Precursor Systems Analyses of Automated Highway Systems

RESOURCE MATERIALS

Impact of AHS on Surrounding Non-AHS Roadways

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PRECURSOR SYSTEMS ANALYSES

OF

AUTOMATED HIGHWAY SYSTEMS

Activity Area I

Impact of AHS on Surrounding Non-AHS Roadways

Results of Research

Conducted By

Delco Systems Operations

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.

Lyle Saxton
Director, Office of Safety and Traffic Operations Research and Development

NOTICE

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16. Abstract

This study considers the influence which automated highway system (AHS) traffic would have on the conventional, non-automated freeway and street system as it approaches and departs from the automated roadway. The higher speeds and capacities possible with an AHS facility will attract traffic into the AHS lane from both the general purpose freeway lanes and the parallel arterials. The increased AHS traffic will have both positive and negative impacts on the surrounding street system.

The analysis includes the modeling and evaluation of the operations of a freeway corridor with and without an AHS lane. Operations with and without an AHS lane on the surrounding roadways are then evaluated using traffic operations measures of effectiveness. The surrounding roadways include the general purpose freeway lanes, freeway ramps, parallel arterials, and cross streets. Additional modeling analyzes the impact of the AHS traffic on the cross streets. The Highway Capacity Software (HCS) program is used to evaluate the level-of-service on alternative configurations of the cross streets and parallel arterials. The physical requirements of the AHS lane and ramps are analyzed to determine the impact on the surrounding streets. The modeling results are also used as input to the Activity P analysis. Qualitative as well as quantitative impacts are addressed. AHS is reviewed from the perspective of an urban planner.

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EXECUTIVE SUMMARY

Activity Area I — Impact of AHS on Surrounding Non-AHS Roadways evaluated the impact of Automated Highway System (AHS) lanes on surrounding roads. The non-AHS roadways include the general-purpose freeway lanes, freeway ramps, cross streets, and parallel arterials. For both urban and rural situations, the study evaluated key issues relating to non-AHS roadways, including: 1) highway re/design issues; 2) spatial requirements of AHS facilities and entry/exit facilities; 3) traffic operations of both AHS facilities and the non-AHS surrounding roadways; and 4) the impacts of AHS facilities on land use.

The key issues were evaluated from the perspectives of highway engineering, traffic operations, and urban planning. The evaluation included gathering information on the issues from transportation experts. Highway engineering principals were applied to evaluate issues involving the re/design of the highway system to accommodate AHS lanes. Highway redesign issues included the location and configuration of AHS interchanges; the design of the cross streets at the AHS interchange locations to accommodate AHS traffic volumes; and the configuration of the traffic intersections of the cross streets with the parallel arterials to accommodate both AHS and non-AHS traffic volumes. Freeway operation analysis models were used to evaluate the traffic operations within both urban and rural freeway corridors. Traffic operations were evaluated using the measures of effectiveness (MOE’s) of speed, travel time and delay. The impacts of the AHS facility on the surrounding land use was also evaluated through a comprehensive analysis of the relationship between the transportation and land use elements.

The key findings of the analysis of the impacts on non-AHS surrounding roadways were:

- The loss of conventional freeway capacity resulting from AHS development should not operationally impact the non-AHS freeway lanes.
- The modeling of the freeway corridors indicated that AHS lanes provide significant travel time benefits in the corridors.
- AHS entering and exiting traffic can have significant adverse impacts on AHS ramps, cross streets and parallel arterials as AHS traffic volumes increase.
- AHS traffic volumes could have significant impact on surrounding land use, particularly as AHS market penetration rates begin to approach 40 percent.

- The metering of AHS lanes with other travel demand management strategies can optimize AHS operations and minimize impacts on the surrounding roadways.
- Based on the above findings, recommendations were made to minimize the impacts of AHS facilities on the surrounding roadways.

The major recommendations are:

- Future research should be conducted on a combined travel demand analysis and traffic operations analysis of freeway corridors.
- Future planning of AHS facilities should evaluate the traffic operations of the surrounding roadways.
- The locations and configurations of AHS interchanges should be evaluated with respect to the surrounding roadways. Planning should consider such things as: 1) split AHS on and off-ramps; 2) balancing the number of AHS interchanges with respect to AHS traffic demand and cost of providing interchanges; and 3) replacing existing freeway interchanges with AHS interchanges as the market penetration of AHS vehicles increase.
- The AHS facility and surrounding roadway system must be planned and designed as an integral roadway system.
- The AHS control system and the traffic signalization system of the surrounding roadways must be integrated and coordinated to minimize impacts on the surrounding roadway system.
- AHS ramps should be metering by the AHS control system to minimize impacts on the surrounding roadways.

INTRODUCTION

AHS vehicles will operate on AHS lanes at higher operating speeds and higher capacities than general-purpose freeway lanes. The higher speeds and capacities will in turn attract AHS traffic into the AHS lane from both the general-purpose freeway lanes and the parallel arterials. As the number of equipped vehicles increases, AHS traffic volumes will increase substantially. The increased AHS volumes will have both positive and negative impacts on the surrounding street system. This activity investigated the impacts of AHS facilities on the surrounding non-AHS roadways including the general-purpose lanes, on and off-ramps, cross streets and parallel arterials.

The approach to this study included the modeling and evaluation of the operations of a freeway corridor with and without an AHS lane. The corridor was modeled using the Frequency Optimization Model (FREQ) operations model. The impact of the operations with and without an AHS lane on the surrounding roadways was then evaluated using traffic operations measures of effectiveness. The surrounding roadways included the general-purpose freeway lanes, freeway ramps, parallel arterials and cross streets. Additional modeling was conducted to analyze the impact of the AHS traffic on the cross streets. The Highway Capacity Software (HCS) was used to evaluate the level-of-service on alternative configurations of the cross streets and parallel arterials. The physical requirements of the AHS lane and ramps were then analyzed as they impact the surrounding streets. The modeling results were also used to perform the benefit-cost analysis described in another report.

Technical Task Discussion

The tasks carried out for this activity include:

1. Highway Redesign Issues.
2. Impact on Non-AHS Roadways.
3. Modeling.
4. Maximize System Benefits.
5. Gather Expert Opinion.
6. AHS From an Urban Planning Perspective.
7. Recommendations.

REPRESENTATIVE SYSTEM CONFIGURATIONS

The representative system configurations (RSC's) were generated very early in this Precursor Systems Analyses of AHS program. These RSC's are used throughout the various areas of analysis whenever a diversity of system attributes is required by the analysis at hand. The RSC's identify specific alternatives for twenty AHS attributes within the context of three general RSC groups.

Since the RSC's have such general applicability to these precursor systems analyses, they are documented in the Contract Overview Report.

TECHNICAL DISCUSSIONS

Task 1. Highway Redesign Issues

The development of AHS will have spatial and operational needs that will necessarily impact the roadways feeding traffic to the AHS itself. The purpose of this activity is to identify and quantify (where possible) these impacts.

For the purpose of this study, surrounding non-AHS roadways are defined as the non-AHS freeway lanes adjacent to the AHS; the parallel streets within the corridor in which AHS is deployed; and the cross streets serving the corridor within which AHS is deployed.

While the title of the activity relates to roadway impacts, our approach includes issues related to the impacts of shifts in traffic patterns on the community at large. Therefore our work deals not only with street and traffic impacts, but also with the land use changes that could result from a major revision to an existing, established transportation network. This section lists and elaborates on the highway and street redesign issues AHS will bring.

Opportunities for accommodating AHS lanes within an existing freeway right-of-way include:

- Narrowing of existing freeway lanes to accommodate width requirements of AHS lanes.
- Conversion of a traditional flow lane to AHS.
- Conversion of a special-use High Occupancy Vehicle (HOV) lane to an AHS lane.
- Construction of AHS without affecting traditional freeway.

Each of these opportunities, with the exception of the last, potentially has an effect on the capacity of the non-AHS lanes of any given freeway.

Areas of limited right-of-way may require traditional lanes to be narrowed in order to accommodate an AHS facility. Such narrowing of traditional lanes could potentially reduce capacity of traditional freeway lanes by up to five percent, according to the Highway Capacity Manual. Figure 1 illustrates that a loss of five percent of traditional capacity will be easily justified as the overall corridor capacity with AHS will increase at low AHS utilization.

Conversion of a mixed-flow lane to AHS will decrease capacity of a traditional freeway by up to 2,200 vehicles per hour. Although arguments could be made that this type of conversion would increase overall capacity of a corridor, justification would be difficult, especially in early years of implementation, when market penetration of AHS-equipped vehicles is expected to be low. Figure 1 indicates that utilization of the AHS lane must be at least 36 percent of AHS capacity before overall capacity of a corridor is increased. Utilization of AHS lanes is dependent on a number of issues, including market penetration of AHS-equipped vehicles and overall benefits of the system. These findings relate to an urban freeway system and in general are not site specific.

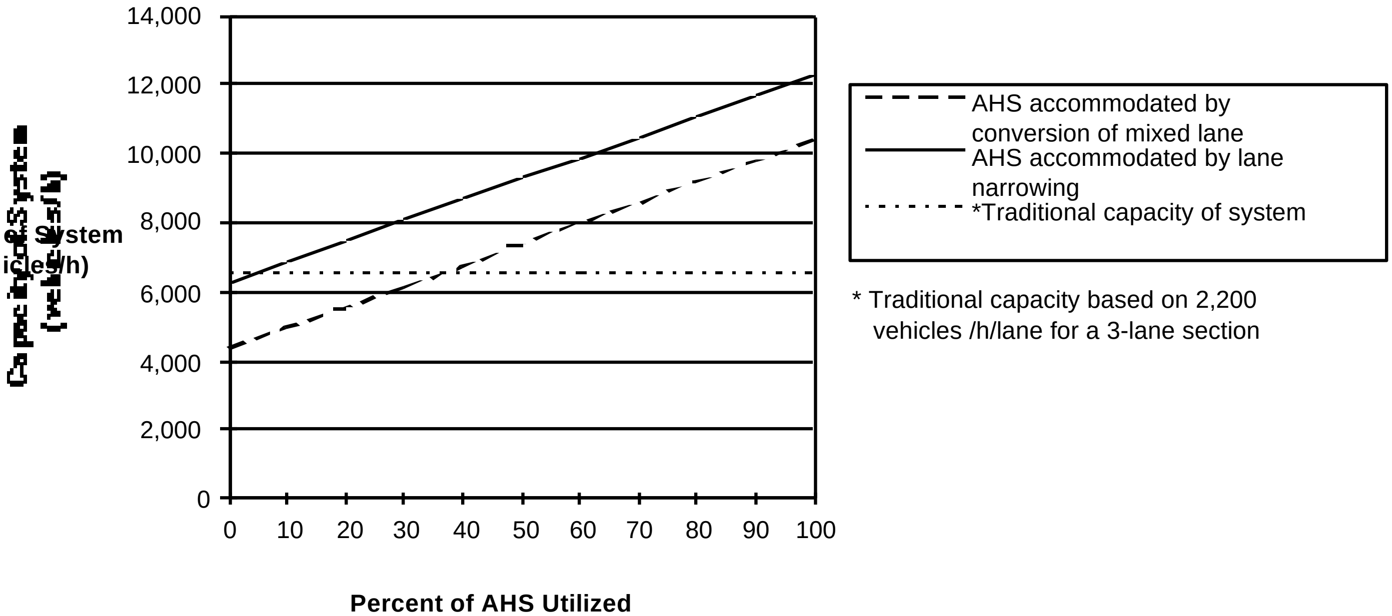

Figure 1. Effect of Freeway Capacity due to Modifying Existing Freeway to Accommodate AHS

Cross section alternative scenarios to accommodate AHS, within the same cross section as an eight-lane freeway (three mixed and one HOV lane in each direction) are presented in Activity Area H — AHS Roadway Deployment Analysis.

