Precursor Systems Analyses of Automated Highway Systems

RESOURCE MATERIALS

AHS Roadway Operational Analysis

U.S. Department of Transportation
Federal Highway Administration

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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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NOTICE

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16. Abstract

In order that the AHS remains a successful component of a transportation system, daily operations and maintenance issues must be prepared for and strategies developed. This activity area identifies issues that are sometimes overlooked in a major deployment project (e.g., the need to provide staffing, vehicles, funding, and risk management to ensure daily success of a freeway management system). The operational needs may be associated with daily traffic operations, maintenance, control strategies, communications, and incident management, among others. Factors that drive these needs are costs associated with personnel requirements and system integration. As AHS continues to come on line in field applications, new information will be gathered on which to build the experience of the operational implications of the roadway facility. This data will be disseminated for use in future AHS development and evolution, resulting in expansion of AHS capabilities and features.

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EXECUTIVE SUMMARY

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 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.

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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

INTRODUCTION

The objective of the precursor systems analyses (PSA) of automated highway systems (AHS) is to examine the wide array of effects that the deployment of AHS may have on the nation's transportation system. The operational issues, risks, and opportunities associated with AHS are identified and analyzed in this effort.

Activity area K addresses the roadway operational analysis elements of a proposed automated highway system. Issues that are analyzed include factors that affect the daily operations of a working system, including maintenance of the system. Specific issues include:

- Control center functional operations.
- Staffing.
- Maintenance operations and staffing.
- Failure/incident management strategies.

This effort defined an approach to the evolutionary deployment of the control center and operational aspects of an AHS system.

Approach

There are many similarities between the concept for the proposed AHS systems of the future and today's transportation (freeway and rail) management systems, especially in the areas of control center functions, maintenance, staffing, and operations. The approach used to identify issues and evaluate their impacts, therefore, was to examine the operations of existing transportation and freeway management centers and to extrapolate the information obtained from these sources into the context of AHS systems.

The approach used by the research team was to survey a number of freeway management systems (FMS) and a sophisticated rail rapid transit system to examine 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 or similar functions will be performed in the AHS system control centers of the future. The information obtained from the interviews with freeway management personnel, combined with a vision of the future of transportation systems in the United

States, including AHS, therefore served as the basis for many conclusions regarding expected future AHS control center operations.

A significant difference between freeway management systems and future AHS systems is in the area of intelligence and control. Existing freeway systems do not provide a direct control function over the operation of vehicles and do not have any direct communications link with the vehicles in the network. In most of the proposed configurations for AHS systems however, the system will be maintaining a continuous inventory of all vehicles in the AHS lanes and will be providing some degree of control over their operation. No comparable level of control is provided in today's freeway systems; however, similar functions are in use today in rail systems, and to some extent in the airline industry.

In addition to interviewing freeway control center managers and staff, the control center at BART rapid transit system in the San Francisco Bay area was visited and the management staff interviewed. The operations and functions of this control center are many times more complex than those of typical freeway management systems and therefore provided a significant amount of information that is more directly applicable to AHS systems than freeway systems.

A number of aspects of the operations of freeway systems are not germane to the future operations of an AHS system, and therefore, care was taken in deriving conclusions from freeway system operations that are not justified or appropriate. For instance, in freeway systems, traffic surveillance is performed primarily by in-road loop detectors, often complemented by video image processing. Incident detection uses these loops, software algorithms, cellular call-ins, and closed circuit television surveillance (CCTV) for confirmation. These technologies and strategies have limited applicability to AHS systems where, under the majority of alternative designs, the status of all vehicles in the system will be monitored, and malfunction and/or incidents will be detected instantaneously by the system. The surveillance function in the two systems are not comparable therefore, and few conclusions regarding the surveillance performed by an AHS system can be drawn from present day freeway management systems, expect as a back-up service to the automated system.

In other operations areas that are analyzed, parallels can be construed between the two types of systems, e.g., regarding system operators. The functions performed by most freeway or control system operators are to monitor the status of the system and be available to respond and take action when malfunctions, faults, incidents, or emergencies occur and where human intervention is needed. The other functions performed by system operators differ system to system, dependent upon the needs of the agency, the system, and staffing availability to perform other tasks. In the case of AHS system operators, the primary duty will be to monitor system operation and intervene in the automatic operation of the system only when necessary. The assumption is that the AHS system will be able to operate in a fully automated mode without the need for human intervention except in emergencies or other failure modes where there is no automated response. There is therefore a distinct similarity between the roles of the operators of the two systems, and parallels can be drawn.

In addition to interviewing managers of existing freeway management systems on the operations of their centers, these personnel and others from a variety of positions within four different State departments of transportation are interviewed to identify other issues. Issues of major concern are:

- Safety, including incident detection and removal.
- Costs (personnel and equipment).
- Field maintenance.

Direct parallels to present day freeway systems cannot be inferred regarding these issues. However, lessons from current incident management techniques can be used to develop new strategies for AHS applications, cost estimates are extrapolated from today's systems, and recommendations for maintenance programs and techniques derived.

The predictions of staffing needs, functional requirements, operations and maintenance costs, and safety requirements are estimated for both urban and rural applications of AHS technologies. As presented below, the research team evaluated six alternative Representative System Configurations (RSCs).

The daily operation, maintenance, and staffing needs for each of the RSCs are similar except for the differences between urban and rural applications. Therefore, the analyses performed in this task relate to the urban versus the rural deployment of AHS rather than the differences between RSCs. The urban and rural applications of AHS will be discussed further in a later section of this report.

To illustrate the similarities in the operational requirements of each of the RSCs, discussion of the alternative RSCs that are being investigated by the research team is presented in the following section.

Representative System Configurations

For the purpose of this document, the research team considered four primary representative system configurations (RSCs). Detailed descriptions of these RSCs can be found in the AHS Precursor Systems Analyses Overview Report. Only the characteristics of these RSCs relative to the research in this activity area are contained herein.

In general terms, the RSCs can be summarized as follows:

Table 1. Representative system configurations.

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
Note: [1]RSC 2 consists of three lane configuration variations, resulting in a total of six specific RSCs.				

Each RSC used in this research requires a specific definition of the associated roadway configuration. Three of the four primary RSCs (i.e., 1, 3, 4) were assigned only one roadway configuration, and one of the RSCs (i.e., 2) was assigned three different roadway configurations. The result is a total of six variations of the four primary RSCs, described by their *mainline*, *AHS access*, and *separation characteristics*.

Mainline

None of the RSCs investigated in this research effort involved a roadway which is completely AHS for all lanes, with no provisions for non-AHS vehicles. However, three distinctly different mainline roadway configurations were associated with the target RSCs and considered:

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.

AHS Access

Access to the lane in which AHS is provided can involve a variety of entry/exit designs, some of which require maneuvering through non-AHS traffic to get to the AHS lane. Others simply provide direct access to the AHS lane via an exclusive ramp system.

For the sake of this research, entry and exit facilities were addressed only at a high level to determine compatibility with roadway design strategies. The main interest in entry/exit for this effort is simply to acknowledge whether a ramp system is on the left or right side of a lane set, spacing between terminals, and whether the ramp is intended for mixed or exclusive AHS flows. Other research teams have conducted detailed studies of entry/exit facilities (Area J—Entry/Exit Analysis) and their deployment, and have documented those results in other reports.

The following AHS lane access components were considered germane to the RSCs in this research:

1. Mixed Ramps—AHS vehicle enters/exits the freeway facility by using the same ramp facilities as non-AHS vehicles. Special lanes may be provided for AHS vehicles on the ramps to facilitate check-in and check-out, but the AHS vehicle must maneuver through non-AHS lanes when traveling between the AHS lane and the ramp system.

2. Exclusive Ramps—All entry and exit points serving the AHS are provided by ramps intended exclusively for the use of AHS vehicles only and are physically located such that no maneuvers by AHS vehicles through non-AHS traffic are necessary to reach the AHS lane.

3. Transition Lane—Similar to the mixed ramp concept where AHS and non-AHS vehicles utilize the same ramps, but includes a transition lane located adjacent to the AHS lane. The transition lane is used for maneuvers into and out of the AHS lane. Traffic flow in the transition lane may be AHS only or mixed flow, and AHS vehicles must maneuver through non-AHS lanes and traffic to reach the AHS lane.

During the latter stages of the precursor analysis study, the teams that were performing the Entry/Exit Analysis concluded that the concept of transition lanes should be excluded from further study based on technical and safety considerations. This task addressing the roadway operations did consider the use of transition lanes as an alternative configuration, and consequently, occasional reference to transition lanes will occur throughout this report.

Lane Separation

The means by which separation of AHS and non-AHS traffic is accomplished is closely associated with how entry/exit may be accomplished. In terms of the RSCs considered for this research, the following two concepts were considered:

1. None—Separation of AHS and non-AHS traffic is accomplished by signing and striping only.

2. Barrier—Physical barrier used to separate AHS and non-AHS traffic streams along the length of the AHS lane.

Using these characteristics, the resulting six variations of the four primary RSCs are summarized as follows:

Table 2. Global RSC characteristics.

RSC	Mainline Roadway Configuration	AHS Lane Access			Lane Separation	
		Mixed	Exclusive Ramps	Transition Lanes	None	Barriers
1	3 Lanes each direction Exclusive AHS Lt. lane	X		X	X	
2A	3 Lanes each direction Exclusive AHS Lt. lane	X			X	
2B	3 Lanes each direction Exclusive AHS Lt. lane		X			X
2C	2 Non-AHS lanes each direction Reversible excl. AHS center lane		X			X
3	3 Lanes each direction Exclusive AHS Lt. lane		X			X
4	2 Lanes each direction Mixed traffic Lt. lane	X			X	

The graphics on the following sheets illustrate the general roadway configurations of the six variations of RSCs used in this research. The basic assumptions as to how each RSC would operate is summarized in table 3. Detailed descriptions of characteristics beyond the roadway deployment characteristics may be found in the AHS precursor systems analyses overview report.

Average Vehicle/Smart Highway/Dedicated Lane/Transitions

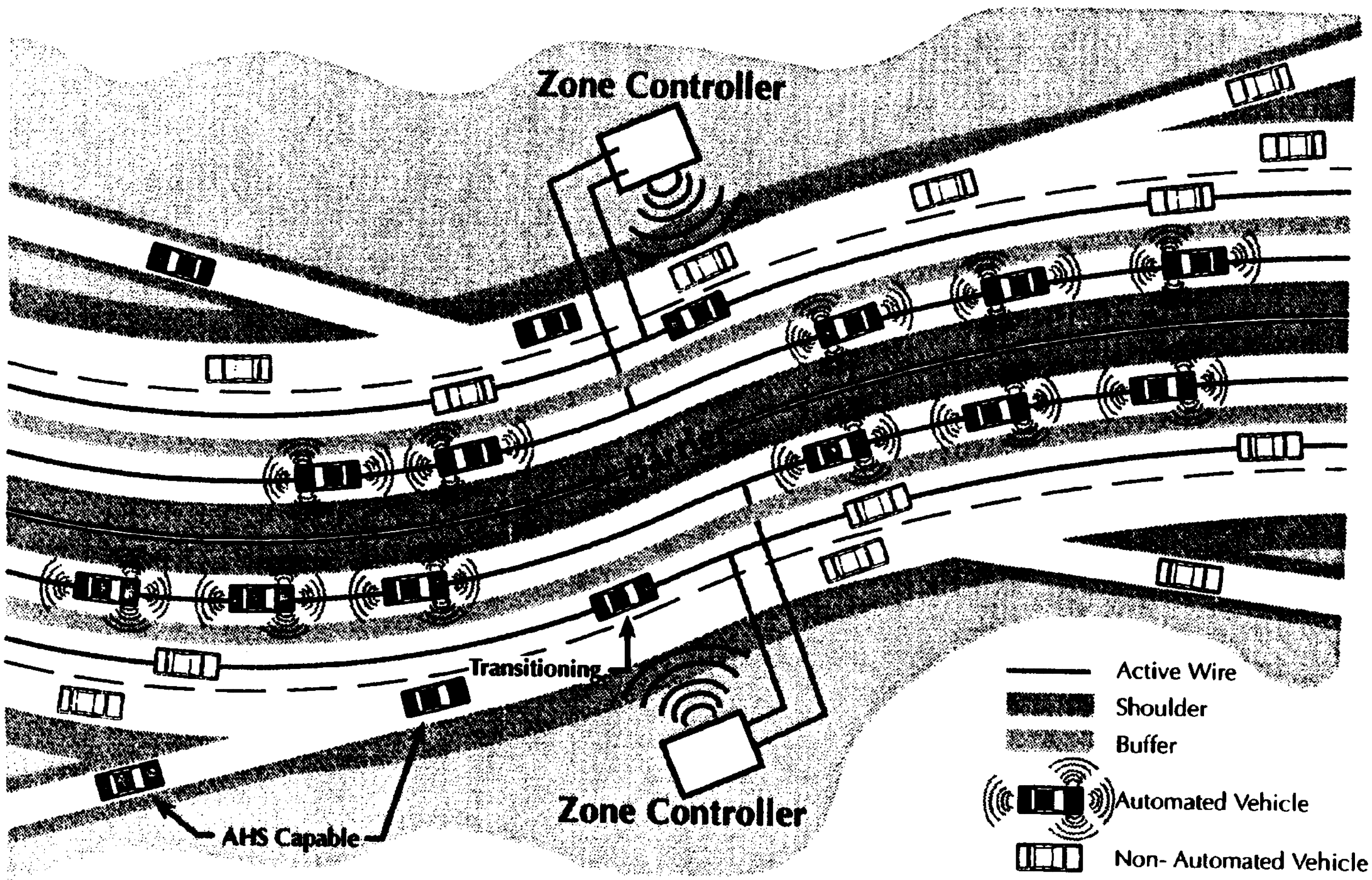

Figure 1. RSC 1.

