. Design generalizations should be avoided. Each application should be evaluated individually for factors such as bridge and drainage structures, ramp systems, cross slopes, and spatial availability.

Activity Area I. Impact of AHS on Surrounding Non-AHS Roadways

Objective and Scope

One of the questions that is frequently raised regarding deployment of an AHS is whether or not surrounding parallel and feeder facilities will be adversely impacted. The objectives of the area I set of activities, therefore, were twofold—to analyze the likely impacts of selected types of AHS deployment on surrounding non-AHS roadways and to identify candidate strategies for mitigating any adverse impacts that might be identified. The heart of this set of activities was an extensive series of computer modeling runs (see Table I-1) for the selected AHS deployment scenarios. The basic modeling tool used in this work was TRANPLAN, a model suited to the desired macro modeling.

The scope of this work included evaluation of the program team's selected set of RSCs in both urban and rural environments. Some attention was also given to the urban-fringe type environment. The models were constructed primarily based on information for actual roadways (e.g., freeways in the Minneapolis/St. Paul area) and a rural situation patterned after a generalized model of Michigan rural freeways.

Methodology

The identification and analysis of issues related to the impact of an Automated Highway System (AHS) on the surrounding non-AHS roadways was accomplished through an expert workshop, a review of comparable system deployment plans, and extensive traffic modeling. The issues addressed included: environmental, land use and socioeconomic analysis; existing facility problems and redesign; AHS malfunctions; capacity impacts; alternative configurations; and traffic shifts. The expert workshop focused the analysis on these key issues. A review and analysis of planned freeway expansions and fixed-guideway transit deployments provided a source of issues relative to the redesign of a freeway to accommodate a new AHS facility.

The major effort within activity area I involved the modeling of an AHS facility within an existing freeway in rural, urban-fringe and urban environments. Freeways in the Minneapolis/St. Paul area were used for the urban and urban-fringe environments and a generalized model of Michigan rural freeways was used for the rural environment. Macro models using the TRANPLAN application were developed, calibrated, and used to develop before and after trip distributions for these environments. A range of RSCs, market penetrations, time indexes, and AHS layouts were modeled. Micro level models were developed for specific intersections to determine local traffic and environmental impacts. From these models, overall impacts to the surrounding non-AHS roadways were determined.

Results

An analysis of models developed to simulate the impact of an AHS to the surrounding non-AHS roadways and a review of comparable system deployments resulted in the results which follow. Additional results and supporting information are provided in the accompanying activity area I topical report.

Facility redesign: The introduction of an exclusive, barrier-separated AHS lane in an existing freeway facility will require conversion of an existing lane or adding a new lane. Converting an existing lane will generally require major reconstruction of the existing freeway to accommodate spacial and access requirements. Costs to deploy an AHS vary widely depending on whether it's simply a matter of converting an existing lane or doing a massive upgrade to add lanes and requiring widening of bridges, upgrading interchanges, and upgrading intersecting arterials. Examples of both these approaches are presented in the area H report. One of the relatively straightforward lane conversion type examples identified involved costs on the order of $3.6 million per mile. One of the relatively complex examples (i.e., adding lanes to a 22 km section of I-494) costs $41.0 million per mile. The redesign costs will be substantially lower for system configurations which do not require exclusive, barrier-separated lanes.

Travel time sensitivity: The selection between parallel AHS and non-AHS facilities by travelers is extremely sensitive to variations in relative trip times. For travel demand modeling, relative trip times are the aggregate of travel time, check-in/check-out time and direct user costs where costs are equated to time. The difference between these relative trip times between modes determines the use of a facility. The lower the relative trip times of an AHS facility, the higher the use of the facility compared to a parallel non-AHS facility.

The urban AHS configuration modeled included a primary freeway with three non-AHS lanes and one AHS lane in each direction. The freeway corridor had a total length of 17 kilometers. The average trip in the corridor was 16 kilometers and took 17 minutes. The corridor also had secondary parallel arterials on either side of the freeway. This urban region surrounding the AHS facility had a total of 450,000 peak hour trips. The AHS and non-AHS freeway lanes were modeled with equal access but the AHS lane had a 15 to 20 kilometer per hour higher operating speed.

The AHS lane was modeled with a range of time index penalties. A time index is defined as the combination of check-in/check-out times and user costs as represented by time. Modeled with a one minute time index penalty, approximately 45,000 peak-hour trips would be positively affected by the AHS. A positive effect is either a reduced trip time from using the AHS or a reduced trip time on other roadways due to less congestion. With a five minute time index penalty, only 500 peak-hour trips would be positively affected by the AHS. Although these results indicate that travelers are very sensitive to relative differences, it is important to note that the relationship between specific time index penalties and AHS utilization found in this analysis is specific to the Minneapolis area and the characteristics of its travel demand model. This time sensitivity is independent of system configurations.

Market penetration: The use of an AHS facility is directly related to the percentage of vehicles in a region that are equipped to operate on the AHS. This is also referred to as the AHS market penetration. In a scenario where the inside third lane of an existing freeway is converted to exclusive, barrier-separated AHS use, the AHS lane must attract sufficient traffic so as not to negatively impact the remaining lanes of the existing freeway. In the urban and urban fringe environments modeled for this analysis, at least 50 percent of all vehicles in the region surrounding the AHS facility must be AHS-equipped in order to prevent a level of service reduction on the remaining lanes. Based as it is on results from the Minneapolis travel demand model, which reflects a travel environment unique to the Minneapolis area, the 50 percent market penetration can be expected to vary by market.

These conditions assume an AHS lane capacity of 6000 vehicles per hour and an access frequency of 0.7 ramps per kilometer for the urban setting and 0.5 interchanges per kilometer for the fringe setting. This level of trip diversion would require a time saving of one minute per trip, which in turn requires an increase in the corridor average operating speed of 15 to 20 kilometers per hour. These results assume that the check-in/check-out time and user cost associated with AHS is representative of one minute of travel time.

Parallel arterial and feeder route volumes: An AHS facility will increase the travel capacity of a corridor. The AHS facility has the potential to attract traffic from parallel arterials to the AHS and increase traffic on routes feeding the AHS. For the urban environment modeled in this analysis, the peak hour traffic on the major parallel arterials within two kilometers of the AHS decreased an average of 20 percent. For the urban fringe environment, parallel traffic decreased an average of 10 percent. These decreases were not as large as anticipated because natural equilibrium caused traffic from other congested roadways to use the excess capacity on the parallel arterials created from diversions to the AHS.

Peak hour volumes on feeder routes to the AHS increased for the urban and urban fringe environments modeled. Peak hour volumes in the urban and fringe models increased by a maximum of 14 percent, with a typical increase in the range from 5 to 6 percent. These increases did not cause the feeder routes to reach capacity as had been anticipated. This analysis assumed AHS access frequency equal to current non-AHS frequency. Decreased access will increase the volume on feeder routes.

Urban AHS closure: For a spot closure of the AHS at a specific location, severe congestion results for scenarios involving barrier and non-barrier separated AHS configurations. For barrier separated configurations, the AHS traffic will attempt to access the parallel freeway at the ramp prior to the spot closure. For non-barrier separated configurations, the AHS traffic will attempt to manually merge into the parallel freeway. In both configurations, the AHS traffic did not attempt to access parallel arterials. The parallel freeway sections prior to the spot closure experienced volume to capacity ratios over 1.2. Within the limits of the demand model used, it is expected that a spot closure will produce safety hazards that will require a significant amount of additional research.