As indicated in the discussion within that activity area, it is believed that, on most typical eight-lane cross sections, a conversion of the HOV to AHS can be accommodated within the same right-of-way without any serious compromises of standards. It is further assumed that the passenger throughput of AHS will equal or exceed the HOV passenger throughput. The net result is that loss of conventional freeway capacity resulting from AHS development should not operationally impact the non-AHS freeway lanes.

Experience in California in deployment of HOV lanes has shown that it is politically impossible to convert mixed lanes to HOV, even if it can be shown that overall total passenger throughput would increase. Based on this experience, it is concluded that AHS would only be deployed as a replacement for HOV in cases where passenger throughput will remain constant or increase.

Task 2. Impact on Non-AHS Roadways

This task investigated the following impacts on non-AHS roadways:

- Lost street capacity from spatial requirements of AHS facilities.
- Spatial requirements of the AHS at interface points.
- Provide new AHS-only access points.

Impact Due to Lost Capacity from Spatial Requirements

The potential of capacity loss resulting from three different modifications to traditional freeway lanes in order to accommodate AHS is discussed in Task 1. In each case the magnitude of capacity loss on non-AHS lanes differed significantly and as a result impacts due to lost capacity will differ according to the configuration discussed.

As discussed in Task 1, narrowing the traditional freeway lanes to accommodate AHS will decrease capacity by up to five percent. Even if the AHS lane was not used at all this would mean a overall capacity loss of 330 vehicles per hour for a three-lane freeway section (one direction of travel). This loss may cause slightly larger delays at peak hour of the non-AHS traffic, but generally would not cause any noticeable change in non-AHS operations. As soon as market penetration increased to provide five percent utilization of AHS the overall capacity of the system would “break even” and operations on non-AHS roadways would theoretically start to improve.

Conversion of a conventional mixed use freeway lane to AHS would result in a loss in capacity of 2,200 vehicles per hour to the conditional freeway. This would require the surrounding arterial roads to handle the extra demand. Since capacity of an arterial lane is approximately 800 vehicles per hour compared with 2,200 vehicles per hour on the freeway lane, large delays and congestion could result especially at intersections. The amount of delay and congestion will depend at what level of service the corridor was operating at prior to the lane conversion to AHS. Theoretically operations would only improve after 40 percent utilization of the AHS lane. As a result, conversion of an existing lane may be very hard to justify, especially if market for AHS can not realize this goal for a number of years.

Impacts due to capacity loss resulting from the conversion of a HOV lane are difficult to determine as the amount of capacity lost is dependent on the usage of the facility. Some jurisdictions require HOV users to have three or more people in each vehicle while others require only two person occupancy. These factors affect the amount of overall “person” capacity of the system. Conversion of an HOV lane to AHS would require HOV users to either get their vehicle equipped for AHS or shift their travel to non-AHS roadways. Depending on the amount of shift to non-AHS roadways, operations could be degraded to similar levels experienced if a mixed lane conversion took place. Capacity would only “break even” when the total passenger throughput of AHS exceeded the throughput of the HOV lane. In order for this to occur, occupancy stipulations may have to be implemented on the AHS facility. As stated in Task 1, justification for conversion of a mixed lane to an HOV lane is difficult, even if passenger throughput is increased. This implies that the conversion of a HOV lane to an AHS lane cannot decrease the overall “person-carrying” capacity, even in the early stages of development.

Impact Due to Spatial Requirements of the AHS at Interface Points

The impacts on surrounding non-AHS roadways due to entry and exit to the AHS could range from very minor to major impacts. If the AHS is configured and operated so that entry to and exit from AHS is through the use of conventional freeway interchanges, then the impacts could be relatively minor. Cross street and ramps may require minor widening depending on demand to use the AHS facility and how AHS is configured.

Any increase in combined capacity of the AHS and non-AHS freeway configuration will require improvements to the cross street at the entry/exit points. For example, if the demand on the system and the configuration of AHS results in a 20 percent increase in the combined freeway capacity/utilization (AHS plus non-AHS), the cross streets and ramps must also be improved by a similar factor to provide the additional capacity requirements of AHS. Reserve capacity refers to an entry or exit point that operates below acceptable levels and can accommodate more traffic volume while still operating at acceptable levels.

If, however, the AHS is a dedicated system, with exclusive entry/exit facilities separate form the conventional freeway, the impacts at the entry/exit points could be significant from an operational perspective. Cross streets must be able to handle the increase in volume at the AHS entry/exit points. There are two main scenarios for placement of entry/exit points for a dedicated AHS facility: 1) modify an existing conventional freeway access point, and 2) provide a new AHS-only access point.

Modify Existing Freeway Access Points

Modifying an existing freeway access point would require the ability to add separate ramps for AHS traffic within the interchange configuration for the conventional freeway.

The main advantage of modification of existing interchanges to add AHS access points include:

- Exploitation of the existing arterial street system to feed the AHS.
- Least requirement for revisions to the overall surrounding street network.
- Least requirements for revised travel patterns.
- Least impact on areas not frequently adjacent to arterial streets with interchanges.

This alternative has two major disadvantages:

- Existing access points (interchanges) will have to be reconstructed under traffic to accommodate AHS. Such construction is extremely disruptive and expansive.
- Existing cross streets would then have to serve not only the existing freeway, but also the AHS. Given that typical cross street interchanges are in a state of equilibrium with the freeway they serve, newly added AHS capacity is expected to overload the interchanges and the streets themselves. It is expected that, very often, the added capacity of AHS could not be utilized due to the bottleneck effect of the interchange.

The additional signal requirements and/or phasing requirements at such an interchange would further degrade overall interchange operation, including delays and levels of service for through traffic on the cross street.

Provide New AHS-Only Access Points

Typically, and on our hypothetical urban freeway used for modeling throughout this study, urban freeways have interchanges with arterial streets at 1.6 km intervals, and freeway-to-freeway interchanges at 8 km (or more) intervals. There is typically a collector street perpendicular to the freeway midway between each interchange. These collector streets usually have no direct access to the freeway nor are structures provided to allow for through traffic movements at the freeway. Figure 2 illustrates the interchange and cross street situation.

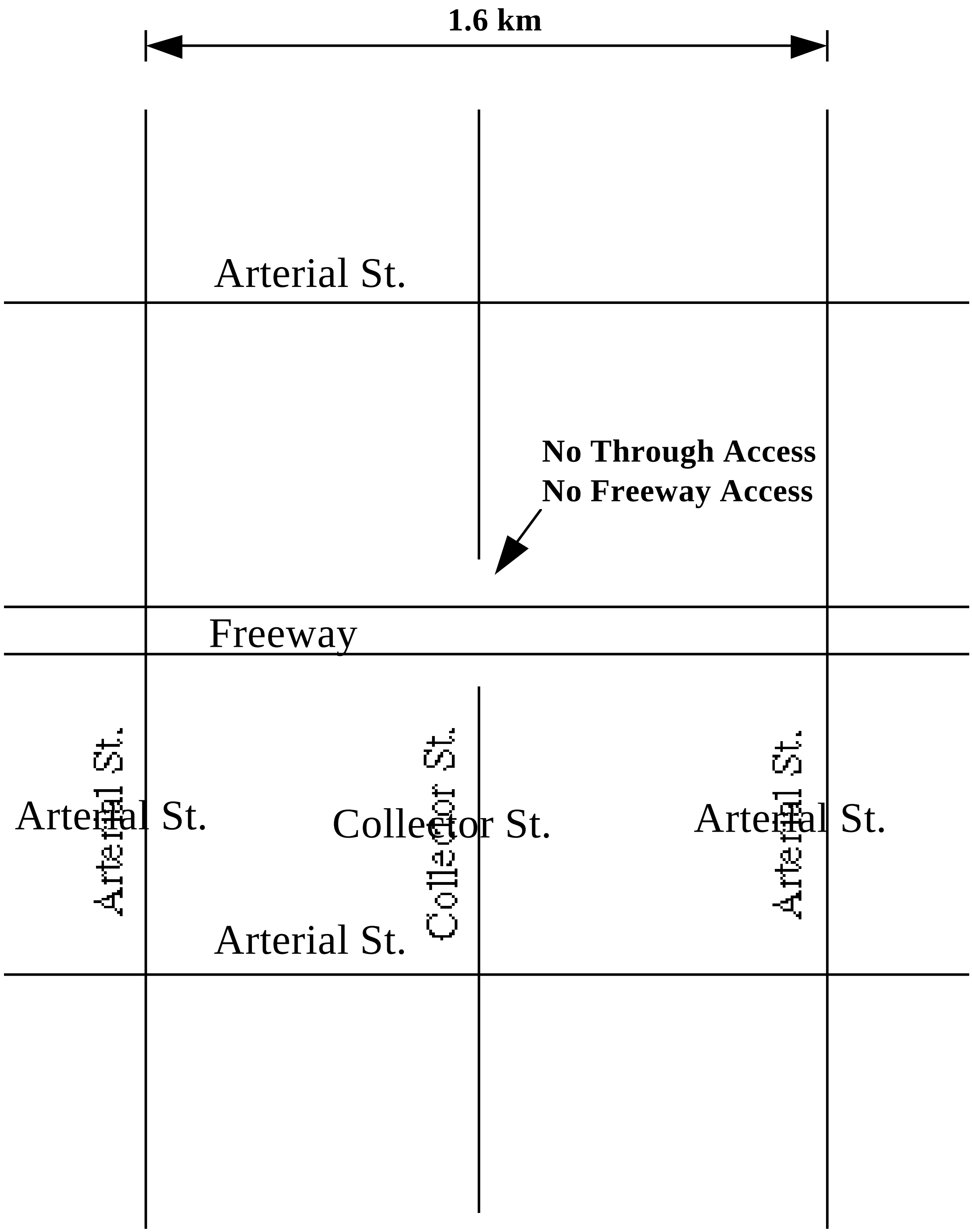

Figure 2. Typical Freeway/Street Network

Geometrical and operational requirements (on-ramp, off-ramp, and weaving and merge-diverge movements) make closer spacing undesirable.

AHS scenarios with physically separated AHS lanes (RSC's 1 and 2) open the possibility of AHS-only access points between existing 1.6 km interchanges. Because the AHS is physically separate from conventional traffic, the geometric and operational issues mentioned above do not apply.

Construction of AHS-only interchanges between existing interchanges raises several issues. Given the assumption of dedicated lanes with access and egress directly from cross-street to median-located AHS, spacing between existing interchanges should almost never be a factor in locating AHS-only interchanges. This is a result of the complete separation of AHS and non-AHS traffic and the fact that no weaving is needed for AHS traffic. Interchange construction would be somewhat easier than deploying an AHS access point at an existing general use interchange. The issue of added traffic volume to the existing interchange and cross street would not apply. Traffic would be dispersed over more streets instead of being concentrated on arterials. However, several undesirable impacts would be expected:

- Collector streets are typically designed for lower volumes and are built to a lower geometric and cross section standards than arterial roadways. The expected additional volumes result in the requirement for improvements to the collector streets.
- Collector streets are more likely to have adjacent residential land use that arterials, and they are far more likely to have direct driveway access to dwelling units. Impacts of traffic volumes, noise, and emissions on residential land use are important issues.

It is likely that conversion of collectors to AHS feeders could also provide the possibility of through movements of non-AHS traffic across the freeway. This issue could be negative in some cases and positive in others, but the net result would be higher traffic volumes on the collector in the vicinity of the freeway. Such traffic, even though unrelated to the AHS, must still be taken into account in evaluating the overall AHS impact.