Smart Vehicle/Average Highway/Dedicated Lane/Transition

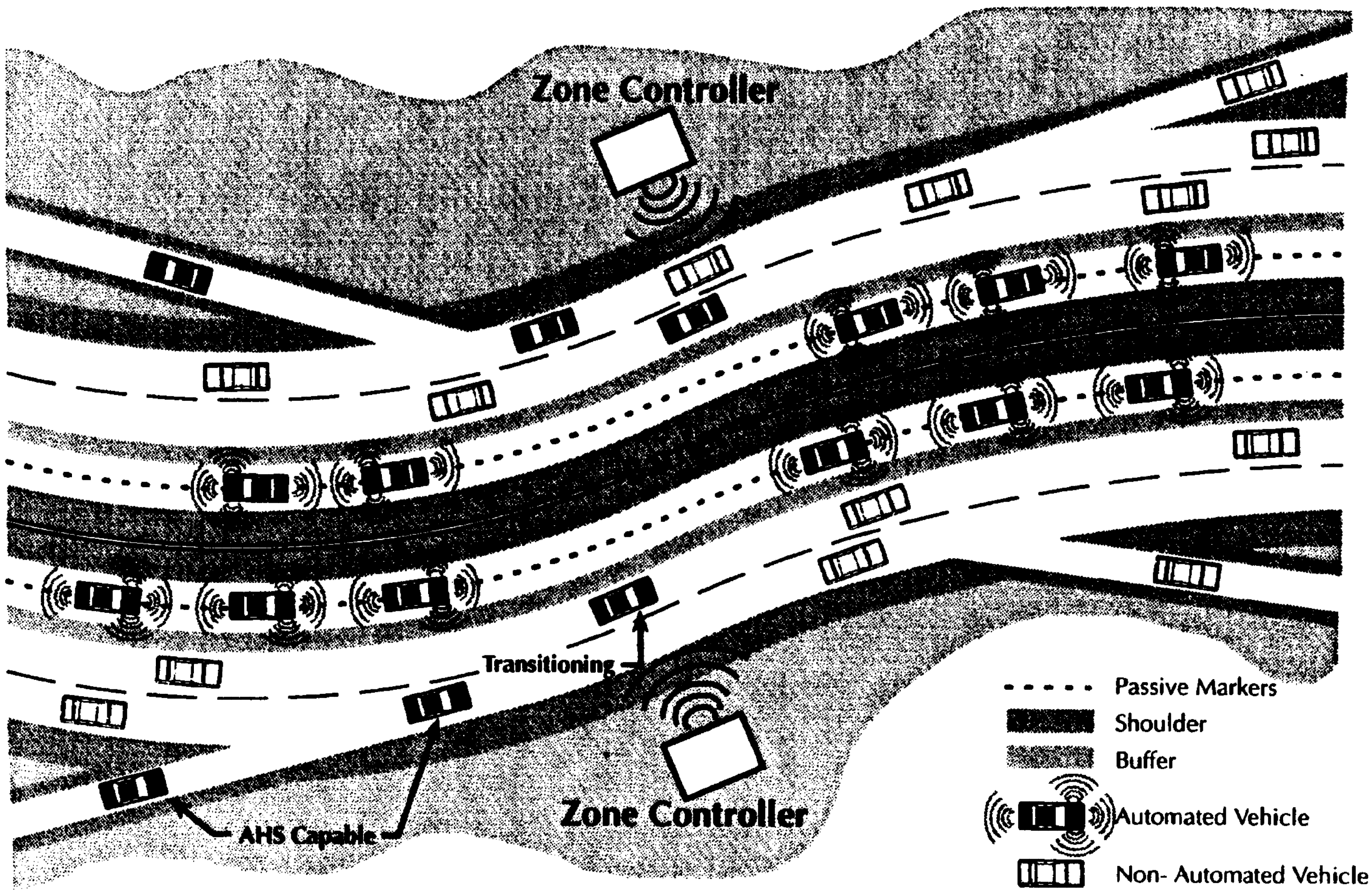

Figure 2. RSC 2A.

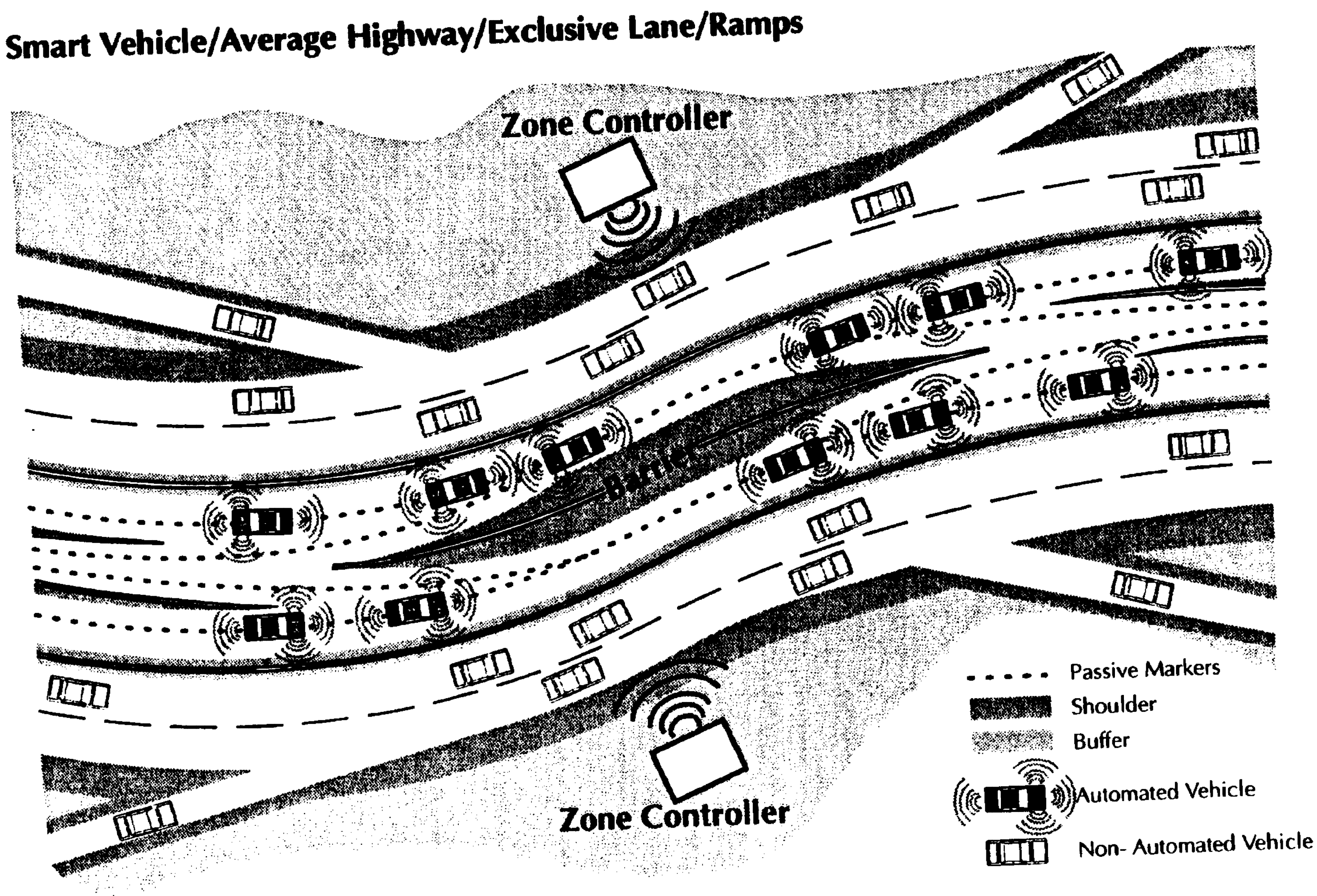

Figure 3. RSC 2B.

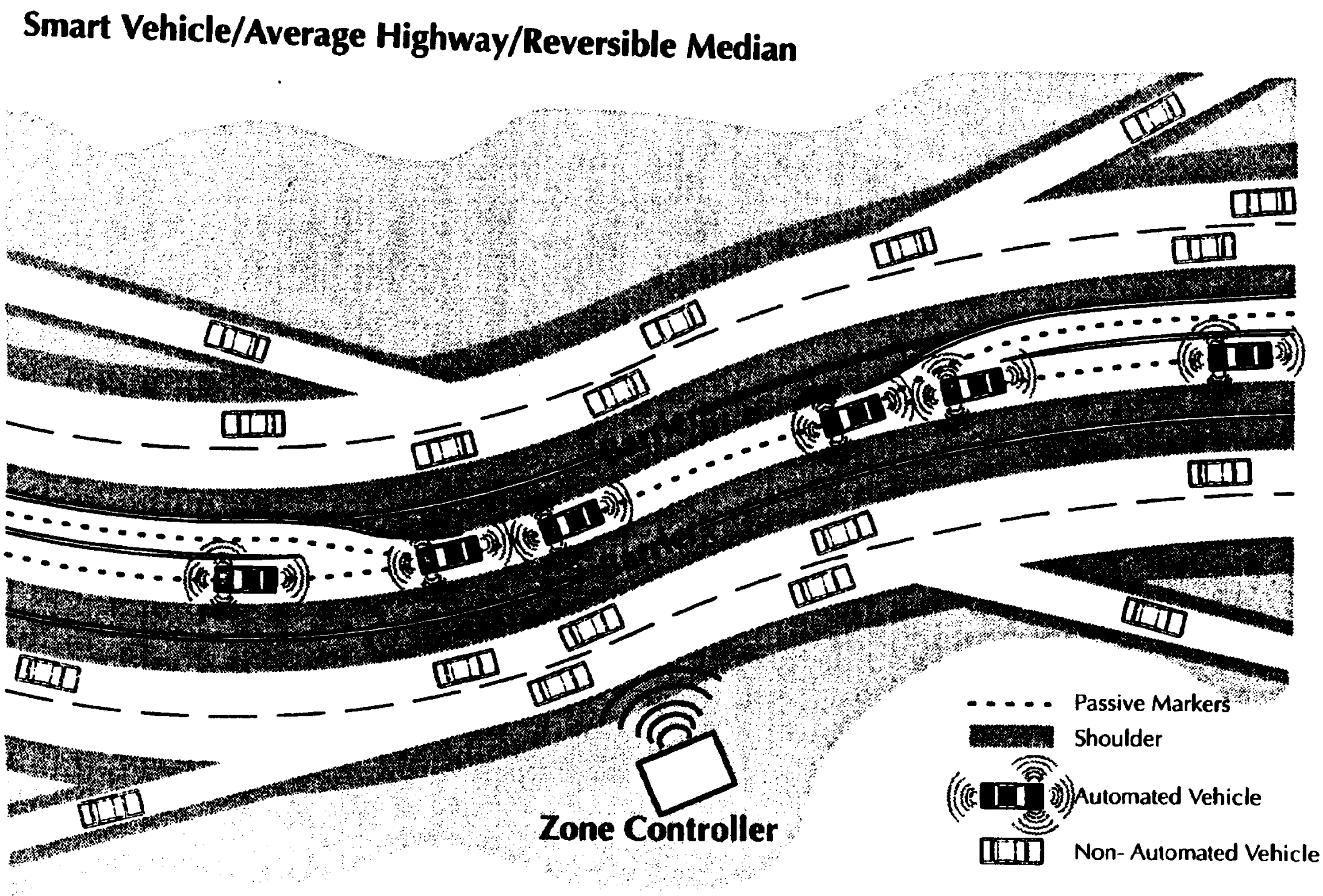

Figure 4. RSC 2C.

Smart Pallet/Average Highway/Exclusive Lane/Ramps

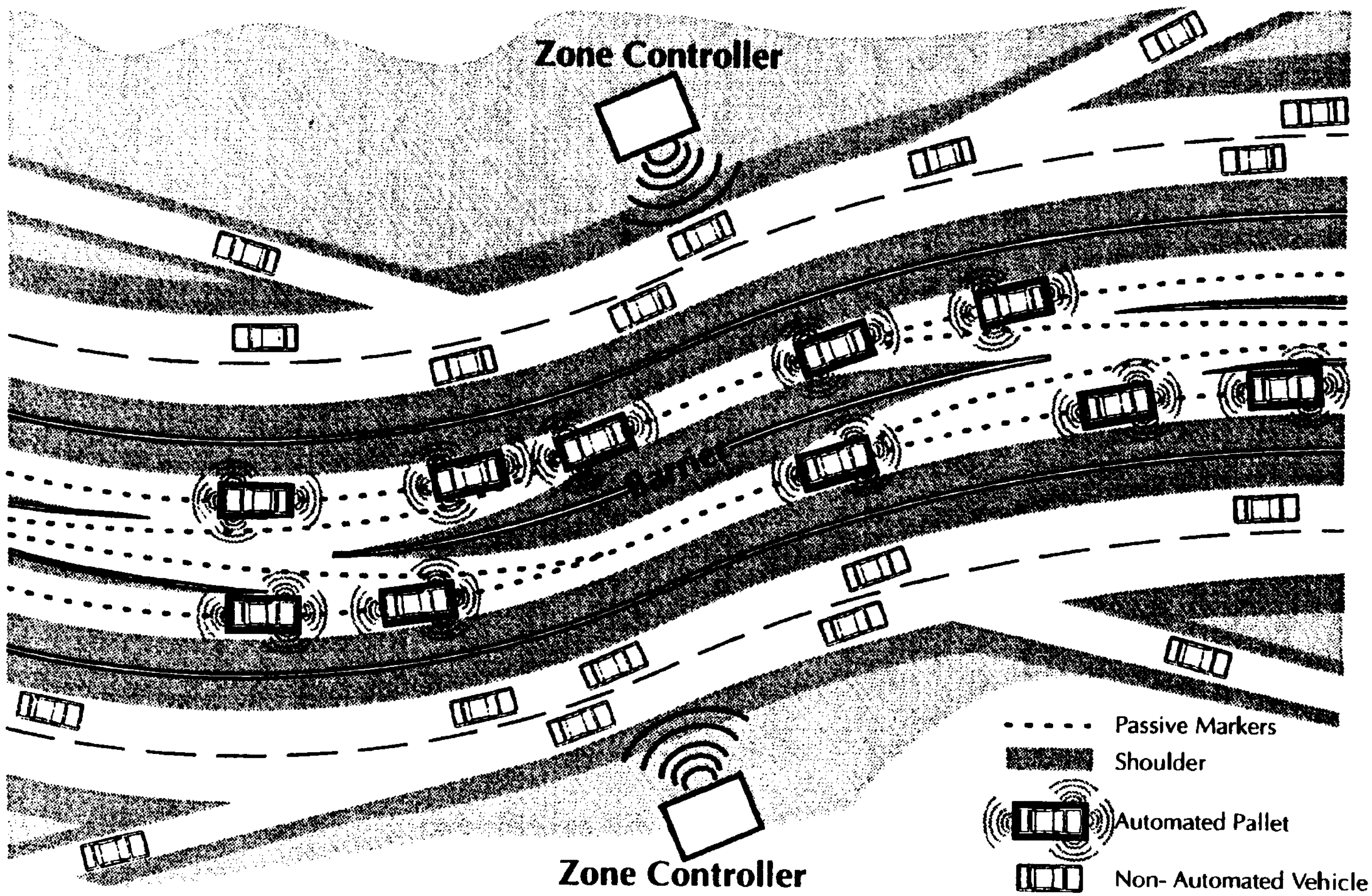

Figure 5. RSC 3.