Local intersection traffic operations: The parallel arterial intersection modeled for this analysis is capable of handling a 10 percent increase in traffic due to the deployment of an adjacent AHS but becomes congested at a 20 percent increase in traffic. At a 20 percent increase, certain approach legs of the intersection become overloaded. At a 30 percent increase in traffic, congestion conditions are present.

Intersection improvements provide immediate benefits to travel conditions reaching near-capacity conditions, but over a few years these benefits tend to deteriorate due to increasing travel demand. Adding capacity to an intersection and the approaching roadways has the greatest long-term benefit in terms of providing acceptable LOS values and delay, but it is also the most costly and often least popular alternative.

Air quality impacts: The analysis of potential air quality impacts of AHS deployment indicates overall air quality degradation despite some localized improvements. The analysis of the single point diamond interchange and the adjacent freeway mainlines indicates that the air quality in those areas will experience a slight improvement as the result of the deployment of an AHS within the existing freeway right-of-way. This improved air quality is a result of the consistent AHS mainline speed of 88 km/h (55 mi/h), an optimum speed for minimal pollutants. Reductions in emissions ranged from 1 to 5 percent for a 10 percent increase in traffic due to the AHS.

The additional traffic attracted to an AHS facility can cause the air quality surrounding the AHS access locations to deteriorate. The partial cloverleaf interchange and the adjacent arterial intersection modeled in this analysis experienced significant increases in air pollution. A 10 percent increase in traffic at the signalized arterial intersection significantly increased the level of air pollution at the intersection. Even when combined with the decrease in air pollution surrounding the AHS mainline due to improved flow, the overall air quality of the entire modeled region deteriorated due to the increased intersection volume. Emissions were observed to increase between 3 and 39 percent with the 10 percent increase in traffic. In the case of the interchange that incorporated access and exit facilities, the emissions in the area exceeded federal and state air quality standards.

Noise quality impacts: The sound levels at locations surrounding the interchanges in this analysis are predicted to increase about 0.1 dBa for a 10 percent increase in traffic due to the deployment of an adjacent AHS. This is an insignificant increase and would not be noticeable to the human ear.

Access frequency sensitivity: Varying the frequency of AHS entrance and exit ramps has a significant effect on the overall diversion of corridor trips to the AHS lane. Access frequency was varied in the urban environment model from a high of the current 0.7 interchanges per mile to a low of 0.4 interchanges per kilometer. The high interchange frequency resulted in a potential peak-hour AHS lane volume assignments from 4,500 to 7,100 vehicles. The upper end of the range exceeds the capacity of the AHS facility, but is reflective of the demand in the corridor. The low interchange frequency resulted in a peak-hour AHS lane volume assignments from 2,900 to 4,100 vehicles. The trip assignments assume 100 percent market penetration, an AHS lane capacity of 6,000 vehicles per hour, and an AHS average increase in the operating speed over conventional lanes of 15 to 20 kilometers per hour.

AHS placement: Modeling analysis indicates that most travelers will make a mode shift to a parallel facility if the facility has at least a five minute time saving to a competing facility. For an average freeway trip length of 10 kilometers out of a total trip length of 16 kilometers, and a non-AHS average freeway speed of 64 kilometers per hour, the AHS lane would require an average speed of 137 kilometers per hour to achieve a five minute time savings. These numbers are representative of the urban corridor modeled in this analysis. If the AHS lane was limited to the current maximum speed of 88 kilometers per hour and the non-AHS freeway had an average speed of 64 kilometers per hour, the average freeway travel distance must be over 24 kilometers to achieve a five minute time savings. This indicates an AHS system will only have significant usage in corridors with long average trip lengths if the AHS lane is limited to current speeds.

Recommendations for further study: The TRANPLAN model used in activity area A provided a macro-level analysis of the operation of a combined AHS and non-AHS freeway. The results provide a general understanding of the shifts in traffic to the AHS lane from a non-AHS freeway and adjacent arterials. The TRANPLAN model does not provide micro-level results of effects such as AHS vehicles entering the freeway on standard ramps and then transitioning to an unrestricted AHS lane. The effects of AHS vehicles weaving across non-AHS lanes can have significant impact to the non-AHS lane capacity and the ability of AHS vehicles to enter and exit the AHS lane when desired.

The merging and diverging of AHS vehicles from and to an unrestricted AHS lane is a complicated simulation that requires detailed analysis. The FRESIM model was reviewed as part of activity area A and was found to be lacking in capabilities, documentation, and support. It is recommended that a model be developed that allows a full simulation of merging and diverging AHS vehicles to and from an unrestricted AHS lane. This model should allow for variations in AHS and non-AHS vehicle lane volumes, variations in AHS and non-AHS vehicle entry and exit volumes, variations in the number and capacity of AHS and non-AHS lanes, the frequency of AHS and non-AHS entry and exit types and locations, and the time penalties of AHS and non-AHS entry and exit.

Activity Area J. AHS Entry/Exit Implementation

Objective and Scope

One of the greatest challenges facing the implementation of AHS is the ability to enter and exit the automated highway system (AHS) roadway effectively, safely, comfortably, and with minimal environmental impact. The primary objectives of the area J activities were to 1) identify strategies for entering and exiting an AHS roadway, 2) develop measures of effectiveness (MOEs) for evaluating these strategies, and 3) evaluate the team's selected set of representative system configurations (RSCs) with the aid of the special entry/exit MOEs developed. This work was coordinated with related concurrent work by other members of the program team—especially those involved in the roadway-related efforts for activity areas A, H, I, and K.

In many respects, entry and exit are “weak links” in an AHS system. For completely dedicated (AHS-only) systems, there are critical issues associated with land use and the influence on the surrounding roadways. For mixed use systems (even with dedicated AHS lanes), critical issues include converting medians and lanes previously used for non-AHS traffic. The feasibility of AHS depends in part on how effectively these and other issues can be resolved.

The scope of the area J activities was focused on entry/exit considerations for the program team's selected set of RSCs. The area J team members did, of course, participate in specialized area J meetings and teleconferences with area J members of other contractor teams.

Methodology

The following three-step approach was used in activity area J:

1. ***Development of entry/exit strategies***—Strategies for entering and exiting vehicles were developed for each of six baseline RSCs defined by the Battelle team. The development of these strategies involved a) defining the “AHS experience” (i.e.,

the generic vehicle and system functions and decision points from the time a vehicle requests entry to the AHS to the time the vehicle is back on the surrounding non-AHS roadway); b) developing sets of assumptions and rules for entry and exit for each of the RSCs; and c) choreographing the vehicle and system functions for each of the RSCs.

2. ***Development of MOEs***—MOEs were developed to evaluate each of the entry and exit strategies. The MOEs were a combination of quantitative measures (e.g., distance and time required for entry) and qualitative measures (e.g., relative safety).

3. ***Evaluation of strategies***—The MOEs were applied to each of the entry/exit strategies, from which an overall assessment of the viability of the strategies and the RSCs were made.

The basic entry/exit strategies considered were developed by defining functional requirements and infrastructural modifications necessary to transition a vehicle from the arterial roadway to the AHS lane and from the AHS lane to the arterial roadway. The functional requirements defined for each RSC then provided the framework for identifying the type of infrastructural changes needed to accommodate implementation of an AHS system. Four functional categories were identified which comprise the AHS entry/exit requirements common to each of the RSCs—i.e.:

- Fault mitigation.
- Lane merge maneuvers/transitions.
- Control transfer.
- ACI/ACO.

The specific elements of each of these functional categories were developed to satisfy the particular implementation requirements of each of the RSCs. The resulting entry/exit strategies were described in terms of their functional execution and roadway configurations.