Task 3. Modeling

The purpose of this section is to describe the general approach which was used to model the alternative AHS highway configurations. The FREQ11PL, freeway corridor priority lane simulation model was used to simulate freeway performance for both the priority (AHS) lanes and non-priority (non-AHS) lanes. FREQ (Freeway Optimization Model) was used to simulate the measures of effectiveness for the network configurations to be studied. FREQ predicts a time stream of impacts and traveler responses for a variety of freeway geometric and operational strategies and situations.

The comparative traffic demand on the alternative AHS configurations was based on estimates of the diversion from non-AHS lanes or other non-AHS facilities to AHS lanes. The diversion estimates were a function of: 1) the relative travel times on the non-AHS facilities compared to the travel times on the AHS facilities; and 2) estimates of the mix of automated vehicles. Operational impacts of AHS lanes analyzed for this study included: 1) speed; 2) vehicle-hours; 3) ramp delay; and 4) vehicle emissions. Operational impacts were analyzed for the following surrounding roadways the study corridor: 1) non-AHS freeway lanes; 2) non-AHS ramps; and 3) non-AHS arterials.

Measures of Effectiveness

The performance of the AHS and freeway sections was evaluated based on the following measures of effectiveness: 1) travel time savings; 2) delay reductions; 3) vehicle emission reduction; and 4) intersection level of service. It is important to note that the measures of effectiveness were based on the characteristics of current vehicles. The exact engine performance characteristics and exhaust emissions of future AHS vehicles are unknown. However, it is anticipated that there will be significant improvements in vehicle performance. Therefore, any improvements in the measures of effectiveness due to AHS facilities are probably underestimated.

Travel Time Savings

Vehicle speeds on a facility are a function of the congestion level of that facility. As vehicle congestion increases, speed decreases. Travel times on both the AHS and freeway were modeled as a function of vehicle congestion. The total vehicle hours on each study section were estimated and compared for the AHS and freeway The travel time savings or loss was then used as a comparative performance measure between the AHS and freeway facilities.

Vehicle Delay Reductions

Vehicle delay may occur on both the mainline and ramps. As congestion levels increase on the AHS, freeway, and ramp sections, the average vehicle delays increases. As vehicle congestion approaches the capacity of the facility, vehicle delays increase rapidly and vehicle queue lengths become long. Vehicle delays also result on the ramps due to traffic volume demand and the intersection control at the ramp terminus.

Vehicle Emissions

Air quality is one potential benefit of improving the performance of a facility. Vehicle exhaust emissions are a function of speed, delay, and vehicle kilometers. In general, as vehicle speeds remain constant (no accelerations), the exhaust-pipe emissions of carbon monoxide and hydrocarbons decrease. Vehicle delays result in engine cycling and idling, which in turn result in increase exhaust emissions.

General Modeling Approach

Traffic and capacity parameters were defined for each of the urban and rural freeway sections. Both AHS and non-AHS operational assumptions were defined, model assumptions were developed and model structural changes were made where necessary to adapt to AHS operational assumptions. The capacity of an AHS lane were estimated based on the platoon size and design speed. The FREQ model was used to analyze on and off-ramp queuing, ramp merging, weaving, and travel times.

Inputs to the model included:

- Mainline and ramp lane configurations.
- Mainline peak-hour traffic volumes (one peak hour was be modeled).
- Ramp volumes.
- Vehicle mix.
- Mainline and ramp capacities.
- Speed-flow characteristics (user defined characteristics may be entered).

Measures of effectiveness previously discussed were analyzed including:

- Travel time.
- Delay.
- Queue length.
- Fuel consumption.
- Vehicle emissions.

The spacing of access points and the impact on adjacent streets were also analyzed using the simulation models. Two separate access point spacings were modeled. Initially, a 1.6 km access point spacing was modeled for urban conditions. Based on the results of the 1.6 km spacing, a second access point spacing was selected and then modeled. The effect of point spacing on AHS operation was determined by comparing the MOE's.

The FREQ11PL, freeway corridor priority lane simulation model was used to analyze point spacing and location requirements with and without AHS deployment for the highway configurations. The freeway lanes were separately modeled without the AHS lane. The AHS lane was modeled as a one-lane freeway with separate AHS ramps.

Urban Freeway Corridor

The urban freeway corridor was based on approximately 12.8 km of existing I-17 in Phoenix Arizona. I-17 connects I-10 in Phoenix to the south to I-40 approximately 240 km to the north at Flagstaff, Arizona. The urban freeway section is illustrated in Activity H. The land use within the corridor is predominately commercial and moderate to high density residential. Tables 1 and 2 present the projected traffic volumes on the freeway section for the years 2010 and 2017, respectively.

Alternative highway configurations were evaluated for varying market penetration rates in two horizon years: 2010 and 2017. The traffic volumes for the year 2010 are from the regional forecasted volumes for the Phoenix metropolitan area produced by the regional transportation planning agency. The 1990 daily traffic volume on this segment of I-17 was approximately 6,000 vehicles per day. The forecasted 2010 daily traffic volumes on this segment of I-17 is approximately 245,000 vehicles per day. The directional evening peak-hour traffic volume is projected at approximately 10,500 vehicles per hour.

The following four scenarios were analyzed for the urban freeway corridor: 1) base scenario consisting of a four-lane freeway; 2) a three-lane freeway with an HOV lane; 3) a five lane freeway; 4) a three-lane freeway and one AHS lane. All the corridors include the parallel arterials on each side of the freeway. Each scenario was modeled for the years 2010 and 2017. The scenarios were also modeled for various assumed market penetration rates which are the percent of vehicles within the study corridor equipped with AHS equipped vehicles. The assumed market penetration rates of AHS equipped vehicles were 15 percent, 40 percent and 60 percent. The modeling scenarios are summarized in Table 3.

Table 1. AHS Urban Freeway Section — 2010 Freeway Traffic Volumes

Segment	**Mainline Volumes (Vehicles per Hour)**	**Ramp Volumes (Vehicles per Hour)**	
		On-Ramp	**Off-Ramp**
Lane Drop — Thomas Road On	9,050		
Thomas On — Indian School Off	10,802	1,752	1,381
Indian School Off — Indian School On	9,422		
Indian School On — Camelback Off	11,333	1,912	1,310
Camelback Off — Camelback On	10,0024		
Camelback On — Bethany Home On	11,546	1,522	1,505
Bethany Home Off — Bethany Home On	10,041		
Bethany Home On — Glendale Off	11,723	1,682	1,381
Glendale Off — Glendale On	10,342		
Glendale On — Northern Off	11,758	1,416	1,664
Northern Off — Northern On	10,094		
Northern On — Dunlap Off	11,523	1,469	1,717
Dunlap Off — Dunlap On	9,847		
Dunlap On — Peoria Off	11,440	1,593	2,124
Peoria Off — Peoria On	9,844		

Table 2. AHS Urban Freeway Section — 2017 Freeway Traffic Volumes

Segment	Mainline Volumes (Vehicles per Hour)	Ramp Volumes (Vehicles per Hour)	
		On-Ramp	Off-Ramp
Lane Drop — Thomas Road On	10,750		
Thomas On — Indian School Off	12,835	2,085	1,643
Indian School Off — Indian School On	11,191		
Indian School On — Camelback Off	13,467	2,275	1,559
Camelback Off — Camelback On	11,908		
Camelback On — Bethany Home On	13,719	1,811	1,790
Bethany Home Off — Bethany Home On	11,929		
Bethany Home On — Glendale Off	13,930	2,001	1,643
Glendale Off — Glendale On	12,287		
Glendale On — Northern Off	13,972	1,685	1,980
Northern Off — Northern On	11,992		
Northern On — Dunlap Off	13,740	1,748	2,043
Dunlap Off — Dunlap On	11,697		
Dunlap On — Peoria Off	13,593	1,896	2,528
Peoria Off — Peoria On	11,065		

Table 3. AHS Urban Modeling Scenarios

Highway Configuration	Market Penetration Rates						
	2010			2017			
	0%	15%	40%	0%	15%	40%	60%
Base Case	X			X			
4 General-Purpose Lanes							
Arterial Lanes							
Convert to HOV Lane	X			X			
3 General-Purpose Lanes							
1 HOV Lane							
Arterial Lanes							
Widen Freeway Only	X			X			
5 General-Purpose Freeway Lanes							
Arterial Lanes							
Convert To AHS Lane*		X	X			X	X
3 General-Purpose Lanes							
1 AHS Lane							
Arterial Lanes							

* Model for Interchanges spaced both at 1.6 km and 4.8 km intervals
AHS lane capacities of 4,000 and 6,000 vehicles per hour

Urban Modeling Assumptions and Parameters

This section addresses the assumptions and parameters used to model the freeway and AHS operations.

Facility characteristics were identified for use in the modeling. The characteristics defined for the urban freeways and AHS lanes included speed, capacity, percent trucks and buses and percent vertical grade. Table 4 presents the characteristics assumed for the urban facilities. The urban freeway corridor was modeled for AHS RSC's 1 and 2. RSC 1 assumes infrastructure centered platoon control. Platoons under this type of control are small, between five and ten passenger cars. RSC 2 assumes vehicle-centered platoon control. Platoons under the type of control are larger, approximately 15 passenger cars in length.

Table 4. Urban Facility Characteristics Used For Modeling — RSC 2

Characteristic	AHS	Freeway
Speed	100 km/h	100 km/h
Speed Flow Relationship	Constant	Parabolic — Speed decreases with volume-to-capacity
Mainline Capacity	6,000 vph/lane	2,200 vph/lane
Ramp Capacity	2,000 vph	1,500 vph
Trucks and buses	0%	5%
Percent Vertical Grade	6%	6%
Physical Barrier	Yes	
Interchange Spacing	1.6 km (at minor arterials)	1.6 km (at major arterials)
Type Entry/Exit	Exclusive On-Off Slip Ramps	Full Diamond Interchange

Urban Demand Volume Assumption

The following assumptions were made for the demand on the urban freeway section: 1) total traffic volume in the corridor is fixed; and 2) spatial shifts occur only between roadways in the corridor. The following assumptions were made to estimate the demand volume for the AHS facility: 1) AHS traffic volumes are based on assumed market penetration rates; 2) the same absorption rates are assumed for freeway and arterial vehicles within the study corridor; and 3) AHS ramp volumes are equally proportional to the up and downstream non-AHS ramps.

Modifications for AHS

The coding for the FREQ model was done as two separate FREQ model setups: 1) the general-purpose freeways plus the parallel arterials; and 2) the AHS lane. A three-lane freeway with on-off ramps at a 1.6 km spacing was modeled to simulate the general-purpose freeway lanes. The AHS lane was modeled as a one-lane freeway with separate AHS on- and off-ramps. The freeway and AHS facilities, therefore, were assumed to have been operated as independent facilities.

Modifications to the parameters of the FREQ model were made. First, the speed-flow relationship for the AHS vehicles was modified to simulate a constant speed of 100 km/h over all ranges of AHS volume-to-capacity ratios. This “flat” speed-flow relationship for AHS lanes is in contrast to the parabolic relationship for freeway lanes where speed decreases as volume-to-capacity ratios increase. Second, because the affect of entering and exiting AHS traffic is different than normal freeway traffic, the weaving analysis in the FREQ model was disengaged.