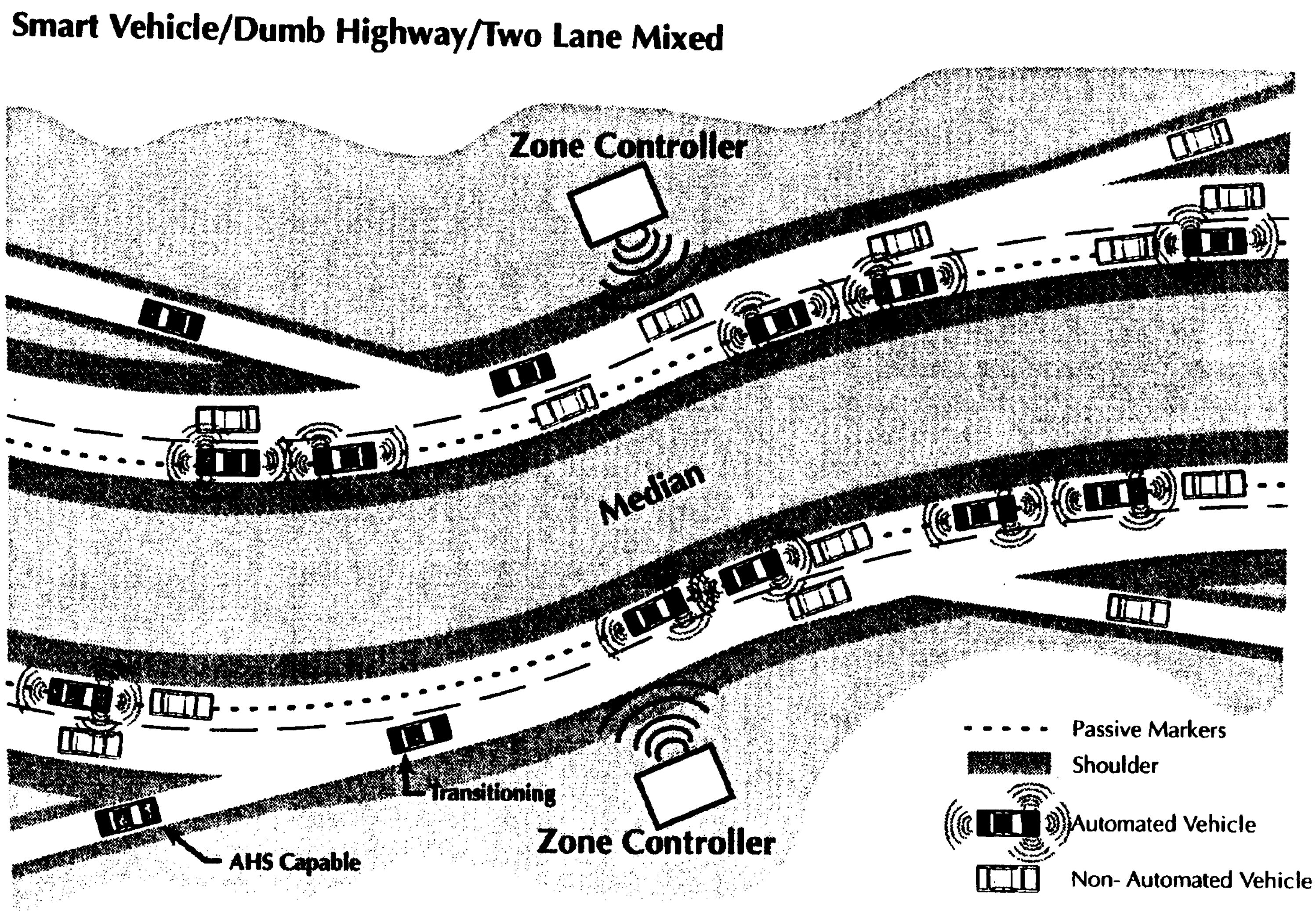

Figure 6. RSC 4.

Table 3. RSC assumptions.

Parameter	RSC 1	RSC 2	RSC 3	RSC 4
Vehicle Type	Individual Passenger Car	Individual Passenger Car	Single Car Pallet, Automatic Control Only	Individual Passenger Car
Headway Policy	Uniform	Platoon	Uniform	Independent
Vehicle Intelligence	Good	Smart	Smart	Very Smart
Roadway Intelligence	Good	Average	Average	Dumb
Lane Configuration	Mixed traffic on inside AHS lane with manual traffic on outside lane	Dedicated AHS lane(s) with transition lane and manual lane(s)	Dedicated reversible AHS lane with pullover space adjacent to AHS lane	All lanes mixed traffic
Barriers	None	None	Between AHS and Non-AHS Lanes Only	None
Entry/Exit Ramps	Current Type	Current Type	Current Types for Non-AHS Dedicated for AHS	Current Type
Transition to AHS	Where: In AHS lane When: At driver command after sector control OK How: Manual switch	Where: In Transition Lane When: At driver command after sector control OK How: Manual switch	Where: In Pallet Attach & Detach Area When: Upon link to pallet How: Automatic with link	Where: In AHS lane When: At driver command after sector control OK How: Manual switch
Check-Out of AHS Vehicle Systems	Combination of periodic certification and polling of internal sensors	Combination of periodic certification and polling of internal sensors	Pallets under control of central authority—Inspected before allowing on AHS	Combination of periodic certification and polling of internal sensors
Failure to Transition Results In:	Driver must continue under manual control	Driver must continue under manual control in transition lane or re-enter manual lane	Essentially cannot fail to transition unless driver refuses to enter destination	Driver must continue under manual control

Urban, Urban Fringe, and Rural AHS

The precursor analyses conducted by the research team investigated the application of AHS in three differing environments:

- Urban.
- Urban Fringe.
- Rural.

Roadway characteristics as well as the characteristics of typical trips, traffic flow, and accident patterns are different in each of these environments. It is probable that the design of AHS facilities will be different in rural areas than that envisioned for urban freeways. For example, the application of barrier and no-barrier alternatives is likely to be associated with the operation environment of application. It is not anticipated however, that urban fringe environments will require a separate treatment that will be distinctly different than those used for either rural or urban, especially in regard to operational issues such as control center functions. The control centers in urban areas will likely encompass urban fringe areas and interface directly with rural area control centers rather than there being a need to deploy separate control centers for different environments. Therefore system operational issues for urban and rural area types are reviewed in this effort to define the differences between the system functions and operations that will be required by each.

TECHNICAL DISCUSSION

Operational Issues

Many of the operational issues identified and analyzed in this study are common to each of the six alternative RSCs; for instance, the need for a central control facility from which to monitor and control the operation of the AHS system. Those issues and risks that pertain to all AHS configurations are presented and discussed first, followed by a separate analyses of those issues that have differing effects on the various alternatives.

The operational issues and risks identified in this study have been grouped into categories as follows.

- Daily operations of the AHS system.
- Control center operations and staffing.
- Evolutionary deployment.

Within the realm of daily operations of an AHS system falls the subject of the functions that must, or may be, performed by the system. The system will not control AHS operation (e.g., in some RSCs, dictating vehicle movements into, from, and within the AHS lane) but will also oversee monitoring and surveillance, malfunction and incident detection, and reporting—and will be capable of performing these functions in a fully automated mode, without human intervention except in extreme cases of emergency.

In addition to these operations, the system must also be able to accept commands from an operator to perform other specified tasks such as:

- Dispatching incident and maintenance teams.
- Providing special reports on request.
- Interfacing with a wide variety of agencies and organizations such as the media. enforcement agencies, maintenance personnel, and other operating agencies.

Each one of these functions will be discussed in greater detail in the following sections.

Daily Operations of the AHS System

Many of the routine and/or generic AHS operational functions which will be performed by the system and those which can be monitored and controlled from a central system site are identified. The details of the functions that are to be performed by the system and the technologies to be used will be dependent upon how the system is designed to operate. However, there will be some functions which can be assumed to be common among virtually all possible systems designs. These functions include:

- System control.

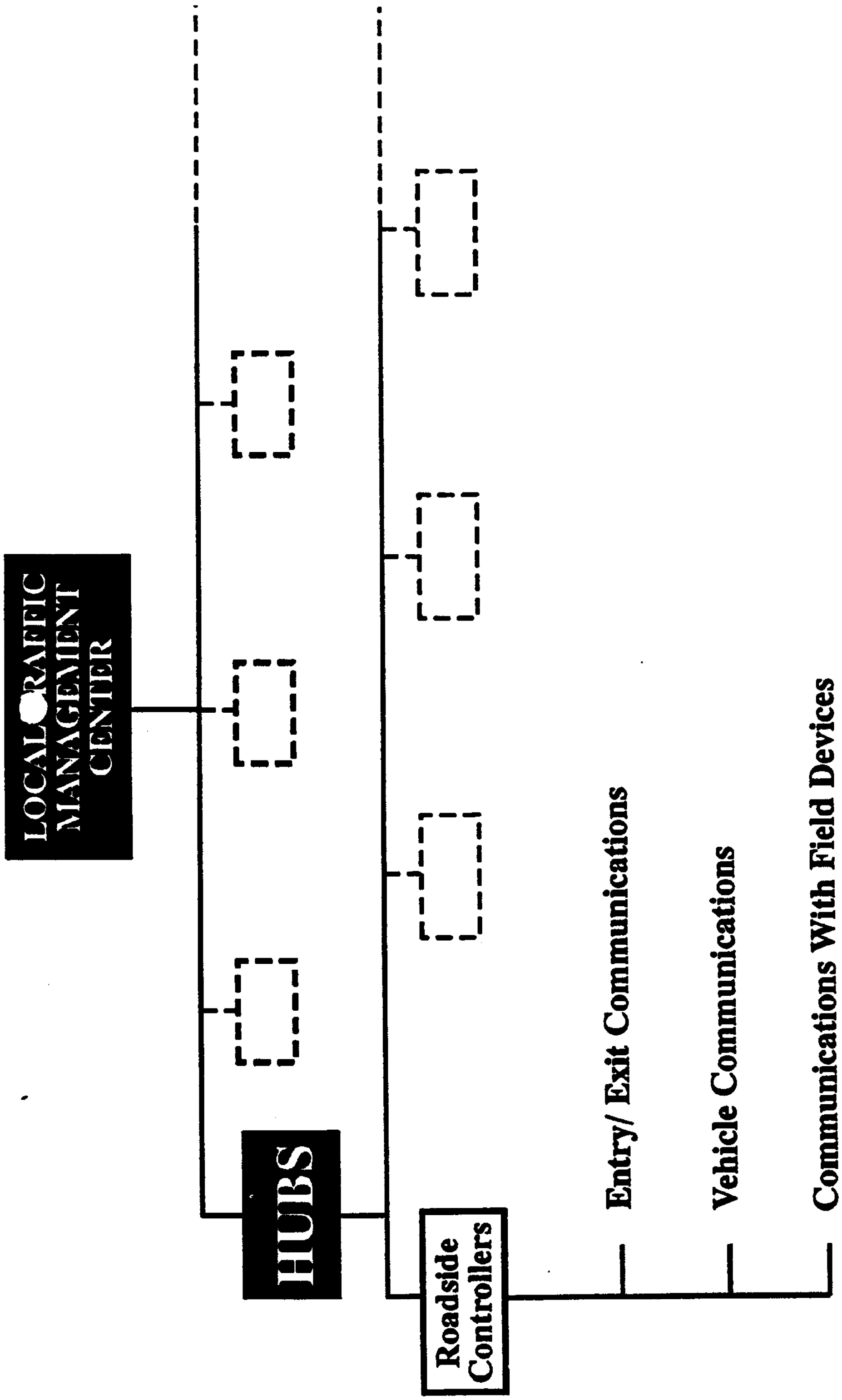

Figure 7. System configuration.

- Monitoring.
- Incident management.
- Maintenance.
- Reporting.

A discussion of each of these elements is presented in the following sections:

System Control

The primary function that the system will be performing comprises the control it will exert over the system elements, and most importantly, the vehicles travelling within the system. The two components of the control function are control over:

- Infrastructure.
- Vehicles.

For purposes of this discussion, the system "infrastructure" is considered to consist of system components which are located outside of the control center. A system configuration was assumed, as illustrated in figure 7, that consists of the following elements:

- Local Transportation Management Centers (TMC).
- Hubs.
- Roadside Controllers.

In this assumed hierarchy, command and control decision making responsibility can be assigned to the lowest effective level thereby minimizing the communications requirements and processing capability of the central system. It is assumed that the system wide command and control decisions will be made at the local TMC level since it will generally serve as the center for information collection and distribution for the local area, and will likely be collocated with the area's freeway management system, if one exists. In areas where a freeway management system does not currently exist, one would need to be developed, at least for the purpose of the AHS control system.

Each center would be staffed by system operators that have the capability to act in case of a failure or emergency which cannot be handled automatically by the system. Incident detection, environmental condition, and entry/exit decisions would be processed by the lowest level elements in the system, the roadside controllers. The hubs would serve primarily as communications hubs for the field network but could also assume some level of processing and control responsibility.

