Precursor Systems Analyses of Automated Highway Systems

RESOURCE MATERIALS

Urban and Rural Analysis

U.S. Department of Transportation
Federal Highway Administration

Publication No. FHWA-RD-95-137
November 1994

PRECURSOR SYSTEMS ANALYSES

OF

AUTOMATED HIGHWAY SYSTEMS

Activity Area A

Urban and Rural AHS Comparison

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

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle PRECURSOR SYSTEMS ANALYSES OF AUTOMATED HIGHWAY SYSTEMS Activity Area A Urban and Rural AHS Comparison		5. Report Date 6. Performing Organization Code
7. Author(s) A. Cochran*, B. Culver, M. Halseth, S. Hayes, F. Mangarelli*, S. O'Brien**		8. Performing Organization Report No.
9. Performing Organization Name and Address Delco Electronics Corporation Delco Systems Operations 6767 Hollister Avenue Goleta, CA 93117		10. Work Unit No. (TRAIS) 11. Contract or Grant No. DTFH61-93-C-00194
12. Sponsoring Agency Name and Address IVHS Research Division Federal Highway Administration 6300 Georgetown Pike McLean, Virginia 22101-2296		13. Type of Report and Period Covered Final Report September 1993–November 1994 14. Sponsoring Agency Code

15. Supplementary Notes
Contracting Officer's Technical Representative (COTR) - J. Richard Bishop HSR 10
* Hughes Aircraft Company, San Diego, CA; ** Daniel, Mann, Johnson, and Mendenhall, Phoenix, AZ

16. Abstract

This activity analyzes the technical and operational requirements of an AHS in urban and rural environments. The characteristics of urban freeways and rural highways are compared to define common issues and risks and indicate areas of divergence in compatible system implementations. The comparison addresses three major areas: the trade among the goals of automated control in urban versus rural environments; the distinct operating characteristics of AHS subsystems in rural highways; and the design considerations for several AHS-specific elements. The issues and risks concerning the most cost effective approach to instrumentation content in terms of the control loop dynamics and potential market penetration in both environments are identified.

17. Key Words	18. Distribution Statement
Urban, rural, issues, risks, system configuration, trade off, operating characteristics, design considerations, vehicle, instrument content, roadway	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified		

Form DOT F 1700.7 (8-72)Reproduction of completed page authorized

(PF V2.1, 6/30/92)

TABLE OF CONTENTS

TABLE OF CONTENTS
(Continued)

TABLE OF CONTENTS
(Continued)

TABLE OF CONTENTS
(Continued)

TABLE OF CONTENTS
(Continued)

LIST OF TABLES

EXECUTIVE SUMMARY

This activity, Activity A — Urban and Rural Automated Highway System (AHS) Comparison, identifies and analyzes, at a high level, the technical and operational requirements of an AHS in urban and rural environments. The characteristics of urban freeways and the needs of commuters and work-day truck and transit traffic are compared with the profile of rural highways supporting relatively long trips with typically low traffic volume. The definition of an urban environment is not absolute, but varies by location across the country. Urban commuters in Southern California travel from all parts of several counties in diverse directions with no single distinct flow pattern. Congestion can be found at any time of day affecting various arteries to a greater or lesser extent from one day to the next. In contrast, metropolitan New York has a distinct commuter pattern into the city from the suburbs in the morning and out of the city in the evening. Other population centers have individual traffic characteristics which affect the characterization of urban freeway travel. Rural highways exhibit regional variation as well, with some locations bearing large weekend exodus loads which rival urban rush-hours. The terrain of rural highways is another significant variable that affects the ability to maintain smooth flow of mixed passenger and commercial vehicle traffic.

The Representative System Configurations (RSC’s) established for purposes of supporting the analyses of each activity area are used to evaluate the compatibility of specific configurations to typical urban and rural environments. The RSC’s are defined to provide a basis of comparison across a broad range of options. A single RSC is not recommended as a viable AHS configuration, but the elements of each are evaluated to determine their relative advantages and disadvantages in the urban and rural applications. An infrastructure-intensive configuration, referred to as RSC 1, is defined to place the maximum instrumentation in the roadway to illustrate the trade-off involved regarding urban and rural scenarios. A vehicle-intensive configuration, referred to as RSC 2, is defined to include the maximum instrumentation in the vehicle as a point of contrast to RSC 1. Both RSC 1 and RSC 2 are platoon-based. RSC 3 presents another approach in which the instrumentation is balanced between the infrastructure and the vehicle, in which vehicle slots are assigned in individual space/time units as opposed to platoon groups.