Modeling Limitations

The FREQ model is based on the characteristics of current vehicles. The mathematical relationship used by the model, therefore, are those for current automobiles, buses, and trucks, and are those of future AHS vehicles. Because of the uncertainty of the exact characteristics of AHS vehicles, modifications, discussed in the previous sections, were made to approximate the characteristics of AHS vehicles to the best of the researches knowledge. Therefore, the measures of effectiveness for AHS facilities are approximations. However, the results for AHS facilities are considered to be on the conservative side. Anticipated future improvements in vehicles and the improvements in operations under AHS would probably result in much larger differences in the measures of effectiveness reported herein.

Results of Urban Modeling

This section presents the results of the FREQ modeling. FREQ was used to evaluate impacts on corridor operations including: 1) AHS operations; 2) freeway operations; and 3) parallel arterial streets. Additional capacity analysis was used to evaluate the impacts on the cross streets.

Key findings of the modeling were:

- An AHS lane increases the overall travel speed within a corridor.

- The total number of vehicle-hours in a corridor is reduced by the implementation of an AHS lane.
- As the spacing between AHS ramps is increased, the traffic volume on the entry/exit ramps is increased and therefore AHS ramp delay is increased.

Impacts on Corridor Operations

The results of the modeling showed that the average vehicle speeds in the corridor increase and that the total number of vehicle hours in the corridor decreases. As AHS equipped traffic shifts to an AHS lane, the operation of the general-purpose freeway lanes improve. Operating speeds increase and delay decreases. The ramp volumes decrease due to traffic shifting to the AHS lane. However, non-AHS traffic from the parallel arterial also shifts to the general-purpose lanes because travel times are better on the general-purpose lanes. The AHS lane operates at high speeds and high capacity. A vehicle's travel time on an AHS lane is, therefore, less than on a general-purpose lane. The total number of vehicle hours on the AHS is significantly less than on the general-purpose lanes with comparable traffic volumes.

Figure 3 compares the average vehicle speeds in the corridor for the alternative highway scenarios with and without an AHS lane for the year 2010. As the figure illustrates, the implementation of an AHS lane increases the overall corridor speed from a low of 40 km/hr for a four lane freeway without an AHS lane to approximately 61 km/hour for three-lane freeway with an AHS lane assuming a 40 percent market penetration of AHS vehicles. The implementation of an AHS lane resulted in over 47 percent increase in corridor speed.

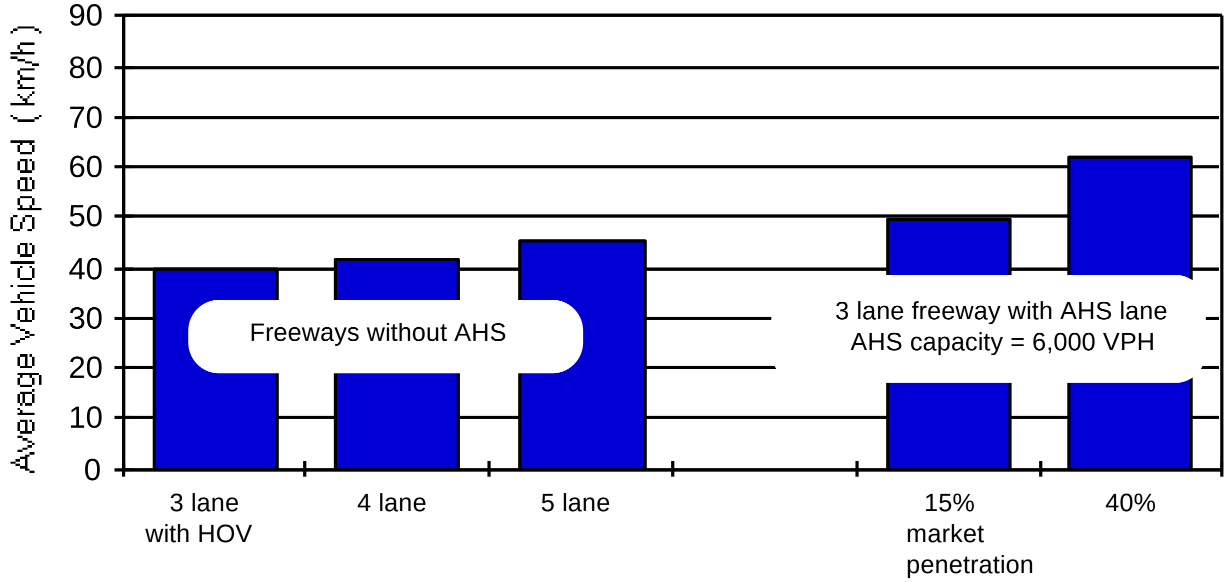

Figure 3. Comparison of 2010 Corridor Speeds

Figure 4 compares the average vehicle hours within the corridor for the alternative highway scenarios with and without an AHS lane for the year 2010. The figure illustrates that the implementation of an AHS lane decreases the overall corridor vehicle hours from a high of almost 10,000 vehicle hours for a four-lane freeway with an HOV lane to 6,000 vehicle-hours for a three-lane freeway with an AHS lane assuming a 40 percent market penetration of AHS vehicles.

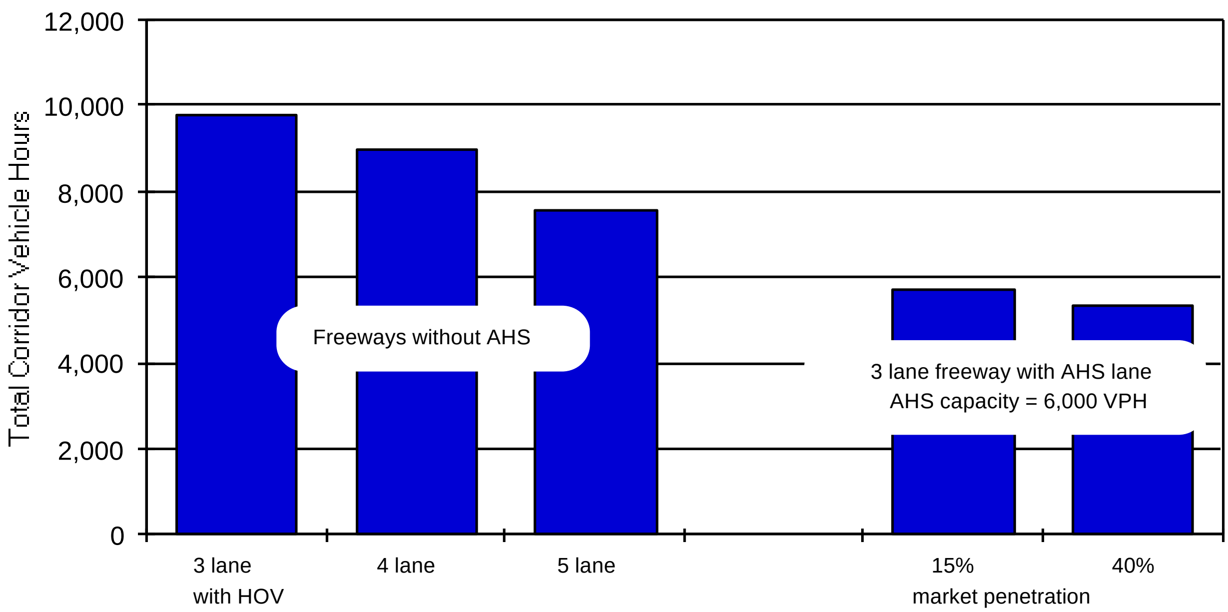

Figure 4. Comparison of Corridor Vehicle Hours — 2010

It is important to note that the number of vehicles served by the freeway varies according to the number of lanes on the freeway. The reason for this is that the capacity of the freeway restricts the number of vehicles which can be accommodated by the freeway. For example, a three-lane freeway has a directional capacity of approximately 6,600 vehicles per hour based on a lane capacity of 2,200 vehicles per hour per lane. The constrained capacity of the freeway has two effects on traffic operations. First, the delay of the vehicles on the freeway is increased significantly. Second, a significant amount of traffic can not use the freeway during the peak hour due to the limited capacity. Therefore, the unserved traffic demand will be served during other hours of the peak period. The resulting effect is that the peak period is lengthened and peak period “spreading” occurs. As the capacity is increased through lane widening or the addition of an AHS lane, more traffic volume can be accommodated by the facility and therefore the peak period will be shortened.

Effects of Entry/Exit Spacing

The impacts of the spacing between AHS entry/exit ramps were evaluated by comparing the performance of the AHS facility with interchanges spaced at 1.6 km to interchanges space at 4.8 km. The traffic volume demand on the AHS ramps increases as the spacing between AHS entry/exit ramps is increased because this results in fewer entry/exit points to serve the desired origins and destinations. This study compared the performance of the AHS ramps with a 1.6 km spacing between entry/exit points to the AHS ramps with a 4.8 km spacing between entry/exit points. Figure 5 illustrates the comparative vehicle hours with a 1.6 km and a 4.8 km spacing. The AHS ramp delay increases from approximately 2,000 vehicles per hour to over 8,000 vehicle hours due to the increase traffic demand.

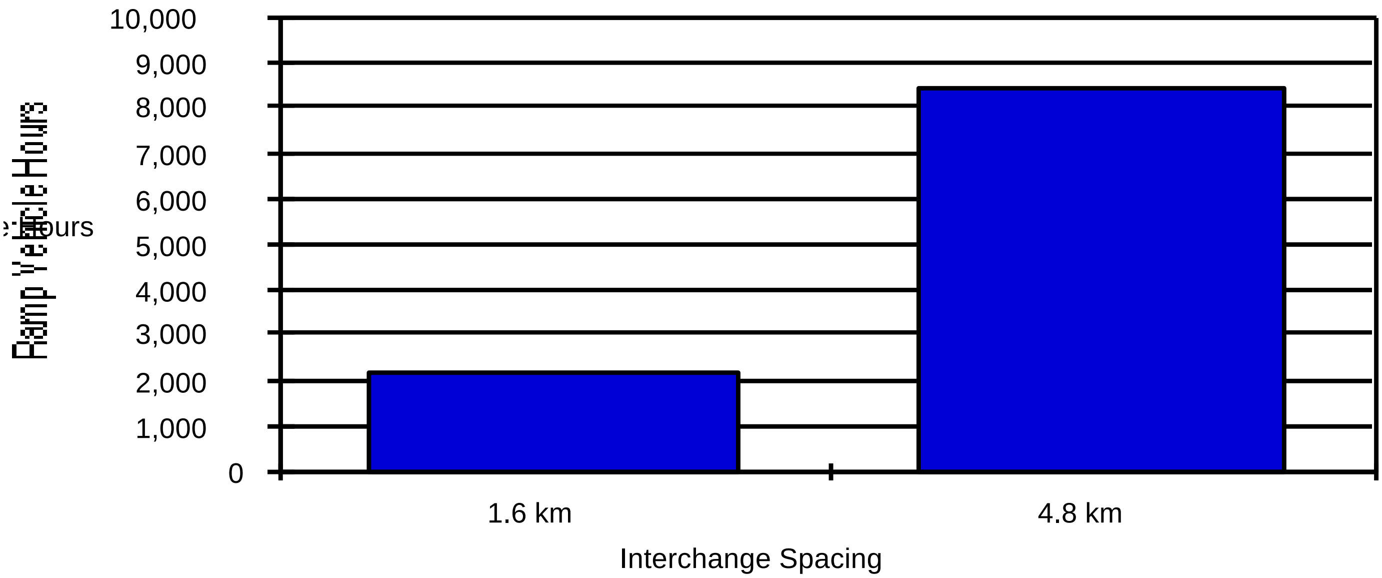

Figure 5. Comparison of AHS Ramp Delay — Vehicle Hours

Cross Street and Non-AHS Arterial LOS

The change in traffic patterns and increased ramp traffic due to the AHS traffic puts significant pressure on the cross streets. In addition to the modeling using the FREQ, other modeling was conducted to analyze the impacts on the cross street using the Highway Capacity Software. The impacts on cross street and non-AHS arterial traffic are discussed in detail in Activity Area J —AHS Entry/Exit Implementation.