This system control configuration could apply to all of the RSCs under consideration by the research team. In RSC #1, where most of the intelligence lies with the system and the system possesses the greatest level of control over the vehicles, there is a greater need for communications between the central system and each vehicle and for processing capabilities at a central control site. Consequently, the communications requirements are more substantial for this RSC with concomitant needs for faster and more sophisticated communications devices, and computers with greater capacity to accommodate the processing requirements.

In this assumed system configuration, the primary functions of each of the local center's elements would be as follows:

- Local AHS TMCs would interface with or be collocated with the local freeway management centers and would accommodate all local travel control on the automated system. They would also be responsible for the exchange of information with other adjacent AHS system TMCs.

- Supervisory command and control of the AHS system would be performed at the local TMCs, including system monitoring, vehicle routing, position monitoring, incident management, maintenance planning and coordination, and failure management.

- Local TMCs would provide supervision of urban and/or rural areas. For example, one TMC may supervise the Washington, D.C. area, a second the Baltimore urban area, and a third may supervise the interstate freeway and AHS system which connects the two urban areas.

At the next level down from the TMCs are the communications hubs. Hubs would serve as the communications compilation and distribution points for information collected the field, including the data exchanged between the vehicles and the field controllers, and for the distribution of commands from the local TMC. In smaller geographic areas, the need for the communications hub may be obviated by the proximity of the local TMC to the roadside controllers.

Roadside controllers are at the lowest hierarchical level of intelligence in the system configuration. The Roadside Controllers would provide the means through which the central AHS system would communicate with all vehicles, with the local monitoring devices, and motorist information devices. Other functions which the Roadside controllers may perform include:

- Accumulate and process vehicle and traffic data.

- Perform malfunction and incident detection for the local area which it supervises.

- Control local motorist information devices (with the ability to override these devices residing with the local TMC).

The system would be required to control some elements of the infrastructure such as motorist information devices, e.g., changeable message signs; check-in devices; and other equipment outside of the control center. The communications subsystem would be made up of the devices which provide communications between the central and each vehicle, external AHS facilities such as check-in sites, and motorist information devices. The system would control the flow of information to and from the central control facility.

The field units which would communicate with the vehicles (in most RSCs) would be termed “roadside controllers”. The function of these controllers would be to oversee the operation of the AHS system in the vicinity of the controller including vehicle entry and exit. Check-in and check-out would be overseen by other units, possibly the same type of units as roadside controllers but with other functions.

Examples of functions which the roadside controller would perform are:

Data Collection:

- Accumulate and process traffic, weather, and AHS vehicle data including requests for entry and exit.

Data Processing:

- Calculate speeds, headways, volumes, and occupancies from field data,
- Identify incidents, unsafe weather conditions, and local malfunctions,
- Transmit sector status and sector vehicle information to hub,
- Process and respond to requests from hub, and
- Process and respond to requests for entry/exit.

Control Functions:

- Control local motorist information devices and CCTV cameras,
- Transmit command functions from the hub to each vehicle within the sector, and
- Accept or reject requests for entry/exit.

The exchange of communications between the AHS vehicles and the roadside controller is summarized in table 4. Other communications exchanges would occur between the roadside controller, the communications hub in the field, and the TMC. These exchanges are summarized in table 5.

Table 4. Communications exchange between vehicle and roadside controller.

Communications Exchange	Upon vehicle entering system and receiving inquiry from system entry sensors	Continuously while vehicle is in system	When vehicle is exiting system and upon request from the system
Vehicle to Roadside Controller	- vehicle identification (ID) information - status of on-board systems - driver status - destination and desired route	- vehicle ID - speed - any changes in destination or routing desired by the driver - any vehicle system malfunction information	- vehicle ID - driver status - vehicle status
Roadside Controller to Each Vehicle	- approval to enter system - maximum speed - minimum gap - optimum routing to destination based on traffic conditions, etc. - merging information where applicable, e.g., gap availability - assumption of control command	- incident, bad weather, congestion information - travel speed - changes in max speed or min gaps - changes in routing	- request for driver status - request for vehicle operation status - relinquishment of control to driver

Table 5. Communications exchanges.

Communications	Information/Data
Roadside Controller to Hub	- Vehicle identification information (ID) and status for all vehicles entering and exiting the system - Vehicle acceptance/rejection information for entry/exit - Destination and desired route for each entering vehicle - Vehicle malfunction information - Average speeds, volumes, and occupancies for each sector - Incident detection information - Status of motorist information devices - CCTV video - System element malfunctions
Hub to Roadside Controller	- Requests for data from the Local TMC - Vehicle specific communications for transmission to the vehicle and/or driver - Commands from Local TMC to motorist information devices - CCTV control commands
Hub to Area TMC	- All information listed for "Roadside controller to Hub" - Communications system status/malfunctions
TMC to Hub	- All information listed for "Hub to Roadside Controller" - Request for communications network status report

The primary function of the hub is to serve as the communications hub in the hierarchical system configuration between the regional center and the roadside controller. The differences between the information that is transferred between the roadside controllers and the hub and between the hub and the Local TMC is dependent upon the amount of processing and control decision making which is performed at the hub. If it is to serve strictly as a communications hub with no processing capabilities, the information exchanged would be identical except for probable differences in format. Some of the processing that might be accomplished at the hub level includes malfunction detection and the performance of communications system diagnostic testing. In the situation where vehicles are traversing between connected AHS systems controlled by different agencies, it is expected that the central system from which each vehicle is exiting will pass the requisite information to the next system such that the transfer will be accomplished seamlessly.

Monitoring of System Operation

The extent of this task includes monitoring the operation of the various components of the system including the automated control functions and safety systems. In all configurations, the system at some level will likely be required to monitor the status of all vehicles travelling within AHS lanes, and possibly on all entrance and exit facilities.

The monitoring task also includes the inventory function that will be performed by the system including keeping a running log of all vehicles in the system, their location, destination, operational status, and other related information. This function might be performed by a central computer system or by hub locations in a hierarchical system configuration. The extent of the monitoring system will be dependent upon the balance of intelligence between the system infrastructure or central system and the AHS vehicle. For a system in which the highway retains most of the intelligence (Smart Highway, Dumb Vehicle as in RSC #1), the monitoring and control functions which must be performed by the system will be extensive. As the amount of control responsibility shifts to the vehicle in the smart vehicle configurations, less control and monitoring will be required by the system itself.

The Monitoring Function Under Alternative RSCs: Under the scenario of RSC #1, it is assumed that the highway will possess most of the intelligence and that the equipment on the vehicle will operate primarily under the control of the central system. There would be communication devices on each vehicle through which the central system could communicate with the vehicle and the driver, and it is anticipated that there would be some level of intelligence on each vehicle such as anti-collision devices.

In this RSC, the infrastructure will be directing the movements of each vehicle in the system, including controlling the vehicle from the time it enters the AHS lanes until it exits. Each vehicle will be guided latitudinally and longitudinally meaning that the system will have primary control of the braking, acceleration, and steering of all vehicles. The system may additionally take over control of the vehicle while it is still in a transition lane, if applicable, immediately following its request to enter the AHS lanes.

In addition to monitoring the status of the roadway as will be the case in all of the RSCs, in RSC #1 sensors on the vehicle would also need to be monitored, and all control decisions would be made and implemented by the system. Due to the extensive monitoring and control functions associated with this configuration, it will place the maximum burden of all the RSCs on the central system and would require the most extensive computing and control capability. Consequently, it can be concluded that this RSC would require a higher level of maintenance and staffing and would incur the greatest overall operational costs.

As vehicles get progressively smarter with their own on-board longitudinal and lateral controls, the vehicle itself would perform its own on-board checking, and the system would then communicate with the vehicle to confirm that all on-board systems are operational. On-board systems might include engine control, vehicle diagnostics, braking, smart cruise control, anti-collision systems, and a communications system which would enable communications between vehicles and with the central control system via zone controllers.

For all RSC configurations, the AHS system will be required to monitor the condition of the driver to ensure that he/she is capable of proper operation of the vehicle when control of the vehicle is returned to the driver upon leaving AHS control. The system will check the driver's condition upon check-in before entrance is permitted, and then will need to check it again upon exit. It is not certain whether continuous monitoring is needed or justified. However, the vehicle must be equipped with devices that can evaluate the driver's ability to function and relate that information to the zone controllers while the vehicle is operating in the AHS lanes.

The central AHS system will monitor the operations of the field portion of the system for system failures including vehicle malfunctions, breakdowns, accidents, and other lane obstructions. Vehicles in the AHS lanes will be communicating with the infrastructure and will be able to notify the central system immediately of any failure or incident. Incidents that are not detected directly by the AHS vehicles and/or the system (e.g., an obstruction in the AHS lane), may come from evidence of stopped vehicles, vehicles exiting the AHS lane (such as using the shoulder), or other similar data. It is likely that incident verification techniques such as CCTV will be implemented on an AHS facility much as they are on freeways or that existing CCTV on freeways be jointly used by AHS and freeway management systems.

There would be no difference between the monitoring function to detect incidents for alternative RSCs. In the case of pallets, the monitoring will need to identify a slowdown or stoppage for the system to determine that an incident or other blockage has occurred.

Check-in and check-out functions will be performed by an element of the system and will also require that the central system monitor (as well as control) this operation. The check-in procedure will be conducted at specific sites and that these sites will report the approval of a vehicle's entrance into the AHS system to the central control system. At that time, the inventory will be updated and the monitoring of the vehicle will begin. The actual monitoring function then does not really begin until the vehicle enters the system. The communication between the check-in facility and the central system is not considered to be a monitoring function for purposes of this discussion.

Rural vs. Urban Monitoring Considerations: Although the configuration of the free-way and its AHS lanes in an urban environment is likely to be different than that for a rural section of freeway, it is not likely that these physical highway differences will impact the monitoring of the system and of the vehicles in the system. The same communications will need to take place between the central control system and vehicle for each of the RSCs whether the vehicle is travelling in an urban or rural area. There would be no difference between the monitoring function as long as the AHS lane is a designated AHS-exclusive lane.

Mixed lanes, even in the configurations where there is no physical barrier between AHS and mixed lanes, will probably not be monitored by the AHS system. There should however be a method for monitoring exclusive AHS lanes, especially those without barriers, for intrusion by non-AHS vehicles.

In the RSCs where there is continuous communication between the infrastructure and each vehicle, there would be no need for the type of vehicle detection that is commonly used in today's freeway systems, e.g., loop detectors and radar sensors. In AHS applications, the system will dictate and maintain vehicle flows and therefore will have no need to collect this type of data. It is expected that vehicle detector information from the mixed use lanes will continue to be collected by the freeway system and will be communicated directly to that central system separately from communication to the AHS central system.

Monitoring of incidents should be identical in urban and rural applications with the exception that verification might be more challenging in rural environs due to the distance covered by the AHS operation and the limited coverage of CCTV implying a number of installations for full coverage.

CCTV is the usual technique for incident verification in freeway systems and will likely also be used in AHS systems. However, it is not expected that there will be complete CCTV coverage of all rural segments of AHS or freeway facilities and therefore, verification will be dependent upon other means, e.g., highway patrol, notification by other AHS drivers or other eye witnesses.

A summary of the monitoring functions which will be performed by AHS systems is shown in table 6, System Monitoring Functions.

Table 6. System monitoring functions.

Monitoring Functions	Applications to RSCs	Urban vs. Rural
Status of on-board systems including driver status	Higher level of monitoring needed for RSC#1 than other RSCs	Same for both
AHS Lane Vehicle Inventory	Same for all RSCs	Same for both
Mixed lane vehicle flows	To be monitored by FMS and possibly AHS	Same for both
AHS lane—conventional vehicle detection	None except possibly for detection of non-AHS vehicles	None except for detection of non-AHS vehicles where no barriers exist (e.g.,rural)
Incidents	Same for all RSC's	Same except that verification more difficult in rural areas

In summary, an RSC that consists of Smart Highways and Average Vehicles will require a higher degree of and control than vehicles with intelligent systems on-board, and it is likely that they will also require a higher degree of monitoring. The monitoring task will probably be more extensive since the central system must not only perform all the functions that it would be performing in other RSCs, but also must provide all the necessary control functions for the vehicle that in other RSCs would be performed by on-board systems. In order to provide this control, the central system must first monitor the actual steering and braking, longitudinal and latitudinal clearances, and all the other functions that would otherwise be performed by the on-board systems.

The monitoring function is essentially identical for urban and rural applications except for (1) the increased need to detect errant vehicles in the AHS lane when there are no physical barriers to obstruct their entrance and (2) the greater difficulty that is anticipated in verifying incidents in rural areas.

Incident Management

Incident Management is a term used in freeway management system operations to describe the function of managing traffic in and around an accident or other incident on the freeway. This definition can be broadened to encompass the traffic management that is necessitated not only due to accidents or system failures, but also due to planned freeway or lane closures or planned maintenance activities. The term Traffic Management then becomes more appropriate than incident management. In this discussion of AHS incident management, the broader concept of Traffic Management will be addressed.

Four alternative approaches to system failures and/or incident management for an AHS system are identified in this analysis and are discussed in this section of the report:

- Eliminate system failures of designing the system for totally failsafe operation.

- Accommodate incidents through traditional incident management with incident management teams working with the highway patrol to provide alternate routing and rapid incident removal.

- Provide incident removal though automated removal of obstructions, possibly using robotics.

- Provide automated alternate routing in conjunction with innovative roadway configurations.

In an ideal failsafe design, an AHS system would never experience any downtime due to failure or for maintenance requirements. In the first scenario above, the concept precludes any failures by providing a failsafe design. Realistically however, there is probably no way to totally eliminate incidents or system failures. Even if the central system and the other hierarchical components of the AHS system under the control of the operating agency are designed to perform in a failsafe manner, there are still those elements which will be outside of the control of the system (the vehicles themselves) that could fail. (This premise is based on the assumption that AHS vehicles will be privately owned and maintained.) Therefore, the response to these failure conditions needs to be planned.