Trade-Off Analysis

The trade-off analysis uses the highly polarized example system configurations to evaluate the relative benefits of the major defining features of the RSC's. Infrastructure versus vehicle-based control and platoon versus non-platoon flow management are discussed in terms of factors including capacity, travel time, operator interface, deployment, safety, reliability, maintainability, and distribution of cost. Each of the design parameters is analyzed with respect to typical urban and rural sections to identify advantages or disadvantages. Specific attributes of each system configuration are evaluated individually in an effort to establish preliminary recommendations for implementation. Vehicle-based range-finding is compared with a roadway-based system for providing inputs to the longitudinal control loop. This function is an example of one which is determined to be most suited to placement in the vehicle.

There is concern that placing a large percentage of the instrumentation for AHS within the vehicle will raise direct consumer costs to an unacceptable level. The division of instrumentation between the infrastructure and the vehicle must be determined by system-level design considerations which take into account the complexity, testability, reliability, and maintainability of the system. The design complexity and testability of the control loop system is directly affected by the placement of the equipment. A vehicle-based implementation simplifies the timing of inputs to the processor, allows for testing prior to system integration, and provides reliability in the sense that a failure affects a single vehicle. The vehicles affected by each control station in an infrastructure-intensive configuration vary in time as the vehicles move along the highway. Precise timing for each vehicle is extremely complex, and the capacity of the communications system will increase. The testability of the system is more difficult, since it cannot be completely tested until system integration. Finally, reliability is a greater concern since a single-point failure of an infrastructure component may affect a large number of vehicles. The most cost-effective and reliable approach is to place the control loop instrumentation in the vehicle to minimize complexity and enhance testability.

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

System Element Characteristics

The functional characteristics of AHS are discussed in terms of the similarities and differences associated with operation in the urban and rural environments. This section focuses on identifying common system elements for the purpose of developing a cost-effective system approach capable of adapting to various operating requirements. The characteristics are analyzed from the perspective of vehicle subsystems, infrastructure deployment, operator interface, and communications and infrastructure electronics. The ability to meet AHS's social goals such as improving the environmental impact of highway travel, supporting older and physically challenged users, and other technical issues are discussed to evaluate the impact that urban or rural users will have on the operating goals of the system. The ability to identify areas of synergy between the urban and rural environments will allow the system architecture to exploit commonalties.

Design Considerations

The effects of differences between urban and rural operating characteristics are analyzed from the perspective of vehicle subsystems, infrastructure deployment, operator interface, and communications and infrastructure electronics. A set of design considerations based on development of system element characteristics are compiled to place an early foundation for the system architecture. Vehicle design considerations are discussed in the areas of hardware content, cost, reliability, maintainability, safety, and the operator interface. Roadway deployment is addressed in terms of highway geometry, typical section features, pavement/structure considerations, interchange and access elements, land use, and maintenance of facilities. Operator interface design factors include driver verification, the role of the driver in emergency maneuvers, user comfort, and information exchange. System requirements affecting the communications system design including data rate, latency, network configuration, and error rates are discussed as they relate to typical urban and rural operating modes. Finally, concerns regarding infrastructure electronics such as availability and reliability of support utilities, utilization of regional traffic operations centers, and functionality of roadside sensors are evaluated. The specific subsystems are analyzed with respect to the three system configurations to provide design recommendations related to each area. The impact of vehicle-centered platoon control, infrastructure-centered platoon control, and space-time slot control on the design of vehicle subsystems, roadway, infrasructure electronics, communications and operator interface are addressed. Conclusions are presented where specific recommendations are appropriate regarding design of each subsystem element.

Successful development and deployment of critical AHS subsystems is dependent on a variety of factors. Two concerns are the technology challenges associated with implementation of AHS functions and the effects of standardization on developing technology. Other issues include the level and method of interaction between the operator and the system, the optimum approach to supporting the interface between AHS and non-AHS highways, and the roadway features critical to AHS implementation.