Effects of Demand Management

An analysis was conducted to determine the impacts of demand management on corridor speeds. Demand management could include metering of AHS ramps, advisory signs or in-vehicle advisories, and pre-trip advisories as part of the overall AHS management. The FREQ model was used to determine the effect on corridor speeds of demand management. For this analysis, the following two assumptions were made. First, based upon the Highway Capacity Manual, all ramps to and from the AHS corridor were assumed to be operating at a maximum capacity of 1,500 vehicles per hour. This assumption seemed to be reasonable for the study corridor since the on and off-ramp volumes were reasonably balanced and within close range to 1,500 vehicles per hour. The second assumption was that the facility was operating at the maximum capacity of 6,000 vehicles per hour. The operation of the AHS lane under these two assumptions was at optimal performance with maximum capacity, maximum speed and no AHS ramp delay. The comparison of the corridor speeds under this optimal operation with the other modeling scenarios is illustrated in figure 6.

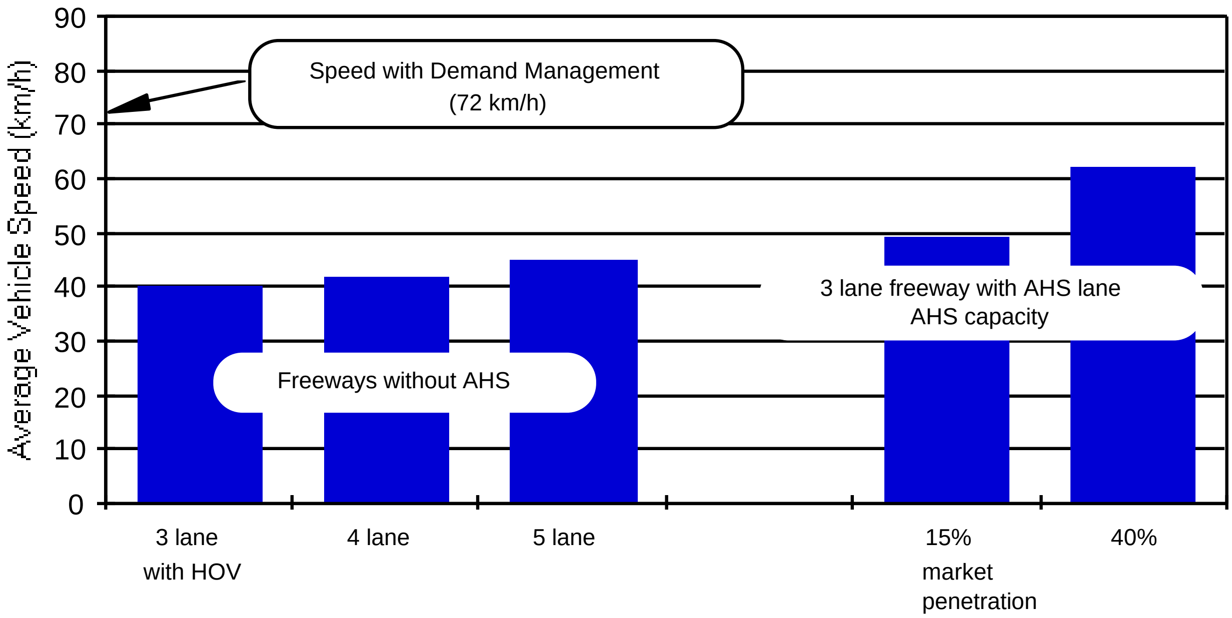

Figure 6. Comparison of Corridor Speeds — 2010 with Demand Management

Rural Freeway Corridor

The rural freeway corridor studied was an 80 km section of I-17 in Arizona. Physical and traffic data for the rural freeway corridor are shown in table 7.

<u>Rural Modeling Approach</u>

Overall traffic operations and ramp configurations of rural freeways differ from corresponding urban freeways. Traffic volumes are often much lower on rural freeways, while interface points are much further apart, due to the lack of demand and less development of land along the freeway. Lower mainline traffic volumes with low demand for ramps provide acceptable ramp level of service. As a result of these characteristics, a simplified modeling approach for the hypothetical rural freeway corridor shown in Activity Area H — AHS Roadway Deployment Analysis was applied for this study.

FREYSYS (Freeway System Analysis Program) was used to predict travel time of non-AHS lanes along the corridor. Travel times on the AHS facility were determined by either the maximum speed possible on existing alignments based on design speed or by the AHS capacity curves assuming no platoons as developed previously. Initially two configurations of AHS operations were modeled and compared to a base case assuming existing configuration. The configurations modeled included:

- Conversion of one general-purpose lane to AHS.
- Addition of an extra lane for AHS use.

As a result of issues generated by the above scenarios (discussed below), a third configuration was also modeled:

- Addition of an extra lane for AHS with limited access to/from the AHS lane.

Each of these configurations was modeled for 10 percent, 40 percent, and 60 percent market penetration. In determining values for market penetration, only passenger vehicles within the corridor were considered. Issues related to truck usage of rural AHS are addressed in Activity Area F — Commercial and Transit AHS Analysis. Vehicles attracted to the corridor as a result of AHS are not considered in this modeling.

Rural Modeling Assumptions and Parameters

Table 5 contains lane configurations, volumes, and vehicle compositions used in the model. In addition the following assumptions/parameters were used in the model (see table 6):

- Free-flow non-AHS speed = 120 km/h.
- Parabolic speed flow curve in which capacity speed is half of the free flow speed.
- Delay occurs when average speed is less than 75 km/h.
- Mainline non-AHS capacity = 2200 vphpl.
- Peak direction is northbound.
- Two lanes each direction.
- AHS maximum speed = 120 km/h.
- AHS capacity based on AASHTO wet pavement stopping distance with preceding vehicle braking at 1 g.
- Only passenger vehicles on AHS lane.

It is noted here that the maximum speed allowed on an AHS lane using existing infrastructure is governed by the design speed of the existing roadway. Traditionally design speed indicates the speed at which a vehicle can negotiate a curve safely or speed at which a vehicle can stop as a result of a driver observing an object. Since AHS vehicles will detect problems ahead and communicate with other vehicles, sight distance elements of design speed will not affect operations or safety. However, it is conceivable that tires and steering operations of vehicles will be much the same as present conditions, and therefore curvature elements of design speed will limit operating speed of AHS.

Conventional highways are designed to a selected design speed over a specified section of highway. In rural highway design, it is desirable for these sections to be substantially long, typically tens of kilometers or larger. This practice is intended to provide consistency among the several elements of highway design (curvature, super elevation, grade, etc.) which depend on design speed, and to avoid violations of driver expectancy.

Another desirable outcome of this design practice is that travel speeds are fairly uniform along the length of a section.

Table 5. Rural AHS Freeway Section Physical and Traffic Data

Segment	Length (m)	Capacity (vph)	Lanes	Base Volumes (vph)			
				Cars	Trucks	Buses	RV's
Deer Valley — Pinnacle Peak	4,875	2,200	2	3,043	306	17	34
Pinnacle Peak — Carefree Hwy.	7,925	2,200	2	2,842	286	16	32
Carefree Hwy. — Desert Hills	9,450	2,200	2	2,094	211	12	23
Desert Hills — New River	4,875	2,200	2	2,184	220	12	24
New River — Table Mesa	6,400	2,200	2	2,005	202	11	22
Table Mesa — Rock Springs	9,450	2,200	2	1,745	176	10	20
Rock Springs — Black Canyon	3,110	2,200	2	1,920	193	11	22
Black Canyon — Bumble Bee	9,450	2,200	2	1,745	176	10	20
Bumble Bee — Bloody Basin	17,525	2,200	2	1,571	158	9	18
Bloody Basin — SR 69	4,875	2,200	2	1,660	7	9	19

Segment	Length (m)	Capacity (vph)	Lanes	AHS Volumes		
				10%	40%	60%
Deer Valley — Pinnacle Peak	4,875	2,200	2	304	1,217	1,826
Pinnacle Peak — Carefree Hwy.	7,925	2,200	2	284	1,137	1,705
Carefree Hwy. — Desert Hills	9,450	2,200	2	209	838	1,256
Desert Hills — New River	4,875	2,200	2	218	874	1,310
New River — Table Mesa	6,400	2,200	2	201	802	1,203
Table Mesa — Rock Springs	9,450	2,200	2	175	698	1,047
Rock Springs — Black Canyon	3,110	2,200	2	192	768	1,152
Black Canyon — Bumble Bee	9,450	2,200	2	175	698	1,047
Bumble Bee — Bloody Basin	17,525	2,200	2	157	628	943
Bloody Basin — SR 69	4,875	2,200	2	166	664	996

* Only passenger vehicles on AHS lanes.

Segment	Length (m)	Capacity (vph)	Lanes	AHS Volumes Limited Access		
				10%	40%	60%
Deer Valley — Pinnacle Peak	4,875	2,200	2	140	540	820
Pinnacle Peak — Carefree Hwy.	7,925	2,200	2	140	540	820
Carefree Hwy. — Desert Hills	9,450	2,200	2	140	540	820
Desert Hills — New River	4,875	2,200	2	140	540	820
New River — Table Mesa	6,400	2,200	2	140	540	820
Table Mesa — Rock Springs	9,450	2,200	2	120	460	685
Rock Springs — Black Canyon	3,110	2,200	2	120	460	685
Black Canyon — Bumble Bee	94,50	2,200	2	120	460	685
Bumble Bee — Bloody Basin	17,525	2,200	2	120	460	685
Bloody Basin — SR 69	4,875	2,200	2	120	460	685

** Assumes half of traffic on AHS will continue on AHS beyond the corridor while the other half will exit/enter at 'Table Mesa' or SR 69 only.

Table 6. Rural Facility Characteristics Used For Modeling — RSC 3

Characteristic	AHS	Freeway
Speed	100 km/h	100 km/h
Speed Flow Relationship	Constant	Parabolic — Speed decreases with volume-to-capacity
Mainline Capacity	Varies	2,200 vph/lane
Ramp Capacity	2,000 vph	1,500 vph
Trucks and Buses	0%	5%
Physical Barrier	No	
Interchange Spacing	No Separate Ramps	Existing Interchange Locations
Type Entry/Exit	No Separate Ramps	Full Diamond Interchange

It is feasible to have an AHS designed for higher speeds where they are safe (on straight flat sections, for example) and lower speeds as dictated by safety, comfort, and geometry in other sections. This concept could have a dramatic effect on travel time, especially on long trips.

Because the hypothetical rural section modeled in this study is rolling to mountainous terrain with curvilinear sections, the AHS maximum speed is limited to 120 km/h.

As implied previously, capacity of rural freeways generally is not a concern except where adverse terrain hinders the operation of vehicles. For this reason, the best MOE for rural freeways was taken to be travel time or speed. Results of the rural hypothetical modeling highlight significant issues related to travel times of the AHS and non-AHS lanes.

Rural Modeling Results

Table 7 shows that at low market penetrations the travel time of the AHS lane was limited by the speed associated with the geometry of the road. As the market penetration increased, the speed on the AHS lane was limited by a combination of the roadway design speed and capacity curve values from figure 7. At about 50 percent market penetration (50 percent of all passenger vehicles on the corridor using AHS) travel times actually increased over the original non-AHS freeway. This is the result of lower densities on the AHS which are based on the combination of 1 g braking of the preceding vehicle and AASHTO wet braking for the stopping vehicle. If technology to increase density at high speeds is achievable, low travel times can be maintained.