Special MOEs were then developed for subsequent use in evaluating the viability of the various entry/exit implementation strategies for AHSs. Seven main MOEs were developed and defined as follows:

1. ***Minimal need for additional land***—A major constraint on implementing AHS is the cost of new entry and exit areas on the highway. Further, in congested urban areas (where AHS may have the greatest potential), the availability of additional land is very limited. A goal would be to retrofit existing entry and exit areas for AHS use.

2. ***Minimal need for additional facilities***—Additional facilities needed for entry and exit may include automated check-in and check-out (ACI and ACO, respectively) stations, loading and unloading areas for palletized vehicles, and traffic metering equipment. These facilities add cost to AHS implementation, and could pose

reliability problems. A goal would be to minimize the need for additional facilities.

3. ***Minimal negative impact on adjacent roadways***—The entry and exit portions of the AHS must not create traffic flow problems on the adjacent streets to and from which the AHS vehicles are transferred.

4. ***Great improvement in potential capacity over comparable non-AHS roadway systems***—The entry and exit portions of the system must minimize any bottleneck effects that would restrict the throughput of the system.

5. ***Minimal disruption of non-AHS roadway traffic flow***—Metering of traffic to and from AHS lanes must not degrade the traffic flow on non-AHS lanes, and vice versa.

6. ***Ability to mitigate safety hazards***—The entry and exit areas must be designed to preclude and/or minimize safety hazards.

7. ***Low cost and complexity***—The overall cost for implementing entry and exit portions of the system should be minimized without compromising the four basic AHS goals of high safety, throughput, comfort, and environmental compatibility. Further, the entry and exit systems should be made as simple as possible, which would reduce the cost to build, maintain and operate, and improve reliability.

Once the MOEs were developed, a six-point MOE rating scale was conceived and applied to assess the relative entry/exit merits of the program team's selected set of RSCs.

Results

A summary of key findings from the area J activities is provided below. Additional results and supporting information are supplied in the area J topical report.

Dedicated AHS: From a safety and performance standpoint, the most attractive entry/exit strategy involves dedicated AHS-only ramps that connect directly to dedicated AHS lanes, which in turn are separated from non-AHS lanes via barriers.

Transition lanes: Entry and exit across non-AHS lanes must involve transition lanes. The transition lanes must be capable of performing vehicle check-in and/or check-out, rejecting vehicles, queuing vehicles (if the transition lane is not continuous) without interfering with surrounding traffic, and releasing vehicles from rest into the AHS lanes and out of the non-AHS lanes. The use of transition lanes would not require exclusive AHS ramps.

Without transition lanes, right-hand-side entry to and exit from inner AHS lanes would require that a) the vehicles are in manual control during some period while in the AHS lane, b) the vehicle entry speed is the non-AHS lane speed, and c) the vehicle exit speed must be reduced as needed to be consistent with the non-AHS lane into which it is exiting. Requirement a) is considered unsafe, requirements b) and c) could result in severe degradation in AHS lane throughput due to “wave action” between vehicles.

Barriers: As safety devices, barriers should be used wherever possible between AHS, transition, and non-AHS lanes. These should be positive barriers that physically prevent intrusion to and from the AHS lanes (e.g., the Jersey barrier). Barriers themselves could create a safety hazard at entry and exit areas, and should be designed and placed to mitigate end-on collisions.

Metering: Traffic metering should be implemented at several levels:

a. Pre-trip—users log-in trip requests to the system; the system in turn needs to evaluate the current and projected traffic conditions and approve or disapprove the request.

b. System Level—the flow of traffic on AHS and non-AHS lanes should be monitored and adjusted as needed to optimize throughput while not compromising comfort, safety, and environmental impact.

c. Local Level—systems similar to current ramp meters are needed to release vehicles onto and off of the AHS lanes based on availability of space.

Four-lane highways: The application of AHS in a four-lane highway scenario (i.e., two lanes in each direction with no additional lanes) may be based, at least initially, on AHS/IVHS systems such as “intelligent cruise control” and accident avoidance. Such a highway would require mixed traffic on the lanes, because without very high market penetration, dedicating two of four lanes to AHS-only would create considerable congestion on the non-AHS lanes. Thus, mixed traffic is a likely requirement for four-lane highways and introduces special safety and control considerations. The cost/benefit values of such an approach needs further evaluation. With regard to entry/exit, an immediate benefit is that no significant changes would be required in the physical layout of the entry and exit areas for this configuration.

Lane Widths and Ramp Geometry: Standard lane widths (typically 12 ft wide) should be used for AHS lanes that involve mixed commercial, transit, and automobile traffic. Smaller width lanes (e.g., 8 to 10 ft wide) should be considered only if use is restricted to specific “AHS class” vehicles. The geometry (lengths, curvatures) of existing ramps are based on current highway design speeds. Modifications to existing ramps should be considered if the operating speeds on the ramps are higher than the design speeds.

Pallets: The primary advantages of the pallet concept are a) automobiles do not have to be AHS equipped, therefore all automobiles are candidates for use on the AHS; b) ACI/ACO during entry/exit requirements would be reduced substantially; and c) pallets could be designed to use more environmentally friendly fuels, to be more energy-efficient, more reliable, and more uniform than today's fleet of automobiles. Primary disadvantages include a) cost of the pallets; b) additional space, time, and facilities are needed for storage, loading, unloading and circulation; and c) a "pallet authority" must be in place for operating the system. Key entry/exit issues are where and how pallets are loaded, unloaded, and circulated throughout the AHS system while maintaining acceptable origin-to-destination travel times, good passenger comfort, and safety.

Surrounding roadways: Surrounding roadways must be evaluated and modified as needed (e.g., by changes in traffic flow patterns, signaling, and AHS-only access) to assure that the flow of traffic to and from the AHS can be accommodated safely and with minimum impact on the AHS and surrounding roadways.

Spacing of entry and exit: To avoid unsafe weaving maneuvers, exit and entry should occur at different locations wherever possible.

Conversion of HOV lanes: Conversion of high occupancy vehicle (HOV) lanes to AHS would provide an effective infrastructure for AHS operation. However, it is expected that the public would resist giving up HOV lanes (as well as any other lanes). An option would be to create an AHS system that is restricted to HOV traffic. From an entry/exit standpoint, the primary advantage of converting HOV lanes to AHS is that suitable dedicated entry and exit systems, and in many cases barriers, already exist.

Control transfer: Except for the four-lane highway "intelligent cruise control" scenario, operation in AHS lanes must be restricted to vehicles under AHS control. Thus, transfer of control must occur prior to the vehicle entering the AHS lane and after the vehicle leaves the AHS lane.

Ranking the RSCs based on entry/exit: The following are brief descriptions of the six RSCs and their associated entry/exit features for which MOE evaluations were conducted by the team:

- RSC 1—Smart Vehicle/Smart Highway with 6 Lanes (2 AHS Lanes): Mixed ramp traffic, transition lanes, no barriers. The entry/exit strategy for RSC 1 requires an additional center lane to be used as an exclusive transition lane. There is a narrow buffer zone between the AHS lane and the transition lane. Traffic in the transition lane is operated in mixed manual and automated modes, but the automated mode of operation is used exclusively for executing merge maneuvers between the transition lane and the AHS lane.

- RSC 2A—Smart Vehicle/Average Highway with 6 Lanes (2 AHS Lanes): Mixed ramp traffic, no transition lanes, with barriers. The entry/exit strategy for RSC 2A uses the center lane as the transition segment, which is operating in manual mode only. As in RSC 1, there is a narrow buffer zone between the AHS lane and the center lane. The transition segment is also the left lane or passing lane for manual traffic.