One of the related functions that will be performed by an AHS control center will be to manage the traffic in the AHS lane and those vehicles attempting to enter the facility during periods of incidents. In freeway systems, this function is most often overseen by the control center staff. Traffic Management or Incident Management Teams are dispatched by the control center operators to the scene of the incident. Their goal is to minimize congestion and delays by attempting to keep traffic moving and by removing the incident as quickly as possible. Typically, the enforcement agency (usually a highway patrol) assumes command of the incident scene, and the traffic management team supports their activities. The team plans alternate routes and implements traffic control to route traffic around the incident. Usually the responsibility for arrangements for removal of the incident are assumed by the enforcement agency on the scene.

Freeway system traffic management teams also usually fulfill the role of developing and implementing alternate routes for planned lane and freeway closures. At most departments of transportation (DOTs) which are interviewed during the conduct of this study, team members have full time jobs in the agency (the DOT) working in or with the control center, planning alternate routes, or performing related activities. They are generally on-call during their off duty hours.

In addition to Traffic Management Teams, freeway management systems often employ roving service patrols to drive the freeways, especially during peak periods, looking for disabled motorists and assisting them to leave the freeway. These patrols are usually equipped to be able to handle minor repairs, provide gasoline, change a flat, or provide a tow. Although they are typically not trained in traffic control and management, because they are already in the field they often are able to respond to incidents more quickly than the traffic management team.

The rapid transit system which was interviewed for this project (BART) also utilizes incident management teams. Their teams consist of maintenance and repair personnel as well as operations staff. The goal of the rapid transit team is to get the trains moving again as quickly as possible and to move passengers. Their strategies include rerouting trains around the disabled train, or if that is impossible, using alternative modes of transportation such as buses to move the passengers. In addition to team members which are on-call in case of an incident, BART maintains a type of roving patrol consisting of roving technicians which continuously ride the trains on specified routes so that, in case of incident, someone will likely be close to the incident thereby minimizing their response time.

The approach to incident and traffic management for AHS systems will be patterned after the freeway and rapid transit systems that exist today. Although it is likely that incident management teams will continue to fulfill a role in traffic management in AHS systems as they do for freeway systems, it is unlikely that role will be as significant or critical to the operations of the facility. This estimation is in part due to the expected high cost of providing the rapid response times that will be required for AHS and also due to the expected diminished role for incident management teams because of the probable extensive use of automation to provide route diversion. New strategies will be developed to accommodate the unique conditions that will exist with AHS. These new strategies will probably include team responses to incidents, alternate routing, traffic control, and incident removal; however, in a structure that will better serve the needs of AHS.

Types of Incidents: There are three primary categories of incidents which will require management of the AHS lane(s):

- System downtime.
- Vehicle breakdowns which cause a blockage of the AHS lane or the shoulder.
- Vehicle collisions.

System downtime may be planned or it may result from a system malfunction. An incident might be a collision, between two or more vehicles or with another object, or it might be a breakdown of a vehicle such as may be caused by a flat tire, a vehicle fire, or any other event which causes the vehicle to come to a stop or otherwise not be functional. Collisions may result from the intrusion into the AHS lane by manual vehicles or failure of one or more functions on an AHS vehicle resulting in a collision with another vehicle.

System Downtime: There are two circumstances under which an AHS system might experience system downtime:

- System failure.
- The need to perform emergency or routine maintenance.

An incident on a large scale would be the failure and consequent shutdown of the entire system. A catastrophic failure would cause total shutdown of the system. It is desirable for the system to be designed to go through what is commonly termed a “graceful degradation” in case of catastrophic failure. This transition between total control of the vehicles in the AHS lane and no control must be accomplished gracefully, meaning that the drivers of AHS vehicles must be alerted that they need to assume control of their vehicles, and the system needs to continue control of the vehicles long enough to bring them to an operating condition which is similar to normal freeway driving so that drivers can comfortably and safely assumed control. For purposes of this analysis, it is being assumed that the system is being designed to provide this form of graceful degradation.

In conjunction with the control of the vehicles being relinquished to the drivers in a safe manner, there must be a means for managing the AHS lane and its traffic during such an occurrence. The AHS vehicles will need to be diverted from the AHS lane safely and efficiently, and no new vehicles can be allowed to enter the lane through the check-in facilities. The means for providing traffic diversion is discussed in later sections of this report.

A second possible situation which would cause the system to be down is for maintenance, either preventive or for repairs. Planned maintenance would result in an orderly shutdown of the system with drivers having been given ample notice that the lane will not be operational or operational at a reduced level. System failures on the other hand will result in the system shutting down without notice to operators or drivers. The requirement for maintenance on the system is discussed in a later section of this report.

In lieu of bringing the system down totally in order to perform maintenance on the system or for other planned shutdowns, there is the possibility that some intermediate level of surveillance and control can be retained. This reduced level of control may for instance only provide vehicles with control commands related to vehicle operations and may not provide for route guidance or keep a running inventory of all vehicles in the system. Safety related functions such as check-in and system monitoring would need to be continued at any level of operation.

Disabled Vehicles: A vehicle which breaks down in the AHS lane will cause a blockage and consequent disabling of the operations in the lane. As with operations on today's freeways, with a shoulder adjacent to the AHS lane, many breakdowns such as result from a flat tire, can be removed from the driving lane to the shoulder.[1] Other types of

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[1] Due to the anticipated operational difficulties that could result from an AHS system design that omits shoulders, it is assumed for purposes of this discussion that all RSCs will have shoulders adjacent to the AHS lane. Shoulders would provide (1) a place to store snow during snow removal, (2) room to maneu-

vehicle failures may cause a vehicle to stop or to otherwise not be able to maintain speed, gaps, or lateral position. Regardless of the cause of the failure, there will be instances where vehicles are not able to be removed easily and consequently block the lane for some period of time resulting in a significant disruption to flow in the AHS lane.

In any case where the AHS lane is blocked or partially blocked causing a restriction to normal AHS traffic flow, an alternative means or route for handling the traffic will be needed, and an expeditious procedure with suitable equipment for removing the incident will be required.

Although it cannot be expected that disabled vehicles can be eliminated entirely from an AHS system, their numbers will be reduced from today's freeway experience.

According to records obtained from the California Department of Transportation (Caltrans), 88 percent of the incidents which occur on urban freeways are non-accident incidents. Approximately 45 percent of these disabilities are caused by failures of some component of the vehicle's mechanical, electrical, or cooling system. AHS systems will be designed to minimize the probability of such occurrences through its check-in requirements. Entry check-in requirements for the AHS system will prevent any vehicles that have operational problems from entering the system. Such conditions as tire pressure, oil and fuel levels, and temperature levels will be self-monitored by the vehicle and checked by the AHS system prior to entry into the AHS lanes. Vehicles which do not pass the entry test requirements will be rejected. It is expected therefore that there will be considerably fewer vehicle breakdowns from that which is experienced on today's freeways.

<u>Vehicle Collisions</u>: The AHS system will be designed to virtually eliminate the possibility of a collision between two vehicles under AHS control or for an AHS vehicle to collide with an object outside of the AHS lane. There is still the possibility however of a collision occurring between an AHS and a non-AHS vehicle or with an animal or other object which has errantly entered the automated lane.

The possibility of a collision between an AHS and non-AHS vehicle is all but eliminated in the RSCs where there is a physical barrier between two sets of lanes, but regardless of the configuration, there is still the possibility of failure of the on-board functions of an AHS which results in a collision with another vehicle, an animal entering the lanes and causing an accident, or for another type of obstruction to accidentally be dropped into the lane.

Although ideally, AHS systems will be designed to be failsafe and never experience any downtime, it is realistic to assume that some form of system failure, vehicle breakdown or collision will occur, however infrequently.

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ver around a blockage in the AHS lane, and (3) a place where disabled vehicles can be temporarily parked.

It should be noted that at BART, which is a highly sophisticated rapid transit system carrying thousands of passengers each day, the management staff acknowledges that, no matter what precautions are taken and no matter how failsafe they try to make the system, there will be downtime of the system. Their efforts are therefore aimed at minimizing that time and at keeping the passengers moving. For purposes of this discussion on AHS operations, it was assumed that incidents will occur resulting in some amount of system downtime, and that the goals will be to minimize that time and to minimize the disruption to AHS operations that is caused.

Having assumed that there will be downtime of some extent, the issue then becomes "what actions can be taken to minimize the effects"?

The actions should be directed at minimizing the downtime and alleviating the roadway congestion by developing a rapid response strategy that will minimize the time before the rerouting of traffic is implemented and/or the incident is removed.

The Need for Rapid Incident Response: The need for rapid incident response is generated by the expected buildup of congestion that will develop following an incident during the time it will take for alternate routing to be implemented and for removal of the incident from the travel way.

It is estimated that every minute of blockage of lanes by an incident on a freeway systems leads to five minutes of delay per vehicle on today's freeways. In an AHS system operating at capacity where the capacity of a lane might be two to three times the volume in a non-automated freeway lane, and headways are less than a car length at speeds higher than traditional freeway speeds, the queue behind an incident could almost instantaneously be unacceptably long.

If the incapacitated vehicle can be moved to the shoulder, normal operations of the AHS can be resumed as soon as the blockage is cleared with removal from the shoulder reserved for an off peak period. However, if the disabled vehicle blocks the AHS lane and cannot be moved to the shoulder, normal operation of the system cannot commence again until the blockage is eliminated.

In the case of barrier separated AHS lanes, under present design schemes there would be limited rerouting for the queued AHS vehicles except at exit ramps and, if the blockage permits it, around the incident on the shoulder. In RSCs with transition lanes or non-barrier separated lanes, vehicles could try to find their own way out of the AHS lane.

This situation creates its own problems with potential safety hazards resulting from lane changing maneuvers that might not be safely executed. Unsafe maneuvers would likely occur when AHS vehicles first go into manual mode and attempt to enter the manual lanes. They would be starting from a stopped position, attempting to change lanes and merge into a platoon of manually operated vehicles on the freeway traveling at typical freeway operating speeds. The longer the time to remove incidents and return the facility to normal operation, the longer the hazardous conditions might exist.

Those investigators who are studying the safety aspects of AHS suggest that AHS vehicles should be diverted only under automatic control of the system. Where automatic control is not possible, the vehicles should only be permitted to move under the direction of traffic control personnel. Automated diversion of AHS vehicles will be treated in a later section of this report which addresses innovative approaches to incident management.

Response Times: The response times in this section refer to the time it would take for an incident management team to arrive at an incident site. There are other responses, discussed in later sections of this report, which may be implemented by AHS system operators or automatically by an AHS system which would not involve dispatching a team to the accident site.

Typical average response times by traffic management teams in today's freeways systems are in the range of 5 to 20 minutes depending upon the agency, the extent of the freeway system, and existing traffic conditions. To reduce response times, it would be necessary to station teams at strategic locations throughout the freeway network. The same logic holds true for response times for AHS response teams. To provide a guaranteed five minute response time, teams would need to be stationed at approximately five mile intervals along the network and would need to be ready at all times to respond to calls. Unless resources are shared between a freeway management operation and an AHS management operation, the costs to provide this coverage would be prohibitive; and, therefore, alternative means for handling incidents would need to be identified. The shared resources concept has validity because the jurisdiction responsible for maintaining the freeway system management is likely to be the same jurisdiction responsible for AHS operations, at least at the local or regional level. If these jurisdictions are not the same, shared resources may still be pursued as the only economical means of accomplishing both jurisdictions' goals effectively.

Figure 8 illustrates the level of staffing that might be required to provide various levels of response time by incident management teams for an AHS facility. The response times on this graph assume that teams would be placed at regular intervals along the length of the facility in order to be proximate to the potential events. The more rapid response times would require that teams be more closely spaced and that there be more teams available to respond at any given time.

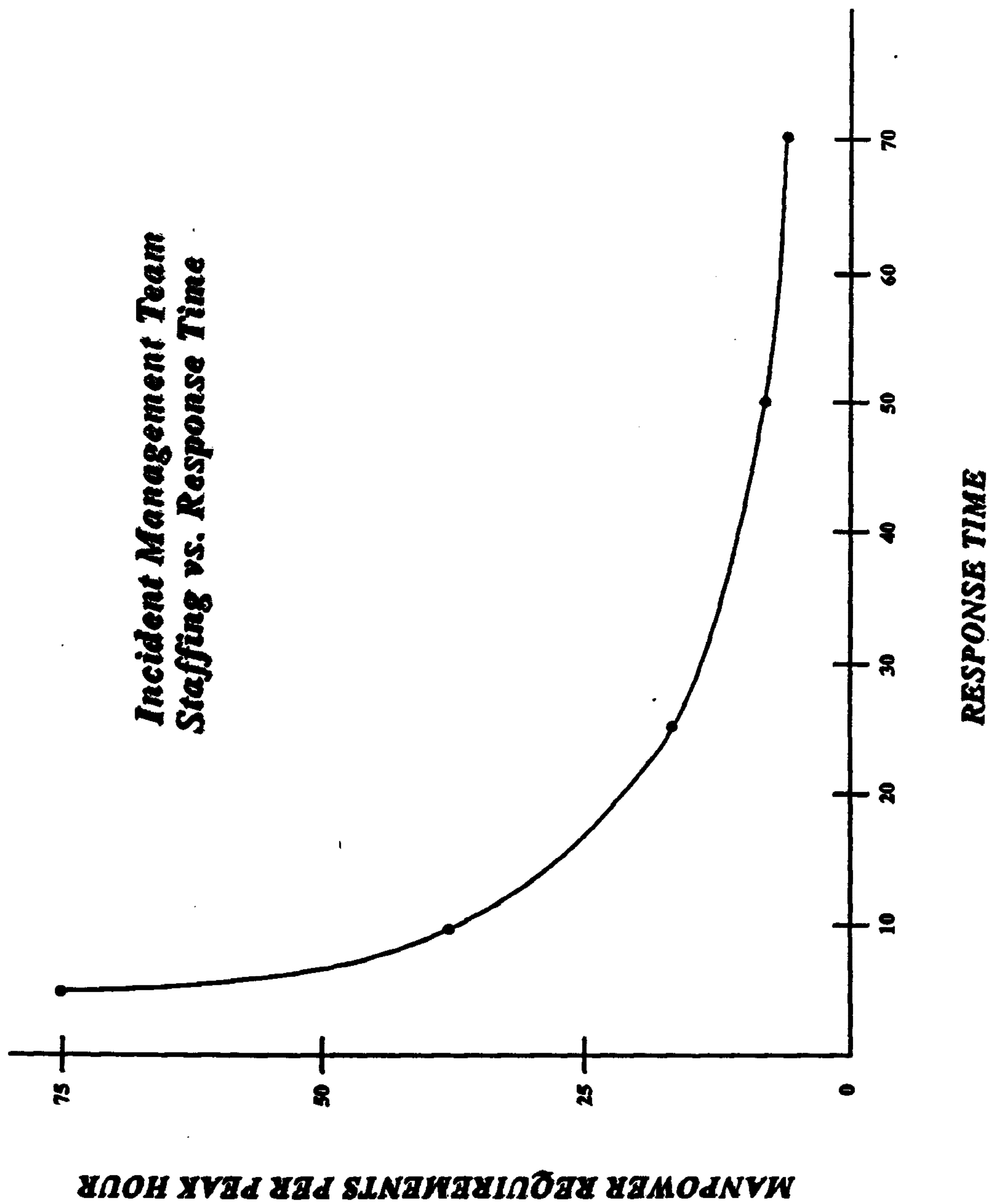

Figure 8. Incident response staffing.