Table 7. Rural AHS Freeway Section Travel Times for Various Alternatives

	Total Travel Time (min.)**						Total Delay* (min.)					
	AHS Lane			Non-AHS Lane			AHS Lane			Non-AHS Lane		
Market Penetration	10	40	60	10	40	60	10	40	60	10	40	60
Base Case (No AHS)	N/A	N/A	N/A	50.41	50	50	N/A	N/A	N/A	1	1	1
Conversion of Lane	39	43	59	104	81	70	0	0	5	43	25	19
Addition of Lane	39	43	59	48	45	43	0	0	5	0	0	0
Limited Access to AHS	39	43	40	49	47	45	0	0	0	0.1	0	0

* Delay Defined as Time Spent Under 75 km/h.

** Minimum Travel Time for Corridor = 38.74 min. which corresponds to a maximum speed of 120 km/h.

These results raise some issues regarding the use of AHS. In order to maintain significant travel time savings along a rural AHS system, a way of controlling demand or limiting access must be implemented. In order to illustrate how a corridor can limit access, a third scenario was modeled which allowed entry/exit to the AHS lane at the beginning, end, and one point along the corridor. By limiting access in this way, only long distance users would use the AHS lane, reducing the volume along some sections of AHS.

By modeling this scenario, it was found that at both 10 percent and 40 percent market penetration, volumes were low enough that the travel time was governed only by the design speed of the road. At 60 percent market penetration, travel time was starting to be governed both by the geometry of the road and the results from the capacity curve mentioned previously. Market penetration used for this scenario is defined as the percentage of destination passenger vehicles using the AHS lane.

The concept of this limited-access scenario raises other issues relating to other activities. Entry and exit from AHS would take place at select rural exits and hence infrastructure (electronic device, etc.) directly relating to entry/exit would only need to be installed at heavy demand exits.

The method of controlling demand on AHS ensures that users will always arrive at the expected time, as once the volume associated with a desired speed has been allowed on the AHS, no further introduction of vehicles would be allowed until vehicles exited the system.

This method of demand could be handled in different ways. A message in the vehicle could indicate to the driver that the rural AHS lane is operating at capacity. The driver could then either take the traditional freeway until a slot became available or wait for another time. Another way demand could be handled would be to wait at some specified area until a slot became available. This operation would be similar to ramp metering.

It is noted that rural freeways do not have daily regularly occurring intense peak hours like urban freeways. Rural freeway peak hours are likely weekends or holidays, depending on the location. With this in mind, controlling demand may happen once or twice a week and may not create the frustrations that control of demand would cause in an urban setting. Also with the comfort and convenience of automated control, drivers may shift travel patterns to more nighttime driving as traditional safety issues related to driver fatigue would be significantly reduced.

Another important issue resulting from modeling is the effect AHS has on the non-AHS lanes. Two scenarios of accommodating AHS were modeled: conversion of one general-purpose lane to AHS, and adding an additional lane for AHS use. The concept of developing a separate facility exclusively for AHS was not considered in this study.

Although it was shown that travel time savings can be achieved for AHS users through limiting access or demand management, the corresponding travel times of the non-AHS lane significantly increase when one lane is converted to AHS. The hypothetical corridor used in this study was a four-lane freeway (two lanes in each direction). Converting one of these lanes to AHS in each direction would provide one AHS lane and one conventional lane in each direction. This configuration is the equivalent of a two-lane traditional highway with 100 percent no-passing zones for non-AHS users. As shown in figure 7, the travel time for non-AHS users is up to 100 percent more at low market penetration than for the base case (no AHS). This travel time is much greater for a number of reasons. The presence of heavy trucks combined with steep grades significantly slows all traffic down, as the ability to pass is non-existent. Large volumes (at or above the capacity of a single lane) reduces the speed of the section significantly.

Conversion of a lane to AHS also raises some interesting issues. It would be politically difficult to degrade operations on non-AHS lanes to accommodate a limited amount of AHS traffic. This is especially true during the early stages of deployment, as very few vehicles will be using AHS compared to the traditional lanes. Since it was discussed that rural AHS cannot be associated with increased capacity, comparison of total weighted average of travel times for all vehicles using the corridor was determined. Figure 7 illustrates that for the lane conversion option, overall travel time on the corridor increased for all market penetrations over the original case. This may cause even more problems politically to convert a lane, as the only advantages would be comfort, convenience, travel time predictability, and safety. Travel time predictability in the AHS lane is at the expense of travel time and travel time predictability in the non-AHS lane.

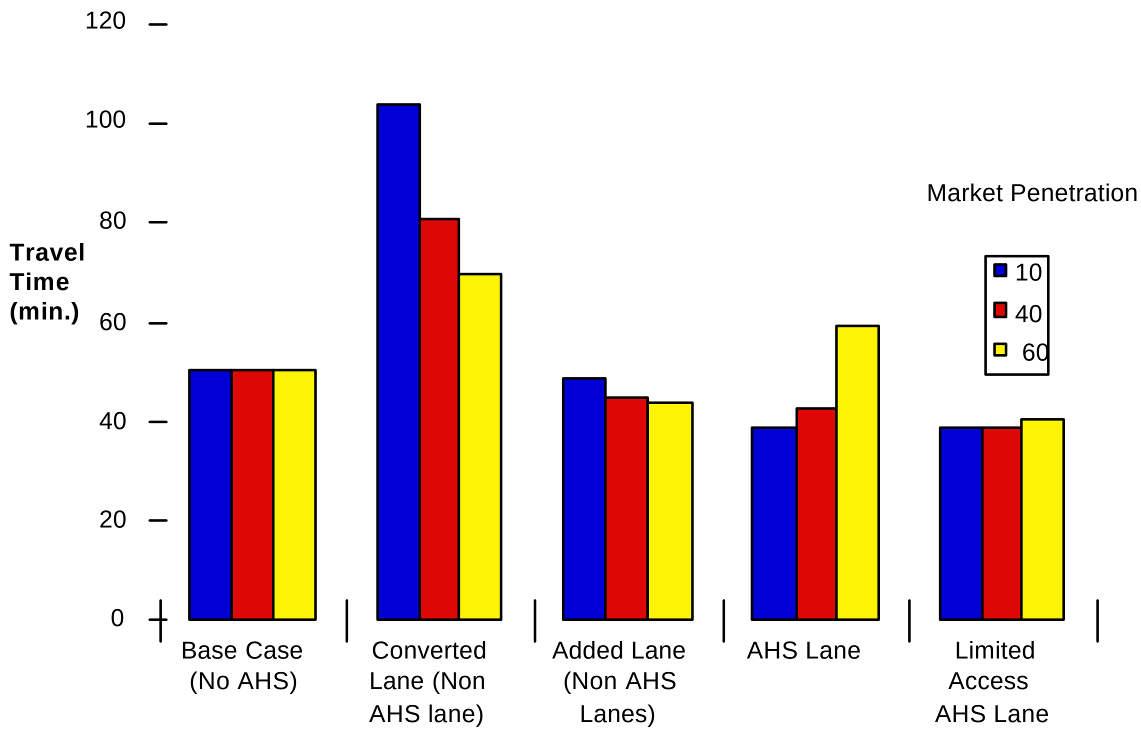

Figure 7. Travel Time Comparisons for AHS Travel versus Non-AHS Travel on the Hypothetical Rural Corridor

Conversion of a lane may also cause some operational concerns. At low market penetrations the AHS lane will only have a portion of capacity using it, while non-AHS lanes could be operating over capacity. Driver frustrations may cause unauthorized use of the AHS lane, as no barrier would exist between AHS and non-AHS lanes. Enforcement preventing this type of intrusion may be slow or difficult in a rural setting. Placement of barriers separating AHS from non-AHS users would eliminate this concern but would introduce new concerns at the interface points.

Adding a lane for AHS, although potentially expensive, would provide the best combination of AHS and non-AHS operations. By adding an exclusive AHS lane, travel time savings are also noticed on the non-AHS lanes as less traffic would be using the non-AHS facility. If AHS use was not controlled as discussed previously, the overall weighted average travel time for the corridor with two basic lanes and one AHS lane at high market penetration would actually be greater than the average travel time on the basic (non-AHS) two-lane facility. Adding a lane in order to incorporate AHS would require spatial requirements similar to widening for an additional traditional lane. Figure 7 illustrates that at lower market penetrations, a three-lane traditional highway will provide better travel time characteristics than a two-lane plus AHS lane. At high market penetrations, the benefit favors the AHS configuration. This raises the issue of portraying the other benefits of AHS in order to offset this potential disbenefit.

While modeling a range of AHS densities is outside the scope of this project, it is again noted that higher AHS densities (if they are safely achievable) have a profound effect on AHS volumes at given speeds. A fundamental result of this activity is that more knowledge of achievable densities is a requirement for good forecasting of AHS volumes and system operating conditions.

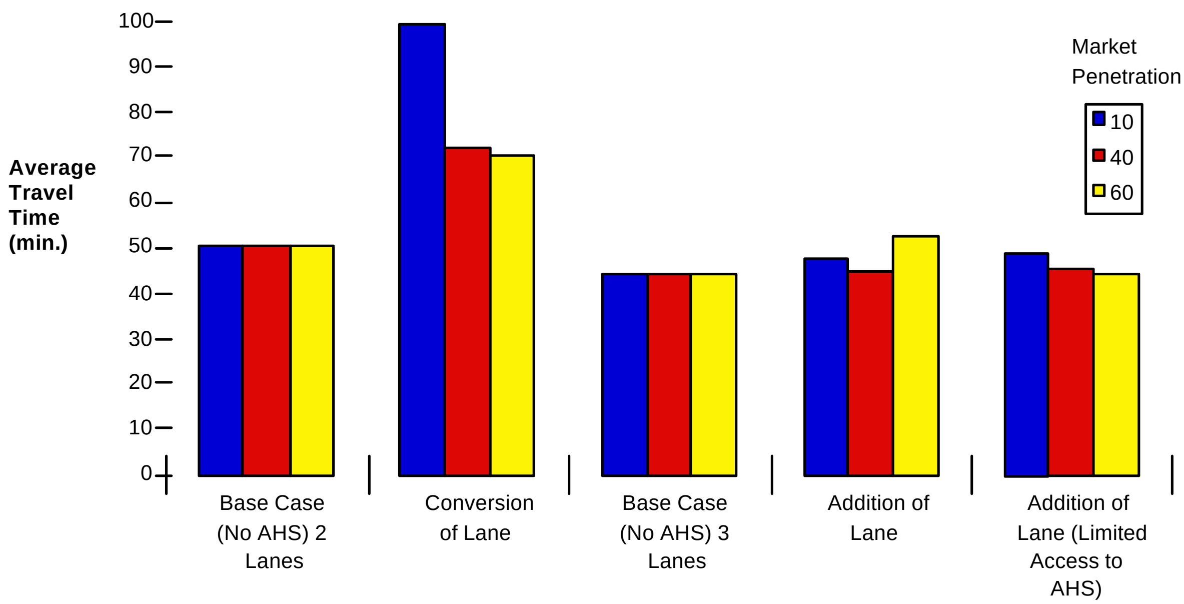

Figure 8. Comparison of Overall Weighted Average Travel Time Along Hypothetical Rural Corridor

Although not modeled, a scenario combining the two scenarios discussed could be considered. Where terrain and/or right-of-way requirements make it feasible to construct an extra traditional lane, traffic operations may improve over the exclusive conversion scenario. It is noted that additional lanes may not be required on both directions of the freeway. For example, in mountainous terrain there may be limited cross section available due to rock faces, etc. where perhaps one additional lane could be added. Adding this lane to the up-hill side would significantly improve overall speed on the non-AHS lanes, as passenger vehicles could then overtake slow-moving vehicles. A disadvantage of providing only partial lane addition would be the potential for bottleneck areas on the non-AHS lanes causing not only operational and problems but also increased safety problems.