- RSC 2B—Smart Vehicle/Average Highway with 6 Lanes (2 AHS Lanes): Mixed ramp traffic, no transition lanes, without barriers. There are three entry/exit strategies for this RSC: 1) right-handed entry/exit fly-over ramps, 2) left-handed entry/exit overpass for ramps, and 3) left-handed entry/exit fly-over ramps. All three entry/exit strategies for RSC 2B use the ramp as the transition segment. ACI, ACO, control transfer, lane merge maneuvers, and fault mitigation occurs on the access and egress ramps.

- RSC 2C—Smart Vehicle/Average Highway with 5 Lanes (Reversible AHS Center Lane): Exclusive ramp traffic, no transition lanes, barriers. The entry/exit strategy for RSC 2C is functionally identical to RSC 2B except provision is made for the roles of the entry and exit ramps to be reversed concurrent with AHS traffic direction changes. The direction changes are indicated by lighted directional arrows. One other distinction is that the right-hand and left-hand fly-over ramps are combined for dual use as both entry and exit ramps.

- RSC 3—Smart Pallet/Average Highway with 6 Lanes (2 AHS Lanes): Exclusive ramp traffic, loading/unloading/recirculation facilities, no transition lanes, barriers. The strategy required for this RSC is unique from the others because it involves single-vehicle pallets. Thus, entry and exit must accommodate the loading and unloading of vehicles, and the circulation of pallets over the AHS system to meet user demands.

- RSC 4—Smart Vehicle/Passive Highway with 4 Lanes (2 Mixed Traffic Lanes): Mixed ramp traffic, no transition lanes, no barriers. This RSC is essentially the same as a manual roadway. However, provision is made for automated operation of a vehicle and mitigation of control transfer faults. Entry and exit ramps are identical to the ramp designs for conventional controlled access roadways. Fault mitigation for entry consists of simply continuing to operate the vehicle in the manual mode. Fault mitigation for exit consists of the AHS bringing the vehicle to rest on the right shoulder or in a park-and-hold area adjacent to the exit ramp. The former option has the advantage that only a small segment of the right shoulder needs to be AHS equipped. The park-and-hold option would require construction of a park-and-hold area adjacent to the exit ramp as well as equipping all of the exit ramps for AHS.

A comparative ranking of the RSCs with respect to these MOEs is provided in table 15. The following observations can be made from the table:

TABLE 15. COMPARATIVE RANKING OF RSCS FOR ENTRY/EXIT IMPLEMENTATION.*

MOE	RSC #1 - Smart Vehicle - Smart Hwy - 6 Lanes/2 AHS - Mixed Ramp Traffic - Transition Lanes - No Barriers	RSC #2a - Smart Vehicle - Average Hwy - 6 Lanes/2 AHS - Mixed Ramp Traffic - No Transition Lanes - No Barriers	RSC #2b - Smart Vehicle - Average Hwy - 6 Lanes/2 AHS - Exclusive Ramps - No Transition Lanes - Barriers	RSC #2c - Smart Vehicle - Average Hwy - 5 Lanes/Reversible AHS Center Lane - Exclusive Ramps - No Transition Lanes - Barriers	RSC #3 - Smart Pallet - Average Hwy - 6 Lanes/2 AHS - Exclusive Ramps - No Transition Lanes - Barriers	RSC #4 - Smart Vehicle - Passive Hwy - 4 Lanes/2 Mixed AHS Lanes - Mixed Ramp Traffic - No Transition Lanes - No Barriers
Minimal need for additional land	4	3	5	2	6	1
Minimal need for additional facilities	4	3	5	2	6	1
Minimal impact on adjacent roadways	3	2	5	4	6	1
Large improvement in potential capacity	3	4	1	2	5	6
Minimal disruption of traffic flow	5	6	1	1	1	1
Improvement in safety	5	6	1	2	3	4
Low cost and complexity	5	3	4	2	6	1

* Rankings range from 1 to 6, with 1 representing the highest rank.

- Relatively high scores were assigned to RSC 2C and RSC 4. This is primarily because these concepts make maximum use of the existing highway infrastructure, require the least amount of additional land and facilities, and have relatively low-cost, low-complexity entry/exit concepts. The primary weakness in RSC 2C is the potential degradation of traffic flow on adjacent roadways. RSC 4 is relatively weak in the areas of improvements in capacity and safety.

- RSC 2B received average to high scores. Because it involves the use of exclusive, direct-access ramps and barriers between AHS and non-AHS lanes, it offers high levels of safety and potential capacity improvement, along with virtually no disruption of non-AHS traffic flow on the roadway. Tradeoffs for these benefits are the significant cost and land requirements for new ramp construction.
- Average to low scores were assigned to RSC 1 and RSC 2A, primarily because of safety concerns associated with mixed ramp traffic, along with the absence of physical barriers. Further, RSC 1 would require the development of a network of transition lanes, which in turn could require significant additional land and complex metering schemes.

- The overall lowest scores were assigned to RSC 2C (the pallet concept). Although pallets provide potentially high capacity on the AHS roadway, the overall throughput could be degraded substantially because of the requirements for loading and unloading. Further, the development of efficient loading and unloading schemes could be very costly and complex. Salient benefits are the potential for a high level of safety, 100 percent immediate accessibility by conventional vehicles, and virtually no disruption of adjacent non-AHS roadway traffic.

Activity Area K. AHS Roadway Operational Analysis

Objective and Scope

At the beginning of this program it was anticipated that the deployment of AHS would introduce new or expanded operational requirements associated with such conventional freeway management type functions as daily traffic operations, maintenance control, communications, and incident management. The primary objective of the area K activities was to identify the operational issues and risks and, where practical, identify significant impacts such as changes in staffing levels. The scope of this review was focused on the six alternative AHSs represented by the program team's selected set of RSCs. While the general nature of this effort was to consider the impacts of a fully implemented version of a given AHS, some attention was also given to defining an approach to an evolutionary deployment of an AHS control center.

Methodology

It was envisioned from the outset that there would be many similarities between operations of likely AHS systems and present day transportation management systems. Accordingly, the area K efforts began with interviews of the management staffs of a number of freeway management systems and a sophisticated rapid transit system. These interviews examined such issues as:

- Control center staffing levels.
- Functions performed by the control center operators and associated staff.
- Control center equipment and facility requirements.
- Incident management team functions and staffing.
- Associated support activities (e.g., service/roving patrols).
- Maintenance needs, staffing, and equipment.
- Interfaces with other agencies and systems.

These issues were then re-examined to see how they might be extrapolated to the following three elements of future AHS systems:

1. Daily operations
2. Control center operations and staffing
3. Evolutionary deployment.

Parallels in operation were drawn where practical to do so. For example, some parallels were drawn between the primary control and monitoring functions of the systems during daily operations. It is expected, of course, that the execution of such functions will be more highly automated in the AHS application. Each of these functions will rely heavily on the communications functions of the system. It is expected that these functions will include communications between both the central system and the field elements as well as the field infrastructure and the vehicles in the system. Further, the communications systems for the AHS control centers and vehicles will be much more sophisticated and reliable than their current counterparts.

The incident management and maintenance functions are not automated functions of the current systems. It is, however, conceivable that within an AHS system, some aspects of incident management, such as the rerouting of AHS vehicles around a blockage, could be automated.