The staffing estimates for figure 8 were derived based on the following assumptions:

1. The network contains 250 miles of AHS lanes.

2. Incident Response teams consist of three persons.

3. Teams are spaced along the AHS facility to allow them to respond within a specific amount of time. For instance, with teams spaced 10 miles apart, a response of approximately 10 minutes is estimated.

It should be noted that the primary response agency is usually the highway patrol and not DOT traffic management teams. In fact, not until it is determined by the freeway system operators that the incident is a major one is the traffic management team usually dispatched. Also, because highway patrol officers are patrolling the freeways, their response time is typically much less than that of the traffic management teams. These factors all lead to the conclusion that the response of the traffic management team is not a critical element in handling incidents on freeways, but rather, that the effectiveness of the role played by the teams is in the support service they provide to the agency in primary charge of the incident.

Although there is a definite need for quick action in freeway operations in response to incidents, the need is significantly greater for an AHS system. Consequently, there cannot be the reliance on incident management teams in AHS applications that there is in today's freeway systems.

In terms of an AHS system, the incident management team concept could assume the same role and provide a valuable service in diverting traffic around an incident when appropriate. Recognizing however that in an AHS lane, congestion will build much more rapidly than in normal freeway lanes, the role of the incident management team is diminished in importance. The first line of attack at accommodating incidents on AHS facilities needs to be strategies or procedures that have the ability to respond more quickly than today's incident management teams. Greater emphasis needs to be placed on innovative technologies and strategies that will provide, for example, for the automated rerouting of traffic and the expeditious removal of any blockages.

Innovative Approaches to Incident Management: There are two strategies or approaches to incident management that are identified earlier in this section that should be considered for application in AHS systems:

- The use of robotics for incident removal.
- Automated rerouting of traffic from the AHS lane.

The first of these alternatives utilizes robotics for the removal of disabled vehicles which are blocking the AHS lane and/or shoulder lane that would be otherwise used by AHS vehicles seeking to bypass a blockage in the through lane. The use of robotics is particularly applicable to the pallet RSC where vehicles would not be able to operate under their own power to bypass any lane blockage.

The robotics concept was developed by researchers at the University of California at Davis who are expanding this concept under contract to the FHWA on this Precursor Analysis project. The applicability and viability of using robotics will lie with the speed at which the robotics can be deployed to remove the offending vehicles and the associated costs to locate the system at strategic points throughout the network. Assuming that the robotics design is fast and efficient at removing incidents, there will still need to be other complementary strategies employed to minimize delay and congestion in the AHS lane.

One alternative which would relieve congestion in the AHS lane during an incident would be to provide a relief valve to allow vehicles to exit from the lane expeditiously in the event of a downstream lane blockage which also blocks the use of the shoulder. Under current designs, the only exit from barrier divided exclusive AHS lane is at the regular exits. The spacing of these exits cannot be estimated here with any likelihood of accuracy, however, a one mile spacing is reasonable to assume. There is therefore the potential for creating a one mile solid queue of vehicles which has no means of escape if no other provisions are made for allowing the traffic to exit from the lane.

A relief valve could be designed into the system which would open gates or other devices in the barrier automatically in conjunction with the detection of an incident. Other devices in the manual lanes would also need to be deployed which would direct manual traffic out of the lane adjacent to the AHS lane in order to free it for use by entering AHS vehicles. Changeable message signs and lane control signs could be used to inform the manual motorists of the lane use changes, and in road pop-up barriers or other physical lane control devices could be implemented to divert traffic out of the adjacent lane. These actions could all be implemented automatically or remotely by an operator at the control center who can observe the operation via CCTV surveillance. Gates could be opened downstream past the incident to allow vehicles to reenter the AHS lane, or they could be forced to exit the freeway and only reenter the AHS lane through another check-in.

The diversion of AHS vehicles from the automated lane through relief gates should be accompanied by the automatic diversion of AHS vehicles upstream at the normal exit ramp locations. This diversion could be accomplished through electronic lane control signing supplemented by changeable message signs.

A similar automated diversion technique could be applied to other RSC configurations which no not have physical barriers; for instance, the pop-up barrier type devices could be used to divert manual traffic from the AHS adjacent lane and to direct AHS traffic into it and around the downstream incident. This strategy would be safer than allowing AHS vehicles to merge indiscriminately into the manual lanes. Both strategies would need to be supplemented by changeable message signs, lane control signs, and/or other notification of lane assignments. All of these types of operations should be monitored by system operators through the use of CCTV cameras.

None of these diversion strategies would have application with the pallet RSC because the pallets would not operate under their own power to maneuver, for instance, around obstructions. As mentioned above however, the robotics concept might work well with the pallets.

It should be noted that the above incident management strategies could all be automated and could be implemented without the assistance of an incident management team. The role of the team in these circumstances would be to assist any vehicles remaining in the AHS lane which could not be accommodated through relief gates or on the shoulder. The teams secondary responsibility after relieving congestion on the facility would be to assist in the rerouting of traffic on the surface streets which would not have the benefit of the diversion being as automated as the AHS and freeway facilities.

With regard to urban and rural applications of the diversion strategies, they are probably more applicable to the urban environment where it is expected that volumes will be greater and merging into a manual lane would be more of a challenge than in low volume rural conditions. Also, it is unlikely that the barrier divided RSC would be deployed in a rural setting, and therefore that diversion strategy would not be applicable.

Maintenance

The maintenance function will affect the operation of an AHS system from the aspect of the system needing to be brought down to perform maintenance on the equipment or alternatively, to perform maintenance on the roadway itself. For the RSC that employs pallets, maintenance considerations will also apply to the maintenance of the pallets themselves.

Many system experts agree that there should be no need to ever take the system down for maintenance if it is designed correctly. Others disagree and believe that there will likely be some time during the life of the system when there will be a need to bring it down for maintenance. Still others believe that there will be a need for a periodic schedule of system maintenance necessitating that the system be brought down on a regular basis. A fourth possibility is that the system may be brought to a condition of partial operation where vehicles are still able to use the facility but at a lesser degree of system control and interface.

If the operation of the AHS system is terminated for whatever reason, the system will need to be brought down through the same graceful degradation as was earlier discussed. However, with a planned system shutdown, the shutdown should be able to be accomplished with advance notice to drivers that the system will be down providing an extra margin of safety. Especially if maintenance is performed on a regular basis, notices to drivers can be publicized continuously through the media, signing, and published notices.

Although rapid transit systems and AHS systems are not directly comparable, the levels of sophistication of their system control, control centers, and operations have distinct similarities. It should be noted that BART and other rapid transit systems do conduct regularly scheduled system maintenance and that the system is brought down for this maintenance. These maintenance procedures are scheduled for nighttime hours when the trains are not running, and major maintenance is performed over Saturday night and Sunday morning (trains do not begin operations until late Sunday morning).

At BART, there is sufficient need for regular maintenance for the management to have adopted this schedule. Maintenance on BART is performed on the infrastructure, including the electrical system which is the heart for all operations. Whereas an AHS system will not have the high power electrical system that is needed by rapid transit or the track system which is subject to wear and failure, there will be elements of the AHS system such as the pavement that will need periodic maintenance. The central computer and communications systems may be designed to eliminate or at least minimize maintenance, but there will be some elements of the system that will require closure of the AHS lanes to provide maintenance. Consequently, the system design needs to include provision for this maintenance to be conducted safely and quickly.

There are unique maintenance considerations for the pallet RSC. Special maintenance programs will need to be developed and facilities will need to be constructed in order to maintain the pallets. The design of the pallets, both its failsafe aspects and the complexity, will define the extent of preventive and repair maintenance which will need to be performed.

The infrastructure that will be required to operate the pallets will also be distinctly different for this RSC than the others. The result is that alternative maintenance procedures will be required and will need to be developed. Due to the need to maintain the pallets themselves and their supporting infrastructure, unlike a concept which puts a portion of the maintenance burden on the vehicle owner, the maintenance staff and facilities which will need to be provided in this RSC are significantly greater than other RSCs.

<u>Reporting</u>

The reporting function of an AHS system pertains to the development of reports by the system itself. The reports should encompass the entire range of system operations including:

- Vehicle information including inventory data, lane usage, number of rejected vehicles, origins and destinations, malfunctions, and volumes.

- Lane operational data including average speeds for time intervals throughout the day, gap data, and incidents and causes.

- Equipment operations including all failures of communications equipment, computers, and field hardware.

- Incident analyses including responses, automated and other system operations including any malfunctions, status changes, and operator input commands.

- Status of motorist information devices and any changes in messages, etc.

The reporting function also includes the generation of reports for the media, providing them with information regarding traffic conditions just as freeway management systems provide traffic reports during peak hours or whenever there is an incident. Interfaces between today's freeway system and the media cover the spectrum with regard to sophistication and amount of data provided. Some media interfaces are via computer links between the control center and a media computer terminal, and some centers still convey information to the media via telephone contact. It is expected that the design of a system as sophisticated as the AHS will be will incorporate a relatively advanced form of communication with the media that will require a minimum of operator intervention.

AHS Control Center Operations and Staffing

This section of the presents a discussion of the control center and staff which will oversee the operation of the AHS field operation and which will dispatch field and maintenance personnel as necessary.

Operations and Staffing

The functions performed at the control center for an Automated Highway System are expected to be similar to the functions which are performed by operators in today's freeway management centers or other sophisticated control centers. The operator's role is typically to complement the automated operation of the system by providing the human decision making element when the need for problem resolution exceeds the automated capabilities of the system.

Most of today's freeway management systems are automated and require little input from operators except for incidents or malfunction emergencies. The same is true for automated rapid transit systems, e.g., BART. Both types of systems function normally without human inputs. It is anticipated that AHS systems will operate similarly, i.e., in a fully automated fashion without the need for operator intervention under normal conditions. However, when normal operations are interrupted, there will likely be the need for human decision making skills.

System Operators

The role of operators in freeway and rapid transit systems researched for this study is to monitor the system and be ready to intervene and take appropriate action in case of emergency or major incident. In all cases, the system operators have other tasks to perform outside of monitoring the system.

Typically operators are assigned to other special projects related to the operation of the system and work on these projects when the system is operating normally. The operators' real expertise and responsibilities come into play when there is an emergency or an incident. Then they must be trained to take the appropriate action to:

- Handle the emergency.
- Assign the responses to the correct emergency units and/or response teams.
- Interface with enforcement agencies, maintenance personnel, and the media.
- Continue these functions until the problem is cleared.

In the case of freeway systems when an incident occurs, the operators determine if the incident management team is needed and if appropriate, alert the team. Operators interface with the highway patrol and summon emergency units as needed. Their objective is to minimize delays and congestion. Sometimes this objective can be accomplished through route diversion which means that the operators must alert the motorists to the problem and possibly identify alternate routes. These are all functions which present day freeway management systems do not perform automatically and therefore human intervention is required.

Rapid transit system control center operators have a similar role in that they monitor the operation of the trains and perform other routine system related tasks during the course of a normal day. They always remain available however to handle a system malfunction or incident which requires their attention. Typical malfunctions are train or electrical equipment failures. The operators' roles then become to dispatch maintenance crews or other emergency personnel or units and to attempt to reroute trains to minimize passenger delays. In the cases of both the freeway systems and the transit systems, the operators' roles involve minimizing disruption to the operation of the system by performing functions which are not currently or cannot be automated.

It is expected that AHS system operators will have a similar role and perform comparable functions; however, it is also anticipated that an AHS system will make use of the most sophisticated software available including expert systems thereby minimizing the need for operator inputs. The system operators will only be expected to assume a decision making role when the situation requires a response that is beyond the capability of the system to determine and to implement. An example of such a situation is if an incident occurs in the AHS lanes of a facility such that the lanes are blocked. The system may not be able to determine the exact cause of the failure or the blockage. In that case, operators would use CCTV cameras to view the incident to determine if there are injuries and the extent of any damage to the vehicle(s) or infrastructure. Also, the type and number of crews and/or incident management teams to be dispatched would be determined by the operator depending upon the severity of the accident.

While the system will be able to determine that a failure does exist and that a vehicle removal team probably needs to be dispatched to the site, additional input which cannot be obtained directly from the system's monitoring system is required to determine the need for ambulances and other services. Other actions that will likely be required by the operator will be to:

- Review and approve messages to be displayed on variable message signs.
- Develop and/or approve messages to be broadcast by an HAR system.
- Coordinate media interfaces including the generation and transmittal of electronic messages.

Some of the more routine functions which freeway systems operators perform today and which will likely be a part of an AHS system operator's duties include:

- The preparation of system status reports, malfunction reports, end-of-day summaries, weekly and monthly summaries, and other reports as requested.
- Maintenance of the system log.
- Reporting to the media (or maintaining the equipment interface with the media, depending upon the level of sophistication of the system itself).
- Interfacing with the freeway management system central control facility and with the highway patrol and/or other enforcement agencies.