Implementation of automated vehicle control will present challenges in the areas of accurate position determination, actuator technology, obstacle detection capability, communication of control information, and software functionality. The technical feasibility of the AHS program is dependent on the ability to produce reliable subsystems cost effectively. The current trend of reducing research and development in U.S. laboratories due to shrinking defense budgets has raised the possibility of redirecting scientific efforts to commercial applications. Feasible solutions must lend themselves to low cost and high-volume production in the automotive environment. Many of the technologies necessary to implement AHS functions have been proven in military environments, demonstrating highly reliable systems capable of operating in complex environments. The next step towards high-volume, low-cost production must incorporate requirements applicable to AHS-specific operating parameters.

Establishment of vehicle position is an integral part of the automated control loop. Accurate position location can be used to evaluate vehicle spacing and assist in maneuver coordination. It is also a key input to vehicle navigation and route planning operations. Information regarding vehicle velocity and acceleration is also required to maintain lateral and longitudinal control of AHS vehicles. Velocity and acceleration inputs are used to determine the adjustments necessary to maintain specified headway between vehicles. The primary requirements for automated headway control are safety, smooth control response, and fuel economy. The feasibility of measurement and communications techniques will rely on the complexity and related cost of implementation.

Current model automobiles utilize electronic control systems to improve the efficiency of power trains and to make cars safer and more pleasurable to drive. Examples of such systems include engine and transmission control, air bags, antilock brakes, suspension control, and

HVAC controllers. Each of these microprocessor-based control systems depends on reliable input data from sensors in order to output the proper commands to solenoids and actuators.

The processing power of AHS vehicles is expected to surpass that of today's in-vehicle controllers. A large percentage of the processing power will be dedicated to tasks related to fail-safe operation. Redundant system checks, redundant processing, redundant hardware, fault detection algorithms, fault mitigation algorithms, and data synthesis are some of the activities necessary to aid in safe operation. The design goals that must be met include: reducing the cost of electronics required to implement fail-safe operation, increasing the amount of memory and the speed of integrated circuits, increasing the reliability of IC's, and improving low-cost sensor reliability.

The AHS vehicle will need actuation capability that is reliable, cost-effective, and low-maintenance. Reliable steering, brake, and throttle control will be a key factor in implementing AHS functions. Actuators and the actuation techniques needed to achieve AHS operating parameters require further research, testing, and validation. Current hydraulic actuation used for some developmental steering systems is slaved to microprocessor-based controllers. Future implementations may consider an electric actuator approach to eliminate high-pressure hydraulic lines and other negative attributes, such as the load the hydraulic pump presents to the engine. The challenge lies in producing highly reliable new technology at costs comparable to existing equipment.

Designers of collision avoidance systems will face the challenge of developing a product capable of detecting a large range of objects, such as vehicles of all sizes, people, animals, and debris on the road. The system must be capable of discriminating between objects that must be avoided and objects that are not a threat to the vehicle or its passengers and thus do not require a maneuver. Existing obstacle detection systems installed in vehicles are intended for enhancing blindspot awareness, often using radar sensors. Low-cost radar currently has limited capabilities in terms of sensitivity and range. Fine resolution is necessary to differentiate relatively small features, such as spilled materials. Alternate solutions may be necessary to achieve the sensitivity, small size, and low cost necessary for AHS application. Higher-frequency radar with smaller size profiles may become viable as GaAs circuitry becomes cost-competitive with silicon. Signal processing in integrated circuits has the capability to improve resolution economically, and rangegating techniques may be considered to achieve all three objectives. Coordination with vendors while the technology is emerging may be necessary to ensure that developing technology will be compatible with AHS requirements in the evolutionary deployment of safety and convenience features.

The architecture of the communications system is a key issue. The long-term viability of the AHS depends on a communications system which provides sufficient data rate and user capacity in the mobile environment. The mobile communications link is subject to multipath and fading. The optimum frequency band, modulation scheme, multiple-access methodology, and data transfer rate are all parameters which must be defined to enhance performance under these conditions. These features must be specified to support the potential high density of urban environments and be flexible to support the rural environment as well.