Because the greatest need for early deployment of AHS systems will likely be in urban areas that already possess operating freeway management systems (FMS), consideration was given to evolutionary deployment of AHS control centers through the collocation of a new AHS control center within an existing FMS control center. In the process of accessing potential staffing requirements, it was found that high potential staffing cost was a key potential impact in the implementation of an AHS operations center. This preliminary finding reinforced the need to explore both the potential for collocation of conventional FMS and AHS control centers and other ways of minimizing AHS operational costs.

Results

The key findings from this analysis are presented below. Additional findings and supporting material are presented in the accompanying topical report for area K.

Evolutionary deployment of AHS control centers: Consistent with the contemplated plans of a number of interested stakeholders for the evolutionary deployment of AHS, the first AHS operations centers would likely share facilities, staff, and field resources with current freeway traffic control centers. The functions and services required of both centers have many similarities. Examples of common functions include system monitoring, surveillance, incident management, and access control. Staff that might be shared include those performing field surveillance, maintenance, and incident management. The collocation of the two operations centers and the sharing of equipment, facilities, and staff would provide a substantial cost differential for the initial deployment of an AHS over creating a completely separate AHS facility. Without evidence of compelling reasons to separate the centers, the operating costs should be lowest with extensive synergistic sharing of resources and expenses with existing FMS operations center(s).

AHS system staffing levels: To operate an independent AHS control center, an estimated staff of approximately 55 system operators, programmers, incident management team members, and related staff would be required to support a 400 km AHS facility. This number compares to a staff of approximately the same size to provide equivalent operation of a similar freeway system. As partly indicated above, it is likely that the functions of many of these AHS staff members would already be performed by existing FMS operations center personnel and, therefore, would be duplicated by the addition of separate personnel for an adjacent AHS facility. It is estimated that the total additional staffing requirement might be reduced by up to 75 percent by sharing staff between a collocated AHS and freeway control operation. Other cost reduction measures (e.g., use of high reliability AHS systems, high durability AHS guideways, and use of driver action to handle minor AHS vehicle disability problems) would further drive total costs of a future shared center down towards the cost of a current freeway control center.

Effect of alternative RSCs on daily operations: With the exception of the pallet alternative, there would be little difference between the daily operations of an AHS system for the various RSCs under consideration. More and higher functions would need to be performed by the control centers in “Smart Highway, Dumb Vehicle” alternatives, but these functions would be performed by the system itself and not require a substantial increase in operations support. Since the AHS facility of all RSCs would operate automatically and virtually autonomously, it is surmised that the same number of system operators and other control center personnel would be required to operate essentially any of the RSCs.

In the pallet alternative, there would be more mechanical equipment (the pallets themselves), which would likely be more susceptible to breakdowns than electrical/electronic equipment designed to be virtually “bulletproof.” It is therefore expected that more maintenance staff would be required in the pallet RSC as well as new operational procedures. Additional staffing would be necessary at each access and egress point to the system where the pallets would be loaded and unloaded. Specialized equipment and staff would probably also be required to handle incident management requirements for pallet based AHSs.

Incident management for AHS lane blockage: Current freeway system incident management techniques and strategies will not satisfy the greater needs of an AHS facility. An incident that blocks an AHS lane serving an anticipated 4,000 or more vehicles per hour would generate an immediate queue involving the entire directional facility. Alternative innovative strategies and methods need to be developed which would remove an incident from the AHS facility faster than current procedures and provide a relief valve from the AHS lane during the period the lane is blocked. One alternative is to provide automated incident detection and alternate routing, possibly through relief valve gates in a barrier separated facility.

The reliability of the infrastructure and vehicle hardware must be higher than what currently exists to reduce the number of incidents. On-line real time diagnostics will be required to detect problems and take corrective action prior to total breakdowns in the system.

Activity Area N. AHS Safety Issues

Objective and Scope

The objective of the area N activities was to identify, consolidate, and discuss the major technical, design, and implementation issues and risks to be resolved for providing AHS users with a collision-free driving environment under normal operating conditions. Normal operating conditions in this context means in the *absence of malfunctions*. Providing safe operation despite the *occurrence of potential malfunctions* was the domain of activity area E (malfunction management and analysis). Area E and area N activities were coordinated to assure comprehensive safety coverage while preventing appreciable duplication.

The scope of the area N analysis covered the entire AHS operating spectrum beginning with entry onto the system to safe exit from the system. With regard to the range of AHS configurations considered, area N's scope was largely non-RSC specific but did cover (at a relatively high conceptual level) 1) all of the generic AHS elements (e.g., the vehicle, the roadway, and the driver) and 2) generic AHS functions (e.g., lane tracking, braking, merging with a stream of AHS vehicles, maintenance of vehicle-to-vehicle gap requirements, execution of collision avoidance actions) featured by this program team's selected set of RSCs.

Methodology

Early area N activities included 1) participating in the entire team activity of defining and selecting a set of RSCs and 2) beginning the process of identifying what constitutes normal operation for these types of RSCs. Construction of a high level fault tree lead to an understanding of the general fault paths that could lead to the undesired outcome of a collision in the absence of a malfunction.

Normal operating conditions were defined as all conditions (specifically including threat conditions) that might occur while the AHS is operating in the absence of system malfunctions. It was decided that the threats to be considered for an AHS include all threats currently faced on a highway system (e.g., threats posed by inclement weather), plus special AHS related threats such as those associated with operating under AHS control in strings of vehicles at close headways and automated exiting of vehicles into potentially unsafe situations.

As each of these threat types was further reviewed, it became necessary to do various ad hoc analyses to develop a better understanding of the nature and magnitude of some of the potential threats.

Results

The key activity area N findings are summarized below. Additional findings and supporting material are presented in the area N topical report.

Safety goals: The stringent safety goals anticipated for an AHS should be achievable through carefully executing a comprehensive system safety plan that encompasses not only normal operation (i.e., operation in the absence of malfunctions), but operation in the presence of malfunctions.

Operating threats: A thorough analysis of the operating conditions that can or should be expected in the course of normal operation reveals that a significant number of threats to safe operation exist even in the absence of vehicle or infrastructure malfunction/loss of function. AHS designers should not fail to address threats because of oversights or arbitrary decisions. Our posture at the outset is that all threats currently faced on a highway system will be faced on an AHS and must be handled. This does not mean that some threats may not be controlled. Some may simply be impractical to control, e.g., the bullet, the bowling ball, and a crash landing 747. (Even these, however, might be controlled if money is not an issue.) In broad categories, the range of primary threats include:

- Primary in-line collision threat agents:
  - Moving manually controlled vehicles operating in the AHS lane.
  - Moving AHS controlled vehicles.
  - Fixed objects (e.g., dropped load, stopped vehicle).

— Any non-vehicle—assumed fixed object (e.g., lane-fouling from adjacent lanes, animals).

- Primary in-line threat situations:

  — Forward
  — Behind
  — Merging.

- Intrinsic threats (e.g., factors that degrade the ability of a vehicle to control its trajectory (snow, ice, wind, sand, road surface changes, vehicle factors such as heavy loading and poor load distribution).

In addition to these primary threats, two other threat types were identified specific to AHS, partly because some AHS concepts enhance exposure to these threats and partly because an AHS offers the opportunity to control this exposure.

- Malfunction-related threats involving control-coupled vehicles, especially those malfunctions that can potentially lead to a worst-case incident.

- Transferred threats—a special case in which the threat control responsibilities of the lead vehicle in an AHS string of vehicles is suddenly transferred to the following vehicle.