It is reiterated here that these results are derived from this particular hypothetical corridor and may not be indicative of all rural corridors.

Task 4. Maximize System Benefits

The AHS PSA effort has brought together a network of specialists in widely separate fields. The conduct of the research presented many opportunities for these personnel to interact, not only within their own contracts, but with other contractors on the same activity.

It has become evident to the researchers that there are many times when knowledge which one specialty considers to be common knowledge, self evident, intuitively obvious, or even trivial, is not at all obvious to those outside his own field of expertise.

The disciplinary approach to the PSA work has returned benefits that were not necessarily expected by many specialists early in the project. The principal benefit is felt to be the importance of a systematic, multidisciplined approach to AHS. It is not sufficient to build an automated vehicle without customers. It is not sufficient to design an AHS with phenomenally high vehicle capacities if the AHS-manual interfaces will fail. It is not sufficient to plan, design, and construct an AHS if an agency is not able and willing to operate and maintain the system on a long term basis.

Instead of a tunnel-vision approach, it has to be recognized by all that every element of AHS reacts with every other element.

Many system issues have been addressed in the PSA. Numerous recommendations have been made to the effect that maintainability and operability should be planned and designed into the system, not "solved in the field."

The recommendation is therefore made that a Total Quality Management approach be taken to the system definition phase. To maximize system benefits, every element of subsequent system design should take a look at the human, AHS vehicle, operating system, and conventional parts of a trip.

Operational Topics

The AHS should be considered only one leg of the total trip. Constant consideration of the other elements of a door to door journey must be kept in mind. The researcher again uses an air travel analogy to make a point on AHS: In traveling from downtown Phoenix to downtown Los Angeles by air (a distance of 600 km), it is not unusual for half the travel time to be spent on the ground in Los Angeles. This can be the result of delays in taxiing after landing, delay at the gates, delays in baggage arrival, and traffic congestion between the Los Angeles airport and downtown.

While high-speed air travel is a tremendous benefit, other elements of the total trip have not kept pace with increased speeds while in the air.

To maximize AHS system benefits, door-to-door travel time should be kept in mind at all times. If AHS congestion is expected, due to either failure or excess demand, the system should be designed to notify the prospective user as soon as he gets in his vehicle (or even before that). The user can then make decisions on how to proceed. Options available include canceling or postponing the trip, taking an alternative AHS route (if available) or traveling the non-automated routes available. Given the interaction between AHS and the other Intelligent Transportation System (ITS) elements, there are numerous opportunities to integrate the legs of a trip into one.

Planning Topics

While this research team reached many of its conclusions through modeling and analyses of quasi-realistic scenarios, it has concluded that future AHS transportation planning should be based on the regional demand model of an actual site where AHS may be deployed early.

While many important findings were made, it is felt that there should be no drawbacks, and many benefits, to beginning to integrate AHS planning into regional transportation planning.

If an actual deployment candidate site is used for future analysis, the following benefits can result:

- The region can begin long range AHS planning, just as some State freeway agencies have provided room for rail transit in medians even when no such system is imminent.
- The regional transportation planners become stakeholders in AHS.
- AHS becomes an element of the regional transportation plan.
- Air quality issues can be addressed and modeled at an early stage of the planning process.
- Land use and social issues can be addressed, analyzed, and modeled.
- Local, regional, and State political leaders become exposed to AHS, and become stakeholders.
- Institutional barriers can be addressed.
- AHS can begin to be seen not only as a laboratory curiosity, but as a likely improvement to the rubber tired transportation mode within a relatively few years.
- Infrastructure issues related to evolution can be given consideration.
- Cost estimating based on actual site conditions can begin.

Task 5. Gather Expert Opinion

While it is possible for the research project personnel to conduct analysis and reach conclusions on its own, such an approach is a narrow one. For this reason, this activity as well as several others include a “gather expert opinion” task. Such expert opinion is not necessarily from the research or academic fields but includes stakeholders from highway agencies who would operate, or at least interact with, the automated highway system.

Senior management personnel from several state operations agencies were interviewed on this subject. The interviewees were members of the Transportation Research Board’s Committee on Freeway Operations, or friends of the committee. As such, they were already somewhat informed on AHS. These persons have long experiences in freeway operations and ITS in urban areas.

The research approach was to briefly describe the RSC’s to the persons interviewed, then to carry on an informal conversation. The researchers stated that the remarks would not be individually attributed but that the list of participants would be published to lend credence to the input provided. The researchers tried to play a neutral role while keeping the conversation going.

The same interview was used in gathering expert opinion for this activity area and Activity Areas K and O — AHS Roadway Operational Analysis and Institutional and Societal Aspects. Only those comments more directly attributable to “impact on surrounding non-AHS facilities” are reported here.

The agency personnel were well versed in capacity issues and were intensely interested in the throughput envisioned for AHS. It was explained that throughputs would vary among RSC’s, but that capacities of 6,000 vehicles per hour per AHS lane were being used for analysis purposes. The agency personnel recognized the importance of such additional volumes being attracted to an existing corridor. A recurring comment was that the freeway/ramp/cross street system is presently in a rough state of equilibrium. Recognizing that such volumes may be feasible on the mainline, they expressed concerns that the added volumes would overload the cross streets and ramps.

Agencies expressed concern that AHS is a single occupant vehicle (SOV) program, and as such is in conflict with air quality and related legislation. The comment was made that a linkage between AHS and HOV and transit needs to be made for AHS to be successful.

Check-in requirements were discussed. Agencies remarked that, for the system to attract users, it would have to be perceived as convenient. Long check-in delays and circuitous travel to get to entry/exit points were seen as deterrents to use. Frequent off-line inspections were also seen as deterrents. Check-in facilities that would require the purchase of land at entry points were viewed as very undesirable by the agencies from a cost, operations, and staffing viewpoint.

Initial deployment of AHS was seen as a big hurdle. None of the agencies represented thought it was at all realistic to build a dedicated AHS without a large base of potential users already on the ground. This was not presented as an anti-AHS position but rather as support for an incremental progression from today’s vehicles and highways, to ITS, to AHS.

The agencies expressed concern that AHS, as a subsystem of ITS, will be competing for funds with other worthy ITS projects. They stated that there are proven, practical, and desirable elements of ITS that should not be precluded by the development of AHS.

Task 6. AHS From an Urban Planning Perspective

AHS planning issues loosely fall into four categories: the built environment; the socio-economic environment; the socio-cultural environment, and the biophysical environment. These categories interrelate and impact one another. This section may reiterate issues discussed in other activity reports, but this is due to the interdisciplinary nature of the planning field. Planning utilizes and coordinates physical design, engineering, science, and sociological aspects of the built environment.

This section is written from the perspective of an urban planner, not a highway engineer. It is realized that many of the concerns raised are not restricted to AHS. Some of the concerns would apply to any other quantum improvement to urban mobility, including extensive improvements to the conventional street and freeway network or provision of a widespread rail transit system. However, most of the concerns are generally those associated with an automobile-dependent society.

Built Environment

Decentralization

Many cities within the United States are experiencing urban decentralization. This trend has occurred in natural response to several factors following World War II: the automobile became the primary means of transportation; the development of single family housing as the desired choice; the environmental and societal decline of the inner city, and improvements to highway networks. Today suburbia sprawls far from the heart of the city. Decentralization has led to increased automobile travel, congested highways, and extended travel times. AHS has the potential to reacquaint Americans with the vehicular freedom they once had. Through the reassurance of travel times and increased vehicular safety, the intelligent vehicle can provide Americans with a reliable means of transportation.

The freedom AHS offers does not come without some complicated issues. A concern to planners is that the introduction of AHS may encourage greater decentralization, possibly to the detriment of an already weakened inner city and central business district. If decentralization continues to weaken or phases out the large urban environment, smaller less dense towns and cities could evolve adjacent to the ingress and egress points of the AHS. Businesses could develop in low density business parks. Their business functions would rely on the AHS to provide inter-city transportation of goods and commuter support. A private vehicle would become a necessity within this decentralized environment due to the inefficiency of mass transit in low density developed areas.

These moderately populated small towns and cities could occur on a regional basis. The reassurance of private vehicular transportation dependability would allow employees to live in a geographic location of their choice while working in a non-related distant location. Commuter travel times may increase or stay consistent as the distance traveled increases. If the work and home environment become geographically separated the potential arises for business districts to develop adjacent to AHS access points surrounded by little or no residential land uses or support facilities. The reliance on the automobile could be greater than ever before in history.

On the other hand, an AHS integrated with higher occupancy vehicles has the potential to enhance mobility utilizing mass transit. If higher density residential and business land uses develop in conjunction with AHS access and egress nodes, unprecedented mobility for users of rubber tired mass transportation could result.

Infrastructure

As decentralization continues, the infrastructure must stretch to meet demand; otherwise, new systems would have to be created to serve development. There is a concern that growth patterns will be based on AHS ingress and egress points. If the access points are fairly close, infrastructure costs will be lessened. Encouragement of infill projects around retrofitted ingress and egress points would be beneficial to the existing community. Infill development would utilize existing open space, creating pedestrian links and uniform land development patterns.

If AHS access points are located five to eight kilometers apart, infrastructure construction would have a lag time and a higher cost. Development in outlying areas would have lower land costs, but higher infrastructure costs. Providing abundant AHS access for fringe development would encourage greater urban sprawl and potentially ignore infill opportunities.

Phasing access point construction and opening to correspond and respond to growth patterns could encourage a more homogenous development pattern, limiting the leapfrog development landscape that is often visible in Sunbelt cities nationwide.

Leapfrog Development

Leapfrog development is caused by a combination of land banking and relatively low land values. Scattered inconsistent development destroys mass transit efficiency, and increases automobile dependence. AHS has the ability to encourage or discourage leapfrog development. Speculative land banking would initially occur around AHS ingress and egress facilities. Phasing the access points would help manage growth. The access facilities would be opened as the area's need for service increased. This is typically a function of density.

Access to AHS

Access to AHS occurs on a community-wide as well as at a neighborhood level. Community interest would be focused on the ease of circulation to and from the AHS access points. Have the arterial roads been improved to carry the vehicular volumes created by these access nodes? Are the ingress and egress nodes within a reasonable distance to residences and businesses? The answers to these questions directly relate to the interval distance between the AHS access facilities. The decision on spacing would have to be made based on several planning related factors: the impact of new facilities on economically viable business centers; disruption of existing neighborhoods; the location of high use facilities (i.e. arenas, schools, and shopping malls that may or may not be spaced at a desirable distance). If high-volume facilities are not immediately adjacent to the AHS freeway, the feasibility of creating AHS service roads as an amenity should be studied.

If AHS access points are widely spaced, commuters might rely on existing freeway transportation systems to provide linkage to AHS ingress and egress facilities. Traffic and congestion around AHS facilities would increase significantly at ingress and egress points, as traffic exits the freeway, travels local streets, and enters the AHS. Commercial and office development would benefit from an increase in traffic but not congestion.

AHS access is desirable in business and commercial areas of existing high traffic volume, but it is equally undesirable in residential enclaves. If AHS facilities are placed at the halfway point between existing 1.6 km spaced arterial streets, existing housing developments would be negatively impacted by AHS access and its accompanying construction. These neighborhoods would then be a reduced to 550 to 800 meter square islands of homes bounded by heavily traveled arterial streets and highways. Residential home values within these areas could decrease significantly. Citizen opposition to the 1.6 km interval AHS access facilities would probably be strong. On the other hand, the value of the land could increase due to future commercial or office development potential. Even though land values might rise on residential property adjacent to AHS access points, owners may not be willing to relocate or sell their property. Rational business decisions are not always made when emotion is involved.