The access protocol to the communications link is another key issue. Conventional access schemes may not provide the millisecond response times necessary in emergency maneuver situations. The access protocol must allow all vehicles to achieve data update rates consistent with vehicle control loop requirements. The message formats must be defined to ensure highly reliable vehicle identification when maneuvers are requested and performed.

The requirements of supporting real-time control of vehicles moving at high speeds is a prime area of consideration. The communications system design will provide vital information in support of safety-critical functions such as steering and braking. Communications supporting the longitudinal control function must have high update rates, low error rates, and high data rates. The systems must be robust in resistance to interference. The reliability of both the communications hardware and the network is important. Communications system reliability will be dependent on both the error rate of the link as well as the hardware failure rate. The robustness of the system design must take into account the high degree of variability in signal environment as well as the large number of potential users and great ranges covered by regional networks. The network design must incorporate redundancy in components and/or interconnects to provide single failure protection.

Software verification and validation will play a key role in assessing the dependability of AHS software. Prior to program verification, AHS specifications must be complete and consistent. Program verification demonstrates whether a program satisfies its specification; therefore the specification itself must be correct. The size and complexity of the AHS software should be kept to a minimum. It is increasingly difficult to adequately test software as the programs becomes larger and more complex, where the adequacy of testing is demonstrated in terms of reaching a target level of software reliability. It is necessary to reverify and revalidate the AHS specifications and programs each time a change is made. There are many approaches available to minimize the amount of reverification and revalidation that must be performed, including modular software design and the separation of safety-critical AHS functions from all other AHS functions. The concept of a safety kernel has been proposed to preserve safety-critical software routines intact. This approach allows modifications and upgrades to be performed without affecting safety-critical functions.

Urban/Rural Issues And Risks

The system-level issues and risks associated with designing, deploying, and operating an AHS in urban and rural areas are evaluated in terms of the characteristics unique to the specific environment. The ability to define an AHS which is tailored to a single operating scenario or one which is compatible to a variety of operating conditions is discussed. Topics include utilization of infrastructure elements, vehicle equipment factors, deployment considerations, communications options, emergency services, costs, malfunction management, and user perceptions. The issues are presented at the system level as a means to introduce the more detailed analysis to follow in the individual activity areas. This task is intended to lay the groundwork for the rigorous documentation of assumptions and conclusions which follow in the balance of the activity reports.

Standardization will play an integral role in reaching the goal of building and maintaining a national network of compatible and interoperable highway systems. A national AHS will require some level of cooperation among Federal, state, and local governments. The interests of each of these entities can conflict, potentially resulting in the conflicts becoming embedded in regional AHS standards. An example which illustrates this point is the difference among states in terms of their transportation policy, which is evident in the differing level of priority and funding allocated to emerging Intelligent Transportation Systems (ITS) projects. States with high degrees of congestion might place greater importance on increased capacity, while states with long stretches of rural highway might emphasize the improved safety and increased speed of travel aspects of AHS.

Corporate involvement in the AHS effort is driven by a profit motive; the automobile manufacturers and related AHS industries are concerned with issues of competitiveness and market penetration. Overly restrictive or poorly formulated design standards can have an adverse effect on competition, profit, or market potential. A certain level of standardization is necessary to ensure interoperability, yet the process must be achieved in a manner which allows technological innovation to flourish. The risk of introducing barriers to technological innovation exists whenever standards are adopted. Care must be taken in establishing the content and number of standards in order to allow widespread implementation of a national AHS architecture which allows continuing incorporation of state-of-the-art technology.

INTRODUCTION

The urban and rural AHS comparison centers on the definition of common issues and risks and identifies areas of divergence between system implementation goals in urban and rural environments. Various aspects of the urban/rural comparison have been highlighted for detailed study, including vehicle electronics and control systems, operator interface and human factors, infrastructure and communications electronics, and roadway deployment and operation. Three Representative System Configurations (RSC's) have been developed to provide a foundation for evaluation of issues and risks as they relate to AHS objectives.