Transient situations: There is a tendency to focus on the steady-state situation in which a string of AHS controlled vehicles is proceeding at a given speed and under relatively short headways. However, as is the case with commercial aircraft, the safety critical periods of operation tend to focus on the transient situations (e.g., landings and takeoffs). In the AHS environment, these key transients include entry and exit; changes in leading and following vehicle relationships; and (at some relatively small frequency) overall startup, shutdown, and restart of the AHS facility.

Safety control systems: Unlike the commercial aircraft situation, the AHS on-board and off-board control systems must essentially constitute the expert system of a typical driver. For example, the AHS control system(s) must be able to detect and identify threats, assess road and environmental conditions, and decide how much it can trust the leadership capabilities/behavior of the vehicle preceding it.

The variations in safety control demands and threats suggest that a portfolio of safety control options will be required for an AHS. This leads to the recognition of the need for a safety management function that directs the selection and application of a specific option, as well as the other responsibilities listed below. This function may be vehicle-based or central controller-based. In either event, however, it must be tasked with guarding the interest of individual vehicles. This function requires diverse capabilities and responsibilities in the following areas:

- Situation awareness—awareness of the current situation to be controlled.

- Restrictive state management, including transitions—i.e., dropping back to less stringent operating conditions/engagement strategies (e.g., longer headways) in response to current conditions.

- Transferred threat management—responding to unusual behavior of the preceding/lead vehicle.

- Normal malfunction management.

- Transition into and out of the AHS.

- Human participation management—authorizing and/or allowing selected driver inputs.

- “True” exit management—extending the safety boundary of the AHS to prevent “outmerging” of an AHS vehicle into a situation that exceeds the ability of the vehicle and its driver to maintain proper control.

The basic concept for collision avoidance used in this report is the management of separation between independently controlled, paired vehicles. The normal control actions of a subject vehicle are determined on the basis of its dynamic relationship with adjacent vehicles (leading and trailing) as developed by inference from sensors on the subject vehicle and/or direct communication between paired vehicles. The response of a string of vehicles to a forward threat reflects, therefore, the effects of daisy chain communications between vehicle pairs in the string.

Additionally, separation requirements do not recognize a “steer-around” potential as a viable normal collision avoidance maneuver. The analyses included in this report are all based on in-line maneuvers for collision avoidance.

Operator input: While normal operation of an AHS will be “hands off, feet off, brain on,” from a safety perspective, the system must function safely with the operator brain *off*. This means that, from a safety control situation, the safety manager cannot *require* operator input to resolve an unsafe situation. Furthermore, while operator inputs may be solicited and accommodated, they should be processed by the safety manager, with the results translated into vehicle motion alteration only after it is determined that this alteration will not result in an uncontrollable threat to the subject vehicle or to other vehicles in proximity. This does not preclude the possible need for an AHS initiated a “panic” stop.

Pallet-based AHS: The use of an AHS featuring pallets would cause a shift of safety management from individual vehicles to the infrastructure. Several possible benefits that could accrue:

- Improved control over system design would increase similarity/consistency of the vehicles (i.e., traveling units) and their operating characteristics.

- Improved control over vehicle/traveling unit maintenance would reduce the likelihood of degraded performance.

- Reduced interruption due to ACI/ACO (i.e., ACI and ACO could be handled off-line).

- Virtual elimination of the problem of transferring control to the human operator. (Transfer would be under stopped conditions. The concern for “true exit” safety problems would also be reduced.)

- Opportunities for incorporating reusable energy absorption techniques may lessen the demand for no collisions and allow minor collisions not perceived as is allowed with other RSCs.

- Controlled use of alternative propulsion systems and/or fuels.

Because of improved control over the designed-in capabilities, maintenance, and check-out of the critical on-board AHS systems—the use of pallets should result in a net increase in safety over the other candidate RSCs. These gains would, however, need to be weighed against possible losses in throughput and changes in the liability situation, financing requirements, land use requirements, etc.

Activity Area O. AHS Institutional and Societal Issues

Objective and Scope

The overall objective of the area O efforts was to develop an understanding of the institutional and societal issues likely to be important in achieving a successful AHS deployment. A secondary objective of this work was to identify courses of action to address all of the institutional and societal issues identified.

Scope of the area O activities is described by the following definitions and descriptions. For the purpose of this program, the term *institutional analyses* refers to the set of meanings, norms, and rules of conduct that shape the behavior of organizations, with particular attention to the patterns of interaction within and among organizations, and the causes and consequences of these patterns. The institutional issues of particular relevance to AHS acceptance include:

1. The **perspective of environmental organizations** and their role in shaping state and local decision making regarding AHS deployment.

2. The organizational structure and **decision process** at the state and local levels (including roles and responsibilities—an institutional "map") that influence how an AHS proposal might work its way through the system to a "go" or "no-go" decision.

3. The **role of the print media** in communicating information about AHS and in shaping how the public perceives AHS.

4. The **legal liability risks** from vehicle accidents potentially facing AHS participants and arrangements for managing those risks.

The term *societal analyses* refers to similar issues but at both an individual and collective level. The societal issues that are important for public acceptance of AHS that this study has focused upon include:

1. **Public perceptions of the potential risks** associated with AHS systems, factors that influence how those perceptions are formed, and how risk perceptions are likely to interact with technical information disseminated about the program.

2. The extent to which AHS is perceived to help move us in the direction of more **sustainable transportation** systems and livable urban environments.

3. A process for encouraging **public involvement** in the program that can serve to engender public understanding and acceptance.

4. An examination of the **equity issues** that may be raised by AHS systems.

Because of 1) the very broad scope just described and 2) the very limited exposure to date of the various stakeholders, the focus of these analyses was on AHSs in general—not on specific RSCs. Nonetheless the results encompass and provide insight on a range of RSCs. For example, the section on state and local decision processes addresses the different perspectives expressed in interviews and meetings regarding perceived tradeoffs associated with programmatic emphasis on vehicles or on infrastructure. Decisions regarding RSC type also raise important liability considerations, as discussed in the section on legal liability risks. The pervasiveness of the institutional and societal issues is such that of the eight activity areas pursued by this program team, this team's area O effort had the broadest need to keep abreast of the activities and findings of other activity area teams—both internally (other activity areas within this program team) and externally (activity area O teams amongst other contractors).

Methodology

Exploring the broad scope outlined above required a multi-pronged attack and involved a wide variety of sources. The approach utilized involved a variety of elements tailored to the particular needs of each of the issue areas addressed. The links between the approach and the analyses of the issues is probably best communicated the condensed table which follows.

TABLE 16. METHODOLOGY.

Issue Addressed	Steps in the Analytic Approach
Public involvement approaches	Reviewed the literature on public involvement strategies that have been used successfully in high-technology programs. Drawn on first-hand experience in conducting training for federal and state officials in how to set up a successful public involvement process and program. Developed a set of recommended approaches to the conduct of public involvement that can be applied to the AHS program.
Equity	Reviewed the literature on equity. Also reviewed societal and institutional transportation literature for perspectives on equity in this context. Discussed equity issues with the various stakeholders interviewed in the course of this study. Assessed the particular equity issues that are likely to be pertinent to AHS.
Sustainable transportation	Reviewed the general literature on sustainable development and particularly focused on the emerging literature on sustainable transportation. Developed a working definition of sustainable transportation, and a general framework for understanding this concept in terms of resource use, environmental impact, and societal implications. Discussed how AHS might be evaluated against a sustainability yardstick.
Legal liability risks	Reviewed literature on legal liability for vehicle accidents. Examined case law that could apply. Developed a conceptual framework for analyzing legal risks of AHS. Applied the framework to three categories of AHS participants: drivers, vehicle manufacturers, and roadway authorities. Identified options for managing legal liability risks.