Zoning

Zoning is the key to developing the land surrounding AHS access facilities. Zoning could be used to create urban nodes, increase density, and provide development incentives. By increasing density and encouraging commercial and business ventures, these transit based urban nodes could potentially replace depressed residential neighborhoods or improve local commercial and business districts.

Rezoning of land around AHS access facilities could encourage high land values and increased commercial and office development and economically stimulate the community. In cases of rezoning where there are existing land use grandfather rights, such as residential homes, market economic rationale does not always prevail. Increasing property value is good for the property owners, but owners often act on emotion instead of good business sense. Public opposition to rezoning could be significant, but in the long run a community could benefit.

Socio-Economic Environment

Growth Management

The concept of AHS, like any other improvement to the transportation infrastructure, encourages growth. Growth often expands outside of existing city boundaries and in some cases outside of county and state boundaries. This external growth would not bode well with existing local governmental entities. Communities would lose revenue from the existing tax base. Loss of these funds would directly impact upon municipal services. To compensate for the loss of revenue, government agencies would be forced to raise taxes and fees on the remaining citizens and businesses. The high inner-city cost of living and the decayed environment would encourage a greater number of residents and companies to relocate to the aesthetic prosperous outlying fringe communities.

Local municipalities would probably not cooperate with AHS development unless a guarantee of limited or evenly distributed development is agreed upon. AHS would have to limit the number of access points outside of existing urban boundaries and encourage development around AHS access points retrofitted within the existing built environment. This development, whether it is residential, commercial or business, will increase the tax base and aid the community financially. If the existing city is prosperous, development of outlying areas would impact the urban core to a lesser degree.

Joint Development

Historically land values around mass transit stations have significantly increased due to accessibility and time travel savings. AHS could potentially plan to market its access points on the same basis. Joint development located at the ingress and egress points could potentially capture commercial and office development. This development could offer instant access to AHS, plentiful vehicular parking, zoning and development incentives, and existing infrastructure and street improvements. Encouragement of infill development would impede development on the outer fringe areas and help cities maintain the integrity of the urban office, business, and commercial environments. These joint development projects would bring increased revenue to the city and county governments. The governments would then support AHS transportation and encourage further development.

Socio-Cultural Environment

Community Services

As mentioned previously AHS has the potential to encourage widespread growth. Lower density development requires greater infrastructure distances, which increases costs. The cost of police and fire protection would rise, due to the increase in areas of required protection. The greater distances and possible remote location lead to longer response times to and from emergency locations. If a significant number of medical patients must be transported by air due to distances, medical service and insurance costs would increase proportionally. Other community services, such as garbage collection, would be impacted by the regional development. Longer times between collections periods would occur, possibly leading to health and safety risks.

Population Increase

Over the last decade, Sunbelt cities especially have experience population growth. AHS transportation supports suburban population growth and wide spread sprawl. If population growth occurs in the suburbs, there will be a greater demand placed upon AHS. AHS must incorporation improvement plans that match the increased population and development patterns of the city or region it is serving. If AHS facilities reach the point of saturation, the fringe communities, which rely on commuter time savings and safety, would be adversely impacted. When AHS reaches its saturation point, turning away vehicles and closing ingress points, local collector and arterial streets and freeways would have to carry the burden of the overflow traffic. The reemergence of a central city may occur if travel times on AHS become questionable due to vehicular saturation.

Neighborhood Integrity

Neighborhoods located near AHS access facilities would benefit from the quick, easy access provided. The locations of the access facilities are critical. The closer the locations are to one another, the greater the number of existing neighborhoods and businesses which would have to be relocated. AHS access roads, infrastructure, and accompanying storage facilities would require a significant amount of land. If AHS ingress and egress points are located at 1.6 kilometer intervals, between major city streets or at equal distance between freeway entrance and exit points, new overpasses and access points for the system would have to utilize 0.8 kilometer collector streets. Once land is taken for AHS facilities and access roads, existing neighborhoods are left with little buffering from major arterial and new AHS collector streets. These existing neighborhoods would lose their environmental integrity and land values. The odds of a neighborhood retaining its vibrancy and character within the new street structure are not good. The location of AHS entry and exit locations is an important element of AHS planning which would have to be carefully reviewed based site specific factors.

Determining the ideal distance between AHS access points is critical. The further these ingress and egress points are spaced apart, the fewer existing enclaves will be impacted. The planning decision of whether to limit the number of access points relies on the economic viability of the existing area. Some cities may see new construction as a way to improve undesirable segments of communities and encourage new development. Other communities, which have strong neighborhood community support groups, might fight any development which would bisect neighborhoods or commercial centers.

Biophysical Environment

Air Quality

AHS has the potential to negatively affect the air quality. Emissions are very high at idling or slow driving speeds. These emissions decrease as the vehicle increases in speed. This decrease in emissions peaks around 88 to 96 km/h. Therefore, if AHS vehicles are running at high speeds to decrease driving times, the emissions from the vehicles will be higher or equal to the current emissions of congested traffic. This effect would be magnified if the number of vehicles running at this speed is increased, e.g. if platooning increases capacity.

An optimum driving speed would need to be determined based on emissions. A solution to high emissions would be to promote AHS vehicles as Earth-friendly and provide for alternative power sources. Promoting efficient transportation without adversely impacting the environment is a strong incentive for change.

Natural Environment

AHS would increases suburban fringe growth and natural open space would continue to diminish. Currently many cities are experiencing a battle between dwindling wildlife habitats and man’s intrusion into the ecosystem. As AHS encourages low density growth and outlying development, more conflicts between nature and man will arise.

Conclusion

AHS has the ability to provide improved highway safety conditions, acceptable travel times, and an efficient, cost-effective way to support its construction and maintenance based on consumer usage. AHS must avoid undermining existing city employment and tax bases. Encouragement of infill growth surrounding AHS access points and relieving current highway congestion should be a primary goal of AHS.

Urban planning issues cannot and should not be addressed by engineers alone. Urban planners are stakeholders of AHS and potentially could make or break a program. While AHS could offer unprecedented opportunities for personal mobility improvement, the social issues involved must be addressed in the planning stages. It is therefore a fundamental recommendation of the report that urban planning agencies from the regional and local agencies be on board from the very beginning as specific sites are planned for AHS. Only then can the social issues covered in this section be addressed and mitigated.

Task 7. Recommendations

The purpose of this task was to develop recommendations in regard to the impacts of AHS facilities on the non-AHS surrounding roadways. The recommendations are based on the major findings of this activity area. The major findings of the analysis are:

- Modeling of the freeway corridors indicates that AHS lanes provide significant travel time benefits in the corridors.
- AHS entering and exiting traffic can have significant adverse impacts on AHS ramps, cross streets and parallel arterials as AHS traffic volumes increase.
- AHS traffic volumes could have significant impact on surrounding land use, particularly as AHS market penetration rates begin to approach 40 percent.
- The metering of AHS lanes with other travel demand management strategies can optimize AHS operations and minimize impacts on the surrounding roadways.

Based on the major findings, the following recommendations are made to minimize the impacts on surrounding roadways.

Future Research

A more comprehensive analysis of traffic demand and traffic operations should be carried out to combine a regional travel demand analysis and a freeway operations analysis. This analysis will permit a broader evaluation of shifting traffic patterns resulting from the use of AHS traffic volumes. The freeway analysis will then evaluate the resulting traffic volumes from the travel demand analysis and produce a more realistic operational analysis on the freeway corridor. Additional study is also needed on the impact of ramp metering on the traffic operations of the AHS facility and surrounding roadways.

Planning and Design of AHS Facilities

The planning of AHS facilities must carefully evaluate the surrounding roadways. AHS lanes have the potential of attracting large numbers of AHS equipped vehicles. The demand on the AHS lane will increase as the market penetration of equipped vehicles increases. The potential travel time benefits of the AHS lane could attract significant traffic to the AHS facility. Travel demands at the on and off-ramps could be high, thereby impact the cross streets and arterial streets. Recommendations have been developed to help minimize the impact on the surrounding roadways for the following categories: 1) location of interchanges; 2) traffic signalization and AHS control; 3) cross street design; and 4) ramp metering and demand management strategies.

Location of AHS Interchanges

The location and configuration of AHS interchanges affect the traffic circulation on the surrounding roadways. The approach to locating AHS interchanges should be to disperse the AHS traffic throughout the surrounding roadway system as much as possible. Split interchange configurations with AHS on-ramps at one location and off-ramps at another location could help to minimize the traffic impact on the surrounding street system. The analysis of the traffic operations indicated that as the spacing between AHS interchanges increases, the AHS traffic demand volumes increases. However, the provision of interchanges at closer intervals means higher costs.

The tradeoffs between accommodating higher traffic volumes at longer interchange spacing and the costs for providing more interchanges must be carefully evaluated in future planning of AHS facilities. As AHS traffic increases and normal freeway traffic increases, some opportunities may exist to replace existing conventional freeway on and off-ramps with AHS ramps at certain existing interchange locations. The reduced traffic at the freeway interchange to be replace would shift to another freeway interchange. Future research should be conducted to determine the market penetration rate at which point it becomes feasible to replace an existing conventional interchange with an AHS interchange.

Design of Cross Streets and Parallel Arterials

The planning of AHS facilities should include an evaluation of the physical configuration of the traffic circulation system. The planning should take a systems approach in analyzing the traffic operations of the AHS lanes, AHS ramps, cross streets, and parallel arterials. The cross streets and parallel arterial streets must be planned in conjunction with the planning of the AHS facility as an integrated system. The cross streets must be planned and designed to accommodate the heavy AHS traffic volumes. In addition, the intersections of the cross streets and parallel arterials must be designed to accommodate the new traffic patterns resulting from the location of the AHS entry/exit points. The planning should include an overall evaluation of the circulation of the surrounding roadways including the analysis of one way travel patterns.

Traffic Signalization/AHS System Control

The integration of the AHS system control and the surrounding traffic signal control is very important to minimize the impact on the surrounding roadways system. The planning of an AHS facility must include the control of the complete roadway system including the AHS lane, cross streets and parallel arterials.

Ramp Metering/Demand Management Strategies

The modeling of the urban freeway corridor indicated that metering of the AHS ramps can significantly improve the operation of the AHS lane and minimize delay at the AHS ramps. Other demand management strategies such as advisory signing and navigational notification of the locations of available ramps should be evaluated to minimize the impacts on the surrounding roadways.

CONCLUSIONS

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

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

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

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

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

BIBLIOGRAPHY

Activity Area F Report — Commercial and Transit AHS Analysis, AHS Precursor Systems Analysis, Delco Systems Operations, November 1994.

Activity Area H Report — AHS Roadway Deployment Analysis, AHS Precursor Systems Analysis, Delco Systems Operations, November 1994.

Activity Area I Report — Impact of AHS on Surrounding Non-AHS Roadways, AHS Precursor Systems Analysis, Delco Systems Operations, November 1994.

Activity Area J Report — AHS Entry/Exit Implementation, AHS Precursor Systems Analysis, Delco Systems Operations, November 1994.

Highway Capacity Manual Special Report 209, Transportation Research Board, National Research Council, Washington, DC, 1985

A Policy on Geometric Design of Highways and Streets, American Association of State Highway and Transportation Officials, 1990.

Transportation and Traffic Engineering Handbook, Institute of Transportation Engineers, 1982.