The RSC's are used as a basis of comparison for the analyses performed in the subsystem categories. Each RSC has unique attributes which provide a broad range of diversity on which to build a discussion of the characteristics of urban and rural travel. Infrastructure-centered platoon control, referred to as RSC 1, is defined to place the maximum practical level of instrumentation on the highway and minimize AHS-specific vehicle instrumentation. Vehicle-centered platoon control, referred to as RSC 2, is defined to place the maximum practical level of instrumentation in the vehicle and minimize AHS-specific highway instrumentation. Both RSC 1 and 2 are platoon-based configurations, allowing a direct contrast between the considerations involved with infrastructure-based vehicle control and vehicle-based automated control. Space-time slot control, referred to as RSC 3, provides a balance between infrastructure and vehicle instrumentation in the vehicle control function in a non-platoon configuration. RSC 3 serves as a point of reference in considering the relative advantages and disadvantages of closely-spaced vehicles controlled in platoons and individual vehicles traveling in a point-following mode. The wide diversity provided in the definition of the RSC's is used to explore issues and risks concerning AHS implementation on urban freeways and rural highways.

The urban and rural AHS comparison is organized into four sections, covering the following subjects:

- Trade-off among goals of an urban AHS in relation to a rural AHS.
- Operating characteristics of AHS subsystems in urban and rural highways.
- Design considerations evolving from operating characteristics as they pertain to each of the various subsystem elements.
- Summary discussion of issues and risks gathered through the analysis process.

The trade-off analysis is an effort to highlight the areas of convergence or divergence between the system goals of a urban AHS and a rural AHS. The trade-off study provides a definition of urban and rural highways in terms of the attributes associated with the infrastructure in typical sections. These definitions are used to evaluate the ability of each of the defined RSC's to meet the system goals. The system goals are also ranked in relative importance for both the urban and rural settings. This approach provides a method for focusing on the system configuration which can meet the greatest number of high-priority goals in both environments.

The characteristics of AHS are next discussed in terms of the similarities and differences associated with operation in the urban and rural environments. The focus of this analysis is to identify common system elements for the purpose of developing a cost-effective system approach capable of adapting to various operating requirements. The characteristics are analyzed from the perspective of vehicle subsystems, infrastructure deployment, operator interface, and communication and infrastructure electronics. Various vehicle subsystem elements are evaluated in terms of their relative impact on urban versus rural concerns, including cost, safety, reliability, and technical feasibility. Infrastructure deployment characteristics such as number of lanes, interchange spacing, and facility maintenance costs are discussed to highlight the impact of urban versus rural operating scenarios.

The implications to AHS development are evaluated with respect to the urban and rural issues developed in the preceding tasks. The trade-offs in system configuration and the operating characteristics are viewed as they impact implementation of the RSC's defined for the analysis. Design consideration are analyzed from the perspective of vehicle subsystems, infrastructure deployment, operator interface, and communications and infrastructure electronics.

Finally, the issues and risks associated with designing, deploying, and operating an AHS under three scenarios are summarized. These include an AHS which is specific to an urban environment, one which is specific to a rural environment, and one which addresses the features of both urban and rural travel. The focus is placed on issues and risks which are related to the fundamental differences between urban and rural environments. The issues and risks are summarized in categories which correspond to related activity areas as an introduction to the detailed studies which are presented in the individual activity reports.

REPRESENTATIVE SYSTEM CONFIGURATIONS

The RSC's are documented in the Contract Overview Report. The attributes assigned to each RSC are presented in table 1 for reference in reading this report.