Issue Addressed	Steps in the Analytic Approach
State and local decision making	Reviewed literature on experience with transportation decision making at the state and local level. Interviewed selected state and local transportation officials, academic experts, and others knowledgeable about transportation issues in Washington State. Examined the institutional structure of transportation decision making in Washington State. Conducted a workshop with members of a Washington State IVHS Resource Group. Submitted a set of questions to be included in a meeting with Arizona DOT members. Participated in several regional and national transportation meetings and workshops where these issues were discussed. Summarized key findings from each of these sources.
Environmental organizations' perspectives	Reviewed literature on environmental groups and their roles and perspective in transportation matters. Participated in and helped facilitate a national meeting on ITS and the environment. Interviewed more than a dozen regional/local representatives of environmental organizations that are actively involved in transportation issues in the Seattle area, guided by a set of discussion topics prepared ahead of time. Summarized findings from these sources.
Role of the print media	Reviewed literature on comparable examples of media analyses. Conducted a comprehensive search of several national computerized database systems. Analyzed each article from the search according to a content analysis strategy. Summarized findings from this analysis, and drew inferences about the role of the media in the future success of AHS.
Public risk perceptions	Reviewed the literature on perceived risk. Examined AHS in terms of factors (attributes of AHS technology) known to influence how people perceive and interpret the riskiness of technology. Inferred strategies from this analysis that may help the Consortium avoid having the driving public view AHS as much riskier than the transportation engineers.

The concluding area O task involved synthesizing the extensive observations and study results into a cohesive set of findings and recommendations for each of the eight issue areas referred to above.

Results

Key findings for the eight most critical issues identified are summarized below. Where appropriate, implications for public acceptability of AHS are noted and strategies are suggested for addressing issues raised by these findings. Additional findings and supporting material are presented in the accompanying topical report.

Perspective of environmental organizations: Regional/local representatives of environmental organizations interviewed in this study are predominantly hostile toward any proposed system that may increase ease of transportation, VMT, or enhance the attractiveness of the automobile. There was some interest in AHS applications to mass transit, but substantial, positive results would need to be demonstrated. Likewise, alternative propulsion AHS vehicles, such as electric power derived through roadway power strips was of interest to some of the environmentalists. Most of the environmentalists interviewed remain skeptical, awaiting further study and some verifiable research tests and data. Any environmental improvements that are claimed by AHS will have to be very thoroughly tested and modeled to withstand the latent skepticism that environmentalists have toward AHS.

Most environmentalists see sustainable transportation as a long-term process that would change land use patterns toward more higher density living and different (and reduced) transportation patterns. They would be willing to consider an AHS approach that is modeled in this context and integrated into a comprehensive urban plan that reduces VMT altogether. For example, AHS could be used to link dense urban areas, and maximize the efficiency and safety of highway travel between these areas.

While these environmentalists are skeptical of AHS technology, their current perspective is based upon limited knowledge. Further research will be needed to understand the views of the larger environmental community. Additional research that can demonstrate environmental benefits and allay fears about induced demand effects may change this basic point of view. Inclusion of AHS into growth planning models, and demonstration that AHS can support growth management objectives may persuade environmentalists to be more supportive. Demonstration of economic benefit accruing from environmentally sound AHS also may help to convince some environmentalists.

State and local decision processes: The key AHS deployment decisions are likely to be made at a state DOT and local MPO level. Though transportation organizations and transportation planning traditionally occur quite separately from urban development and growth management planning, many state and regional planning agencies are coming to recognize the importance of institutionally integrating major planning programs in such areas as growth management, energy, and transportation. Regional deployment of AHS will need to take account of this kind of integrated development planning process.

State DOTs and MPOs vary substantially with regard to the institutional structure of their decision making about transportation innovations. Differences include: degree of coordination among state and local agencies; existence and content of SIPs and TIPs and associated proposed project evaluation criteria; existence and clarity of procedures for how an AHS proposal will be considered; existence of or desire to include ITS elements in state transportation plans; and the like. In sum, state DOTs and MPOs often are not well prepared to evaluate innovative, non-traditional transportation programs like AHS. A single blanket AHS template is not likely to lead to acceptance and a deployment decision. In addition, many states face serious organizational constraints on their capacity to operate and maintain an AHS with regard to such things as staffing, training, command and control capabilities, integrated facilities, and financial resources.

Role of the print media: A role of the media is one of interpreting AHS technology for a public readership (who are the potential end consumers). The media can exert a significant impact on shaping public opinion and public acceptance.

AHS is currently most often represented in the print media as a far-in-the-future technology (at least 25-30 years away), the apparent end point of the long list of ITS technologies being applied to our transportation systems. While media treatment of AHS specifically has been limited, science fiction terminology like “Buck Rogers” and “The Jetsons” is not uncommon. The media often present an image of a platoon of vehicles traveling at very high speeds (80 to 100 mph) with very close gaps (~1 yard). Some benefits of AHS as represented by the media include: congestion relief; driver safety; reduced air pollution; economic stimulus; improved public transit; enforcement of traffic rules; and, aid to older drivers. While the majority of media articles appear to represent AHS in a positive or neutral light, some are decidedly negative. Some potential drawbacks in media reports include fear of major accidents, high cost, unwillingness of drivers to relinquish control, loss of privacy, competition with public transit, urban sprawl, liability risks, impacts on secondary roadways, complexity, and lack of demand. In sum, while the media are supportive of the AHS concept at this early period in the conceptualization of AHS, their representation of AHS is neither accurate nor complete. As AHS becomes more visible, the risk is that its complexity will lead to misunderstandings and misrepresentations that may jeopardize public acceptance.

Legal liability risks: To succeed, AHS will have to secure the participation of the corporate and individual driving public, who purchase, operate, and maintain fleets and vehicles; motor vehicle manufacturers (and their suppliers and dealers), who design, manufacture, sell, and service vehicles; and state and local transportation agencies (and their contractors), who plan, finance, design, build, and operate roadways. One important factor in obtaining the necessary level of acceptance by these participants will be their assessment of the impact of AHS on their risks of legal liability for damages resulting from vehicle accidents. In evaluating these risks, participants will take into account not only the risks of actually being held liable for alleged AHS-related accidents, but also the “litigation risks” of incurring the transactions costs and reputational damage that can result from merely being named in lawsuits.

To the extent AHS results in an overall improvement in highway safety, it should reduce the costs of motor vehicle accidents, and thus decrease liability risk in the aggregate. However, three aspects of this overall reduction in accident costs could create disincentives for vehicle manufacturers and roadway authorities to participate in AHS.

Whether these risks will be unacceptable will depend on the potential participants' evaluation of specific system configurations in light of the offsetting benefits. The underlying safety of the system and the allocation of control among the driver, vehicle manufacturer, and the roadway authority will be fundamental to this evaluation. In principle, it should be possible to manage the legal risks of AHS accidents to overcome disincentives to participation. To the extent AHS increases highway safety and thus reduces liability for accidents in the aggregate, it creates a windfall for the liability “winners,” which can be tapped if necessary to create institutional arrangements that compensate the liability “losers” so that all participants would be as well or better off as in the absence of AHS. These arrangements need not be direct payments, but rather could take a variety of forms, including vehicle industry or roadway association standards for AHS systems, regulatory standards, government indemnification, or insurance pools.