Even if the freeway management system is collocated with the AHS system, it is unlikely that the same operators will be used to supervise both systems, and therefore a certain degree of interface and exchange of information will be required of both.

As a result of interviews with various management personnel at five freeway management centers at three different State Departments of Transportation[2], it was concluded that the functions performed by the operators at these centers vary widely. They vary not only between DOTs but also between Districts within DOTs. The differences are a matter of historical preference and management philosophy. On one extreme of the function spectrum is the situation where the control center staff handles all functions related to lane closures, permits for lane closures, traffic control for maintenance and planned lane closures, and other routine functions including emergency operations.

While the operators at all freeway system control centers handle emergencies and incidents, it is the related work that is handled by staff persons at some centers that varies widely. There is no reason to believe that these staffing and task assignment differences would be any different in an AHS application unless there are standards developed and

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[2] Caltrans, District 7; Caltrans, District 12; Caltrans, District 11; Minnesota DOT; Texas DOT.

staffing guidelines established for the functions which are to be performed by AHS control center staff. Since one of the goals of the Intelligent Transportation Systems (ITS) program in general is to achieve some level of standardization in applications so that the proverbial wheel is not reinvented for every new system, it is reasonable to assume that the standardization of other aspects of ITS systems such as personnel requirements and staffing might also be desirable. These standards will need to be developed in conjunction with the design and development of the central system.

Since it is expected that AHS system design will be standardized, and that all systems implemented in this country will be built according to these standards, system functions will be standard as will be operator functions. In conjunction with the system design, staffing levels should be defined for the standard AHS system. It can therefore be anticipated that staffing levels will be determined for all AHS systems which are deployed, and that staffing requirements will be in direct proportion to system size. The absolute number of operators and other personnel positions required to staff an AHS control center should be the subject of a rigorous analysis which takes place in conjunction with the system design task.

System Operator Skill Levels

An aspect of the control center staffing issue which needs to be addressed in detail is the skill level associated with the operator function and for other personnel at the control center. At the freeway operations centers which are surveyed in this study, the education level of system operators ranged from degreed transportation engineers to non-degreed computer technician with two years of college or two years of related engineering technician experience.

Degreed engineers are generally shift leaders or supervisors in the control centers. In all agencies which are interviewed, on-the-job training forms an important part of an operator's education although formal programs of training are not implemented. For the future AHS systems, due to expected advanced technological aspects of the system, it is anticipated that formal training for operators will be a necessity and that some prior experience in systems control, preferably freeway systems, will be required for entry level personnel.

It should be noted that system operators at the BART control center began their tenure as operators only after having been train operators and having had experience in the day-to-day operation of the system. It was the opinion of management that the position of system operator required a considerable amount of experience with the system and that no amount of classroom training could fulfill that need. AHS control center operations will be at least as complex as those for a rapid transit system, but there will be no test bed for training new AHS systems operators during the early implementation efforts. Consequently, some allowance for learning curves should be considered when defining roles and staffing requirements for the early deployments of AHS.

Other Control Center Functions and Personnel

Roving Patrols: In addition to the system operators which will monitor the system and ensure its continued safe operation, it is expected that there will be complementary functions conducted by other personnel within the center. The identification of these functions in this report was based on using freeway and rapid transit systems as examples. For instance, both types of systems use the concept of roving patrols. In the freeway systems, these service patrol vehicles are usually tow trucks which drive the network looking for disabled motorists, and on rapid transit systems, roving maintenance personnel ride the trains in anticipation of maintenance problems. In both cases, the purpose of the roving patrol is to provide reduced response time to handling problems in the network, and both functions are based at the operations control center of their respective systems.

Typically, a dispatcher is in charge of dispatching roving patrols or coordinating the activities of roving maintenance personnel. The dispatcher may or may not have other dispatch duties, for example, the dispatch of other maintenance personnel. Placing these functions in the same center with the system operators enables direct communications between these personnel without the need for telephones or other interface devices.

It is expected that a similar function will be defined and implemented in an AHS system where roving AHS vehicles are in the field and coordinated by a dispatcher at the control center. Roving patrol dispatchers in freeway and transit systems occupy positions at the control center where they can be in voice contact with the system operators. A similar arrangement is proposed for an AHS system.

The numbers of roving patrols that are in the field at one time should be based upon the demand for the services of such a patrol. It is also expected that there will be freeway system roving patrols in operation in addition to the roving patrol for the AHS system. It is possible that the two functions can overlap and that a freeway roving patrol might be able to assist an AHS vehicle. In the case of a barrier divided RSC, it might be more difficult for an AHS vehicle to obtain assistance across the barrier from a freeway service patrol and vice versa.

Incident Management Teams: In addition to roving service patrols, freeway management systems frequently use incident management teams whose function it is to manage traffic and to reduce congestion due to the incident. Usually, incident management teams (or IMTs) are asked to respond only to major incidents. In Los Angeles, for instance, a major incident is one which blocks two or more lanes of traffic for two or more hours. The IMT will assist the highway patrol at the scene to divert traffic around the incident. This task frequently means the use of traffic control devices such as moveable changeable message signs (CMSs) to direct traffic to alternate routes. The team will also assist in the coordination of efforts to remove the incident and perform other functions which expedite the return to normal traffic operations.

Teams are typically comprised of three members with a team leader. Usually all team members are provided with vehicles, some with portable CMSs, and others are equipped with communications devices to provide links to the control center, highway patrol, and emergency services. Team members are usually regular DOT employees who are on-call to provide the incident management function. In larger urban areas where there is a greater demand for the services of an IMT, there are sometimes personnel who are assigned exclusively to this function.

When they are not involved in managing an incident, the duties of dedicated incident management team personnel in typical DOTs usually revolve around other aspects of traffic control for special or planned events. Usually these personnel are stationed at the control center. On-call team members are often drawn from other sites (such as maintenance facilities) which can provide better response time for the incidents which occur near these sites. On-call team members are usually volunteers who have other job assignments and who receive overtime pay for any call-outs outside of their normal working hours. Dedicated incident management team members usually work overlapping shifts so that all peak hours are covered.

It is expected that in AHS applications the role of incident management teams will be smaller than that which it is in freeway systems. One of the primary functions of IMTs is to implement the diversion of traffic around incidents until the accident is cleared. One factor in the effectiveness of IMTs is their ability to respond to incidents rapidly before congestion has time to build. In freeway systems where per lane volume levels are much lower that those expected in AHS systems, the response time is not as critical as it would be for an AHS system.

Since response times needed for AHS in order to prevent congestion build up need to be in the range of seconds instead of minutes, a better response to the traffic diversion problem for AHS will be to automatically divert traffic upon detection and verification of an incident. This solution is discussed in more detail in an earlier section of this report (Innovative Approaches to Incident Management). It is anticipated that IMTs associated with the freeway system wherever AHS systems are deployed will assist in any AHS incidents and that separate IMTs for AHS may not be necessary or effective.

Another function which will likely be dispatched from the AHS control center is field equipment maintenance. Typically in freeway systems, electronics maintenance crews are dispatched from the control center, and major highway maintenance (e.g., for pavement) is dispatched through a separate dispatcher located elsewhere. It is probable that maintenance of field equipment such as communications devices, roadside controllers, and other electronics in an AHS system will most effectively be coordinated through the control center.

Planned maintenance for pavement and other infrastructure that will require that the AHS lane be closed needs to be coordinated with the control center operators. This coordination is simplified when the dispatchers are nearby the operators, and they can relay the information directly to those who need it. The dispatcher who handles this function might be the same one who dispatches electronic maintenance personnel.

Summary: If the AHS control center is collocated with the freeway management system, some of the functions which have been identified may be duplicated in both systems. For instance, electronic maintenance may have one dispatcher for each system. It may be possible to combine these positions into one. The same is true for the dispatcher who handles the roving patrols for both systems. Also, when the two systems are collocated and can coordinate operations, there will probably not be a need for separate incident management teams or service patrols. The following estimates however are based on the lone operation of an AHS system, and they include the support functions that would likely be associated with its operation.

The following section provides estimates of staffing needs for control center operations for an AHS system. The estimates assume that the control center operates as an independent unit and that all staff are dedicated only to the AHS system. As will be discussed later in this report, it is likely that AHS center facilities and staff will be shared with existing freeway system control centers which will have the effect of reducing the total number of staff for both system operations. The estimates in the table 6, AHS Control Center Staffing, however reflect only AHS operations.

The staffing estimates are developed based on an extrapolation of data obtained from freeway management system staffing averages. The staffing was approximated based on the supervision and control of 250 miles (400 kilometers) of urban AHS lanes. For purposes of comparison, the range of number of staff persons assigned to freeway management systems positions for facilities of comparable length is also presented. The high and low numbers represent the largest and smallest number of staff members which are employed in the freeway management centers which are interviewed in the conduct of this study for systems of comparable length.

The basis for comparison of the staffing levels of the two system types was the number of freeway miles and the number of AHS miles rather than vehicle-miles of travel or lane-miles. Some of the rationale for using these numbers are that the surveillance of highways is by segments, not lanes, and that the response time to the site of an incident is dependent on the milepost location, not the lane number. Both the surveillance function and the incident management function will be factors in the number of staff members that are required to operate an AHS system, and therefore, the miles of facility provides a reasonable parameter on which to base a comparison.

The number of system operators that appears in table 7 is based on an estimated need of one operator for each 50 miles of AHS lane during the day and evening hours and one per 100 miles overnight. The number of operators in a comparable freeway system ranged between one and four. The AHS system will be more sophisticated technologically than a freeway management system (FMS) with more active subsystems (e.g., entry/exit, vehicle communications, etc.) indicating a potential need for more operators than a FMS. On the other hand, it is also expected that the AHS system will be more fully automated than an FMS, thereby requiring fewer operators. The staffing analysis for this study examined and compared the functions of both classes of operators.

Table 7. AHS control center staffing.

	Functions	Estimated AHS Staffing/Vehicles (per day)	FMS Staffing High/Low
System Operators	- Monitor system - Handle incidents: interface with IMT & hwy patrol; control motorist info devices; monitor CCTV & other sensors; modify system control as needed - System management during malfunctions - Interface with media - Interface with field maintenance function - Interface with FMS, etc. - Reports - Update data base - Develop graphics - Trouble shoot - Maintain system - In-house S/W maintenance and development work	- one op. per 50 mi of AHS lanes; one per 100 mi: Total = 13 persons	one to four ops. per 100 mi of freeway lanes during peak periods; one to two during nighttime = 7-22
Maintenance Dispatch	- Dispatch maintenance vehicles for emergency maintenance	- one for each shift: Total = three	- one - all hours of TMC operation - zero to one for each shift
Service Patrol (SP)	- Patrols AHS highways to assist motorists	- one vehicle per 25 mi: = 26 persons + 13 vehicles: Total = 25 & 10 veh/day	- none to one vehicle per 25 mi during peaks (no off peak coverage)
Service Pat. Dispatch	- Dispatches Sps in response to requests	- one per shift Total= three	- one per shift
Incident Mgmt. Team	- Responds to incidents - Traffic control during incidents - Assists hwy patrol - Provides info to center	- teams of three 24 hr/day - three teams on-call - peak hours and two off-peak: Total = 21* & 21 vehicles	- 0-14 (plus on call team members)
Highway Patrol	- Heads incident mgmt effort and provides info to TMC on incidents; interfaces with other enforcement agencies	- two - peaks, one - off-peaks: Total = five	zero to three
Local Enforcement Agency	- Provides interface bet locals and hwy patrol during incidents, events, etc. for traffic control	- zero to one per shift: Total = three	zero to two
Central Equipment Maintenance	- Maintains central equipment including comm	- one or two per shift: Total = five	zero to three
Software Staff	- Debugs, updates software	- two programmers	zero to two programmers
TOTALS		= 55 persons/day *	8-54 persons/day

The staffing estimates for the IMT reflect current staffing levels for FMS systems rather than the significantly greater estimates that were presented earlier in the report based on achieving low response times. It was felt that, due to the probable automated response in an AHS system, the IMTs would have limited usefulness in AHS. Additionally, the manpower, facility, and equipment costs to provide very low response times would be prohibitive. It is projected that existing FMS IMTs will provide the necessary traffic control to supplement the automated diversion that is implemented by the AHS system and that separate AHS IMTs will not be required. This proposal to share personnel between FMS and AHS systems is presented in further detail in a later section of this report.

It has been concluded from this analysis that a reasonable estimate for an AHS would be what is considered to be a median level of staffing for an FMS. Similar arguments are applied in the development of staffing estimates for the other positions at an AHS control center and in the field.

The total number of persons assigned to the control center floor or to operations in the field for a one day period in this estimate is 55 (not including the local enforcement personnel). This estimate does not include roadway maintenance personnel or management personnel other than the control center supervisor. It also assumes that some of the computer equipment maintenance is performed under contract to an outside agency which is typical of the operation of today's freeway systems.

One significant difference between the AHS and FMS staffing numbers lies with the service patrol figures. Of the group of freeway systems that are interviewed, none is currently using service patrols on a 24 hour basis. The AHS staffing estimates however assume that service patrols will be in place at all times. The primary purpose of the service patrol is to provide assistance to disabled vehicles. This function is deemed to be important enough to warrant 24 hour coverage of the AHS facility with these patrols. Experience with an operating system may prove however that service patrols are not an efficient use of resources which will reduce the staffing estimates considerably.

For purposes of estimating daily personnel costs, representative salary figures are obtained from operating agencies for system operators, dispatchers, and other control center personnel. An average figure of $36 per hour was calculated for these personnel. Using this figure to estimate costs of staffing an AHS center in accordance with the staffing estimates presented in table 5 yields a daily payroll figure of approximately $15,800.

Estimated equipment costs for the central AHS system equipment and for service patrol and incident management team vehicles are presented in table 8.

Table 8. Central control center equipment and vehicle costs.