Table 1. Representative System Configurations with Attributes

Attribute	RSC 1 — Infrastructure-Centered Platoon Control	RSC 2 — Vehicle-Centered Platoon Control	RSC 3 — Space/Time Slot Control
Coordination Unit	Small Platoon	Large Platoon	Single Vehicle Slot
Inter-Unit Control	Asynchronous	Asynchronous	Synchronous
Vehicle Class	Passenger and Light Truck	Passenger and Light Truck	Passenger, Light Truck, Heavy Truck, and Transit
Lane Width	Normal	Narrow	Normal
Performance	Inclusive	High Performance	Inclusive
Vehicle/Roadway Interface	Rubber Tires	Rubber Tires	Rubber Tires
Propulsion (ICE = Internal Combustion Engine)	ICE and Electric With On-Board Source	ICE	ICE
Lateral Control	• Wayside Communication-Based Sensing • Wayside Electronic Map Reference • Wayside Control	• Vehicle Sensing of Magnetic Markers • Vehicle Control	• Vehicle Optical Lane Sensing • Vehicle Control
Longitudinal Control	• Wayside Communication-Based Sensing • Wayside Electronic Map Reference • Wayside Control Enhanced by Vehicle Collision Avoidance System	• Vehicle Communication-Based Sensing • Vehicle Control Enhanced by Vehicle Collision Avoidance System	• Wayside Generation of Vehicle State Requirements • Vehicle Control
Collision Avoidance	Vehicle Radar System	Vehicle Radar System	Vehicle Vision System
Longitudinal Position Location	Wayside Communication-Based Ranging	Vehicle Sensing of Coded Magnetic Markers	Vehicle Wheel Speed Sensing Enhanced by Wayside Tag System or GPS
Check-In Delay Time	Delay	No Delay	Delay
Unqualified Vehicle Entry Prevention	Physical Barrier	Electronic Barrier	Enforcement
Entry To Automated Lane	Dedicated Facility	Dedicated Facility	Normal Highway Lane
Driver Monitoring For Check-Out	Localized Roadway/Vehicle	Localized Roadway/Vehicle	Continuous In-Vehicle Monitoring
Traffic Management	Regional	Regional	Regional
Inter-Vehicle Control	Zone	Vehicle	Zone/Regional
Malfunction Management	Zone	Vehicle/Zone	Zone/Vehicle
Communications Vehicle To Vehicle	None	Vehicle Based Communications/Ranging	None
Communications Vehicle To Roadside	Two-Way Communication Tag	Same As Vehicle To Vehicle Or Public	Two-Way Communication Tag

TECHNICAL DISCUSSION

Task 1. Trade-Off Analyses

The RSC's defined for the Precursor Systems Analysis (PSA) effort are intended to provide diversity for the purpose of detailed analysis. The attributes assigned to each RSC are selected to support the individual configuration without attempting to create a single "best" configuration. Each of the RSC's is evaluated in terms of operational requirements including performance, cost, and benefits. The operating requirements are weighted for the three RSC's in both the urban and rural environments. Objective examination of individual elements is used to identify critical factors as a function of the system configuration. The goal of this analysis is to evaluate the operating requirements to determine which elements are key to the success of AHS. The RSC's are then assessed to determine which attributes of each configuration have the greatest effect on the feasibility of AHS.

Several assumptions are made in the trade-off analyses of the RSC's in the urban and rural environments which are dependent upon the characteristics of urban and rural freeways. Table 2 presents a number of features and how they typically differ between urban and rural freeways. No single attribute should be taken as an absolute, since there is no single attribute which may be used to definitively separate urban and rural freeways. Definitions based on population or typical interchange spacing were discussed early in the analysis and used to refine top level concepts.

Urban Environment Analysis

The results of evaluating the operational requirements for each of the RSC's in terms of the urban environment are summarized in table 3. The requirements are defined in the Operating Requirements section of the Contract Overview report. The requirements are weighted to indicate their relative importance in the urban environment. The relative weights are assigned on a scale of one through ten. Equal weights are given to requirements which cannot be favored over one another but must be balanced in the system design. An example of equally compelling requirements are capacity and safety. While maximizing capacity might be considered the highest priority for AHS in the urban environment, it cannot be increased without regard to safety.