Public perception of potential risks: The nature of public concerns, particularly about potential risks associated with prospective AHS features, is speculative in the absence of survey research that focuses on that topic. However, some assessment of public perceptions is possible based on an examination of the extensive literature on perceived risk, coupled with interviews with various AHS stakeholders. A number of technologies have been measured in a two-dimensional risk space. The first dimension contrasts technologies perceived as uncontrollable, involuntarily imposed, and having fatal and potentially catastrophic consequences with those seen as controllable, voluntary, and having only individual consequences. The second dimension contrasts known risks like handguns and motor vehicles with those where the effects are less well understood (by the public) such as DNA research and solar electric power. Technologies perceived to be high on both dimensions (unknown and feared) face great challenges in winning public acceptance. Informal interviews and literature review of AHS descriptions suggests that AHS technology may be located somewhere in the middle of both dimensions. AHS is, at this early stage, not well known by the public, and it is perceived to have potentially fatal or catastrophic consequences (an image represented in the media).

Literature review shows that most people are positive about automatic controls as long as human control is possible as a back-up; automatic elevators and airport terminal trains are examples. While the public has learned that human error is ubiquitous, knowledge about and familiarity with the technology can help reduce concern.

In sum: 1) The public will have substantial safety concerns about AHS. These will have to be carefully predicted and taken into account in design and initial deployment. 2) Phased deployment that does not require the public to place blind faith in unproved technology will be essential. 3) Technologists and developers must be careful not to oversell AHS, and they must be careful that they are not perceived as claiming that "nothing can go wrong." Either error will provoke public distrust and lead to anger when problems do occur.

Sustainable transportation: Environmentalists and other citizens concerned with how public policy can help shape the relationships between technology, the environment, energy use, development, and quality of life, are increasingly applying sustainability as a yardstick to measure success. Sustainability in the transportation sector raises particular questions about the use of non-renewable energy resources, pollution of urban air, and impacts on human communities and settlement patterns. The acceptability of AHS as a new transportation technology is likely to be increasingly judged in terms of its contribution to helping meet sustainability goals. Politically influential stakeholders, such as environmental organizations, along with selected federal and state agencies, are pressing for greater attention to sustainability, and transportation managers can expect to be held to similar performance standards.

AHS can demonstrate responsiveness to these emergent concerns by incorporating into its mission and goals a balanced focus on both mobility enhancement (flow, congestion relief) and sustainability (VMT reduction, demand management, congestion pricing, alternative non-vehicle modes of access, less pollution, and use of alternative fuels).

In sum, AHS should be positioned as much more than a stop-gap measure designed to address current congestion. Rather, AHS should be coupled with transportation demand management (TDM) and transportation systems management (TSM) measures, as well as selected capacity enhancement measures, that serve to manage congestion problems over the long-term without inducing demand that spirals into worse congestion in the future.

Public involvement process: The overall goal of public involvement (PI) can be framed in terms of improving the quality of decision making. Within this overall perspective are the supportive objectives of developing a shared understanding of the nature of the problem among stakeholders and the project proponents, developing a PI process that is viewed by stakeholders as fair and rational, and reaching a decision that is acceptable and implementable. A review of studies of the implementation of technologies comparable to AHS reveal important lessons for this program.

There is a lack of societal consensus on key societal goals and priorities and increased concern about the environment and public health and safety. In addition, there is increasing lack of trust of managers of those technologies perceived to embody risk. This lack of trust is manifest in a rise in the number of public interest groups and activist organizations. The deployment of AHS must be able to work with this diverse collection of stakeholder groups and individuals.

PI offers a process for bringing together AHS proponents and disparate stakeholder groups that hold a wide range of opinions and concerns about this technology and its potential deployment consequences. AHS developers and manager should be prepared to work from the outset with stakeholders who best understand the institutional and societal context within which AHS will be sited, and be prepared to negotiate approaches and decisions about AHS conceptual development and deployment with them. AHS management must be prepared to alter decision making based on input from the PI process.

With a relatively unknown technology like AHS, members of the public and stakeholder groups are more likely to find AHS acceptable if 1) they are invited in as active participants in design and deployment decisions; 2) they are invited into the process early on, before key decisions have already pretty much been made; 3) they actively help shape the PI process itself; 4) they feel they have some ownership in the outcome of the participative process and thereby can see how AHS really helps meet their needs.

- Establish stakeholder identification and interaction processes very early in the program conceptualization and definition phase. Don't wait until deployment. This is especially important for AHS technology that carries with it higher levels of perceived safety risks.

- Make PI specialists members of the AHS design and deployment team.

- Involve upper management in the PI enterprise and be sure they fully subscribe to and support the goals of PI.

Equity: Concerns have been expressed by various stakeholder groups that ITS technologies may impact minority (race, age, physical handicap) and low-income populations differentially. More specifically, questions have been raised about AHS in terms of the ability of various segments of the population to be able to afford AHS equipment (low income), to have adequate access to AHS (people without personal automobiles), or to have the requisite operating skills (elderly, disabled). Questions also have been raised about the fairness of dedicating existing lanes to AHS, thereby restricting those who choose not to acquire AHS capabilities, or increasing the tax burden for everyone when only some will benefit. Finally, open and fair access to AHS decision making processes is a measure of program equity that ties in with the public involvement challenges discussed in this report.

The perceived equity of AHS will be a critical factor in its ultimate acceptability and implementability. AHS management should set equity-related goals for the program, and monitor progress toward the achievement of these goals. The AHS public involvement process needs to be sensitive to equity concerns and make particular efforts to include low-income, minority, elderly, and disabled interests.

Conclusions and Research Needs

Without a sufficient degree of key stakeholder and general public acceptance for AHS, state legislatures, state DOTs, local MPOs, and other AHS proponents are not likely to be able to successfully win the measure of support needed to proceed with deployment. Our interaction with a number of state DOTs, including findings from a public meeting at the Transportation Research Board (TRB) meeting in January 1993, further suggests a large amount of skepticism about whether AHS is even worth pursuing, so there are large hurdles ahead for this program. Environmental groups are likely to be especially reluctant to endorse AHS, unless its benefits can be clearly demonstrated. We have found that acceptance of AHS is likely to depend on the resolution of an interrelated set of institutional and societal issues. The findings summarized in this document reflect those issue areas and suggest some strategies for addressing the issues. We also find some additional validation of these findings, given a measure of comparability of findings across the variety of different issue areas investigated here.

Much remains to be done to better understand how these and other institutional and societal issues will interweave with the AHS program as it unfolds. A few research suggestions include the following:

- We need to better understand how AHS may influence VMT and potentially induce additional demand for travel.

- For candidate deployment sites, we need to research how state and local organizations are structured with regard to decision making on innovative transportation technologies like AHS, what their selection criteria are, and what processes are used to identify and engage stakeholders in a productive dialogue.

- Research is needed to identify the kinds of information that the public would like to know about AHS so that informational materials can be made responsive to identified needs.

- We need to learn more about how members of the public perceive the riskiness of AHS technologies and what the preferred configurations look like. Focus groups, survey research, and deliberative polling approaches with a national sample of the public are useful ways to gather critical data.

- With regard to better understanding liability risks, research needs include 1) validating and refining the legal liability concerns of the corporate and individual driving public who purchase, operate, and maintain fleets and vehicles; motor vehicle manufacturers (and their suppliers and dealers) who design, manufacture, sell, and service vehicles; and state and local transportation agencies (and their contractors) who plan, finance, design, build, and operate roadways, applying the framework developed in this chapter; 2) identifying legal risk management models from other domains and analysis of their applicability to the management of the risks identified in this report.

- The media analysis should be expanded to include television coverage, since a large portion of the population gets its news from that source.

APPENDIX C
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