Items	Costs
- 10 central workstations	$ 300 K
- two dispatch workstations	$ 100 K
- 31 equipped vehicles	$ 400 K
- central system incl. comm	$ 700 K
- displays and peripheral	$ 500 K
Total	= $ 2 M

As mentioned earlier and as will be discussed in more detail in later sections of this report, it is likely that initial AHS systems will share facilities and staff with existing freeway management systems. This sharing is also applicable to center and field equipment and vehicles. It is especially likely that existing freeway incident management teams and roving service patrols will service both the freeway and AHS facilities meaning that new equipment and personnel may not need to be purchased specifically for AHS. Other pieces of equipment which will likely be shared are the dispatch workstations which are already existing in most freeway control centers.

Rural vs. Urban Control Center Operations

The basic functions which are performed by the operators of an AHS control center are generally the same for urban and for rural environments. Differences will likely be in the numbers of personnel which are needed to monitor the operations with a greater number needed to handle the urban environment. There are no freeway systems deployed in rural areas which can provide a point of comparison for AHS systems that are proposed, and consequently, estimates of the number of personnel that will be needed are based on other factors such as accident statistics. Accident statistics are an indicator of the relative need for systems operators since one of the operators' primary functions involves handling incident situations which cannot be accommodated solely by the automated system.

Accident statistics in rural and urban areas of Minnesota indicate that there are over twice as many accidents per million vehicle miles of travel of travel in urban areas. Also, assuming that exclusive barrier divided AHS lanes are deployed in urban areas, the amount of field equipment, the communications network, and the complexity of traffic operations will be greater in urban areas with an expected higher incidence of malfunctions. All of these factors point to a need for more operators in urban than in the rural areas. Based on the assumption that there will be less than half the number of incidents in rural areas as in urban (as is the case in freeways), it is estimated that there will only need to be half of the system operators in a rural system as there would be for an urban system with a comparable level of vehicle miles of travel. The absolute number of operators will need to be determined in more rigorous staffing studies for AHS system deployments.

Space Needs

In interviews conducted during this study with agencies operating freeway and rapid transit systems, there has been little consistency in defining space needs for the system operators and others within the control center. Generally, there are two or more positions in the control center for system operators, and there may be additional positions for the following personnel as defined in table 6:

- Maintenance dispatcher.
- Service patrol dispatcher.
- Highway patrol officer (one or more).
- Media interface personnel (one or more).
- System maintenance/testing personnel.
- Incident management team coordinator.
- Motorist information device operator (one or more).

Usually, there is also a position for a control center supervisor.

Most advanced freeway management centers have individual personnel designated to perform the separate functions that are listed in the report. It should be noted that the highway patrol position is for an actual officer who interfaces with his/her own department's system via a computer-assisted dispatch (CAD) terminal.

As noted earlier in this report, most operators and other personnel perform routine functions or work on special projects during periods of low activity. When an incident occurs, these personnel are then available to perform their assigned incident/traffic management or other related function.

In an AHS system, it is probable that at least these many positions will be occupied on the control center floor. Additional personnel might be needed for the maintenance of the control system function since the complexity of the system will be beyond any of the systems that have been investigated by this researcher. It is therefore estimated that there will need to be a minimum of 10 positions allocated on the AHS control center floor to operators and other related functions as follows:

- system operators 2
- system supervisor 1
- maintenance dispatch 1
- service patrol dispatch 1
- highway patrol 1
- media interface 1
- system maintenance 1
- IMT supervisor 1

- CMS operator 1
  TOTAL 10

Each position within a control center usually contains one to three monitors (e.g., operator's terminal, graphics, and malfunctions). Working space is needed for each position as well. Consequently, desk space which provides approximately 24 sq ft of surface space is needed per position. Typical total space requirements are approximately 50 sq ft per position.

Other space needs within the center include:

- Computer and communications room.
- Supervisor's office.
- Manager's office.
- Large screen display area.
- Storage/library.

Evolutionary Deployment

Evolutionary deployment of an AHS system refers to a progressive implementation of the various elements of a system leading to the eventual implementation of a complete operating AHS. The first step will likely be the integration of intelligence into vehicles which will enable them to avoid collisions, travel in platoons without benefit of driver interaction, maintain a path in a lane, and other functions leading to complete hands-off operation. The last step in the evolution is the deployment of the central system and its related functions. This study addressed the daily operations of an operating AHS, and therefore this report begins its discussion of evolutionary deployment with the deployment of a centrally controlled AHS system.

The following discussion presents a concept for the evolutionary implementation of an AHS control center which supports the evolutionary deployment of an AHS system. It is assumed that the initial efforts toward the deployment of an AHS system will be directed at equipping vehicles with the on-board intelligence that will be needed to allow a vehicle to operate successfully in an AHS environment. The next stages will involve instrumenting the roadway and implementing the central system that will provide the control function. This discourse on evolutionary deployment addresses the initial implementation of an AHS control center and associated functions.

For purposes of this discussion, it is assumed that the first AHS systems to be deployed will:

- Not utilize pallets.

- Implement one of the RSCs where a significant amount of intelligence is located on the vehicle.

- Be deployed in urban areas where freeway management systems are already in operation.

Early Deployment

It is assumed that the evolutionary deployment of the system will include the early deployment of an initiatory section of AHS lanes and that the system will expand by the addition of new sections of highway with a concomitant expansion of the control operation and supporting infrastructure.

The assumption that the area where the AHS system is to be deployed already has an operating freeway management system has many implications which will ease the deployment process and contribute to the evolutionary aspects of the implementation.

First, the existence of an already functioning facility provides an opportunity for the AHS system to collocate with the freeway system control center. There are inherent advantages to collocation which are derived from proximity and from enabling a direct interface between the two systems. Since the two systems must coordinate their operations, the ability of the operators of each system to communicate directly with one another is a distinct advantage over having to rely on computer interfaces or telephone communications. Operators of present day control systems contend that voice and visual contact is important during normal as well as emergency situations.

In addition to these advantages, collocation of the new AHS system with the existing freeway control center means that the AHS system will be able to take advantage of an already constructed control room, some of the existing communications infrastructure and equipment, and interfaces with other agencies and systems such as with the highway patrol.

It is assumed here that the AHS system will be incorporated into the already existing freeway management system center. This plan requires that there be a reallocation of space or an expansion of the existing space to accommodate the new control function. It also means that some new equipment for AHS control and communications will be installed and that additional personnel will be assigned to the facility. Although there will be a perturbation in the existing operation when these changes are incorporated, the advantages are that the cost of the center will be less than if an entirely new facility had to be constructed to house the new function. In the long term, it will also be advantageous to have both of the control functions housed together since their operations are similar and there are many commonalities which can be shared.

Shared Functions

The second implication of there being a freeway management system already in existence is that many of the existing freeway functions can be utilized by the new AHS operation. Several of the functions which are conducted out of a freeway management center will need to be replicated in an AHS operation; e.g., maintenance dispatch, dispatch of roving patrols, incident management, changeable message sign control, etc. The duplication of these functions can be avoided by joint-using some of the existing freeway management system staff. At least during the initial stages of AHS system operation, these personnel can perform the same functions for the AHS roadway as they are currently performing for the freeways. Especially during the early deployment years while the number of miles of AHS facility is few, shared facilities, staff, and equipment should be advantageous by keeping costs low while not constraining operations.

It is estimated that the number of staff positions which are required at the control center to operate an AHS system can be reduced by almost 75 percent over the figures that are presented in table 6 by the sharing of staff between AHS and FMS systems. The staff members from table 6 that could be shared include:

- Maintenance dispatch.
- Service patrols.
- Service patrol dispatch.
- Incident management teams.

It is recommended that the AHS system operators and the software support personnel be dedicated to the AHS since their expertise is specific to the operations of this system. Operators of the motorist information devices however can be shared between the two systems.

Some of the control aspects of an AHS system which need to be separate from the freeway system include the control function and the communications between the central system and AHS vehicles. Separate operator terminals would need to be provided for the AHS system including monitoring and communications equipment. Also, separate displays would need to be developed and installed.

A minimum system configuration for a short section of AHS lane (assume 20 miles) would require at least one operator during off peak periods and two during the peaks. For a small system, there would not necessarily be a need for a system supervisor, especially if the freeway system supervisor continues to manage the functions which are used jointly be both functions. Therefore, only two or three new control positions (with their displays) would need to be added to the control center to accommodate the AHS function. It is assumed that two positions would be for the AHS system operators and a possible third position would be used by development personnel for system testing, etc. As the system expands, provisions would have to be made to add additional positions, larger displays, and additional personnel.

The functions that might be shared by the freeway and AHS system include:

- Incident management including team responses.
- Interfaces with the highway patrol.
- Maintenance dispatch.
- Roving patrols and dispatch.

- Motorist information device control (e.g., changeable message signs).
- CCTV surveillance.

The terminals which are used by the dispatch personnel will need to be modified so that they can obtain AHS system information, or the dispatchers may need to be supplied with separate AHS terminals. Also, some specialized training will be required for the dispatch personnel and others to enable them to handle the functions associated with the AHS system as well as the freeways. For instance, maintenance dispatch personnel will need to be instructed in the maintenance problems that are encountered in an AHS system in order for them to be able to relay messages to maintenance personnel accurately. Also, incident management team members will need to be trained in the operation of the AHS system and in the strategies that will be employed to manage traffic when there is an incident in AHS lanes.

The advantages of being able to utilize the freeway system personnel to provide these common functions for the early deployment of AHS system are:

- Minimizes new personnel requirements.
- Minimizes space requirements.
- Reduces control center implementation costs.

Alternatives to Sharing Facilities

There may be significant hurdles to overcome with the proposed collocation of an AHS and the freeway system including space requirements, equipment sharing, shared staff assignments, and management. In fact, collocation might not be a viable option if space is not available in the existing facility to accommodate the new function. Alternatives in this case may be to construct an adjacent facility, build onto an existing structure, or utilize a temporary structure and locate it adjacent to the existing freeway system facility.

Later Deployment

It is assumed that the initial deployment of AHS will be followed by an expansion of the system with the addition of newly instrumented lanes and the expansion of the control center operations. If the early AHS control operation are able to reside in the same facility with the freeway management system and utilize some of their space, there will come a time when the AHS system will expand beyond that which can comfortably be accommodated in the early facility. Long term deployment plans must include a facility which can accommodate a fully operational AHS system in conjunction with the freeway management system.

As the AHS system grows, it will require a full complement of dedicated operations personnel as presented in an earlier section of this report. Due to the complex nature of the system, it is expected that the eventual size of an AHS control center will be double the size of a freeway management center which oversees the same number of miles of highway.

The jointly shared functions that are discussed in the early deployment section of this report may continue to be shared as AHS matures and deployment expands. Only experience in the joint operations of the two systems will prove if this arrangement is viable.

Future deployment of AHS systems will need to interface not only with freeway management systems but also with other systems, e.g., transit systems and traveler information systems. AHS will be only one element of regional transportation systems in the future. Some functions and facilities will likely be shared between systems and other which are unique to the operation of AHS will have to remain separate. For instance, the transmission of control commands to AHS vehicles from the central computer control system is a function that cannot be shared with other systems. However, functions such as route guidance and in-vehicle motorist information which will be an integral part of AHS may in the future be expanded to other systems. Consequently, the design of AHS should be versatile enough to accommodate the unforeseen demands of future deployment.

CONCLUSIONS

This report has analyzed the daily operations of a newly deployed AHS system, the functions that will be managed from its control center, and the personnel that will be required to operate and maintain the system.

Monitoring and Control for the Alternative RSCs

Six alternative RSCs are examined in this study. The operations of the AHS control center are analyzed relative to each RSC. Control center functions and staffing requirements are found to be similar for all RSCs. More complex monitoring and control functions will be required by the RSC that uses the smart highway/average vehicles design; in the pallet RSC, the system will be communicating with pallets rather than vehicles; and the monitoring and control functions will be virtually identical for the remaining RSCs. Because the basic monitoring and control functions are the same for all RSCs, control center operations will be similar with the result that conclusions and recommendations formulated in this study regarding center operations and staffing will generally apply to all RSCs.

Control System Operations and Staffing

The primary functions that the AHS system will perform are system control and monitoring. These activities will be executed by the computer system and overseen by the system operators. The role of the operators is to deal with events that occur that cannot be handled automatically by the system. The personnel who fill these operator positions are key to the operation of the system. They will be supported in the control center by an array of other personnel who will provide support functions such as maintenance and service patrol dispatch, software support, and interface with other agencies.

The number of operators required to oversee operation of an AHS system will depend on the number of lane miles of AHS. It is estimated that in urban areas, one operator per 50 miles of AHS lanes will be required during peak traffic conditions and one operator per 100 miles for off-peak periods. In rural areas, where traffic volumes are lower and incidents are fewer, fewer operators will be needed to oversee the system.

Evolutionary Deployment

It is assumed that the early deployment of AHS systems will be in urban areas that already possess operating freeway management systems. It is also assumed that the evolutionary deployment of AHS control centers and their functions will likely begin with the first AHS control center situated with the existing freeway control center. There are numerous benefits to collocating the two operations: sharing of some facilities (communications, building, etc.) and some personnel (dispatchers, incident management teams, service patrols, etc.) within the control center and in the field, and the ability of the personnel in both systems to interface and coordinate directly with each other. The requirements to staff and operate an AHS system can be significantly reduced by sharing functions and personnel between AHS and FMS systems. Absolute numbers of operators and other personnel needed to oversee and operate an AHS, whether or not it is collocated with a freeway management system, need to be the reexamined during the design of an actual system. The system design will specify the functions that need to be performed by the operators and support staff and will provide a better foundation for estimating staffing needs.

Future deployment of AHS systems will likely entail the continued collocation of AHS with freeway management system centers and, in fact, will probably include other systems centers in large complexes which oversee the operation of all regional transportation systems. Those elements of the system that need to continue to be separate from the functioning of other systems include the control system itself and its communication system. Other functions might be shared with the freeway system; however, the many operations of the AHS system are separate and distinct and will need to remain that way (e.g., check-in/check-out, communications with the vehicle, vehicle monitoring, and commands to the vehicles). Other functions of the AHS system may eventually be adapted to use by all vehicles in the transportation network, e.g., route guidance. This function has been demonstrated in test installations in this country, but there has been no large-scale implementation of such a system. AHS may provide the vehicle with which to accomplish this implementation.