Table 2. Attributes of Urban and Rural Freeways

Attribute	Urban	Rural
Interchange Spacing	≥ 1.6 Kilometer	≥ 8.0 Kilometer
Gas Stations	Frequent	Infrequent
Rest Areas	None	Approx. 80 Kilometer Spacing
Jurisdictional Boundaries	Frequent	Infrequent
Utilities	Adjacent	Variable
Median	Narrow With Barrier	Wide Without Barrier
Trip Length	Short	Long
Percent Trucks	Low	High
Peak Hours	Intense	Dispersed
Seasonal Factors	Minor	Major
Peak Day	Weekday	Weekend
Number Of Lanes	6+	4
Adjacent Development	High Density	Undeveloped/Low Density
Right Of Way Cost	High	Low
Terrain	Flat, Rolling	Flat, Rolling, Mountainous
Jurisdictions	Incorporated	Unincorporated
Enforcement	State, County, Local	State
Maintenance	State, County, Local	State
Construction Funding	State, Federal, Local	State, Federal
Trip Purpose	Commercial, Commute	Commercial, Commute, Pleasure
Driver	Familiar	Unfamiliar
Accident Type	Multiple Vehicle	Single Vehicle
Freeway Management System	Present	Absent
Illumination	Present	Absent or Interchange Only
Guide Signing	Overhead	Ground Mounted
Sign Lighting	Present	Absent
Animals	Small	Large
Hazardous Cargo	Absent	Present
Emergency Patrol	Present	Absent
Incident Detection Time	Short	Long
Incident Response Time	Short	Long
Call Boxes	Present	Absent
Speed Limit	Based On Conditions	Nationwide Maximum
Congestion	Prevalent	Unusual

Table 3. RSC's versus Operating Requirements in Urban Environment

System Parameter	Weight	RSC 1 Infrastructure Platoon Control	RSC 2 Vehicle-Centered Platoon Control	RSC 3 Space/Time Slot Control
Capacity	10	High	Highest	Medium
Travel Time	7	Better	Best	Good
Operator Interface	5	Good	Fair	Better
Deployment	8	Complex	Complex	Complex
Operating Environment	4	Not Well Suited	Not Well Suited	Well Suited
Efficiency	3	Best	Good	Better
Safety	10	Safe	Safe	Safer
Reliability	9	Higher	High	Highest
Maintainability	6	More Difficult	Not Difficult	Less Difficult
Emergency Service	2	Good	Good	Good
Vehicle Cost	9	Medium	High	Medium
Infrastructure Cost	5	Higher	Medium	High

Next, the RSC's are ranked relative to one another in their capability of meeting the specific requirements. There are slight distinctions which cause one RSC to be considered more effective in several cases. The criteria used for determining the relative effectiveness for each requirement are discussed in the following paragraphs.

Capacity

Capacity has the highest relative weight (10) in the urban environment, indicating that it and safety are the highest-priority requirements for AHS. The mature AHS system must be able to support future urban traffic demand in order for its deployment to become reality. Infrastructure and vehicle-centered platoon control have similar capabilities for increasing capacity. Vehicle-centered platoon control is given the higher effectiveness rating because the RSC definition includes larger platoons, thereby increasing capacity. RSC 3 has the lowest capacity rating because space/time slot control inherently limits the density of vehicles in the system.

Travel Time

Point-to-point travel time includes both trip length and variability and is rated at 7 in relative importance in the urban environment. Vehicle-centered platoon control obtains the highest effectiveness score among the RSC's because it is defined as compatible with high-speed vehicles, providing the greatest potential for reducing trip length. All three RSC's are capable of meeting the goal of reducing the degree of variability in trip times. Space/time slot control has the lowest effectiveness in this category because it allows trucks to use the same lanes as passenger cars, reducing the maximum speed.

Operator Interface

The AHS vehicle user interface is rated at 5 in relative importance in the urban environment. All three RSC's meet the requirement of being capable of transferring information such as destination and access status between the driver and the system. The user friendliness of the operator interface is highly dependent on the quantity of information which must be communicated as well as the medium in which it is presented. Another factor in rating the user interface is the impact the driving environment has on user stress and comfort with the safety of highway driving. The operator interface in RSC 2 is rated as fair because the close spacing and high speeds is most likely to cause a lower comfort level with AHS travel. RSC 1 has lower speed platoons, but close spacing remains an issue. The operator interface in RSC 3 is considered better because the slots will provide a comfortable environment and access to the system is straightforward.

Deployment

Ease of implementation and transition to AHS is rated at 8 in relative importance in the urban environment. Each of the RSC's has a level of complexity which will impact deployment of the mature system. Complexity of vehicle-centered platoon deployment is significant from the perspective of required vehicle equipment, but is least complex from an infrastructure standpoint. RSC 2 involves electronics for vehicle control, check-in/check-out, and entry/exit functions, as well as infrastructure impact for entry/exit facilities and lateral control. Infrastructure and space/time slot control both have greater potential impact to traffic flow during highway upgrades due to high levels of infrastructure modification. Both RSC 1 and RSC 3 have less vehicle equipment than RSC 2, balancing the increased complexity in infrastructure deployment. Deployment effectiveness is affected to a great extent by highway disruption and extent of modifications. Vehicle electronics become a deployment issue when providing a sufficient population of AHS compatible vehicles to justify implementation of the system is a factor.

Operating Environment

The effectiveness of the AHS configuration on both urban and rural freeways is given a priority rating of 4. All three RSC's are capable of operating in both urban and rural environments. RSC 1 is not particularly suitable to the rural environment because the definition includes dedicated entry/exit plazas, which would cause a deployment problem over long distances. RSC 2 is not well suited to the rural environment because it requires a greater vehicle upgrade cost in addition to entry/exit facilities, which may discourage a user population large enough to justify its deployment. RSC 3 is well suited for deployment in the rural environment because it does not require access facilities, vehicle costs are minimized, and the slot configuration is compatible with traffic densities.

Efficiency and Support of Alternative Propulsion

Reduction of fossil fuel consumption is rated at 3 in relative importance in the urban environment. Infrastructure platoon control has the best effectiveness rating because it is defined as compatible with electric vehicles. Vehicle-centered platoon control has good effectiveness in this category because it eliminates inefficiencies caused by stop-and-go traffic, but does not support alternative propulsion. The amount of fossil fuel consumed per vehicle kilometer traveled may be reduced within platoons, but the higher speeds traveled in RSC 2 are viewed as negating any benefits obtained by drafting. Space/time slot control is more efficient than RSC 2 because it provides constant traffic flow, and the speeds are within the more efficient range of engine performance. RSC 3 is not as effective as RSC 1 since it does not support alternative propulsion.

Safety

Safety has a relative weight of 10, indicating that it has the same priority as capacity in the urban environment. The proposed AHS design must be safer to travel than existing freeways for the concept to receive broad-based support. Any AHS implementation will be required to meet certain safety standards. The issue in this analysis is the feasibility of meeting that standard in a given configuration. Space/time slot control has the highest potential safety rating because the vehicle spacing is optimized for safety. Infrastructure and vehicle-centered platoon control have similar safety potential, but the platoon configuration is more prone to multiple vehicle accidents in situations where hazards are involved. All configurations must be considered equally safe from a malfunction standpoint because the design of the system will require a certain accident per vehicle-kilometer rating.

Reliability

Reliability is closely tied to safety and is given a relative weight of 9. The reliability of any AHS implementation will be required to meet certain criteria. Again, the issue in this analysis is the feasibility of meeting that standard in a given configuration. Space/time slot control obtains the highest effectiveness score among the RSC's because it is the least complex and contains the minimum opportunities for component failure. Infrastructure platoon control is rated as having slightly greater difficulty meeting reliability standards because it has added complexity in the entry/exit infrastructure and physical barriers to non-AHS traffic. Both infrastructure-based RSC's are subject to greater system impact of single-point failures than RSC 2. The vehicle-based control of RSC 1 lends itself to functional redundancy due to its implementation of distributed control. The reliability of a single unit in vehicle-centered platoon control is extremely high; however, the overall system reliability is judged as most difficult to achieve in this category because of the extent of vehicle based equipment. The cost and complexity of providing fault tolerance for every vehicle-centered control system is multiplied over every vehicle in the system.

Reliability of the system is dependent on the reliability of the individual unit, which is largely based on component failure rates. This category can be thought of in terms of an analogy; it is much more likely for a disabled vehicle to occur somewhere along a typical commute route than it is for a ramp meter to malfunction. System reliability is basically 1 minus the product of the probability of failure of every subsystem in a given AHS configuration.

Maintainability

The maintainability of the infrastructure and vehicle electronics is rated at 6 in relative importance in the urban environment. Vehicle-centered platoon control obtains the highest effectiveness score among the RSC's because the logistics involved in maintaining individual vehicles is straightforward and does not impact travel lanes. One important factor to consider in the case of RSC 2 is a method for verifying that candidate vehicles are maintained to AHS standards. Infrastructure platoon and space/time slot control are considered more difficult to maintain because they incorporate infrastructure complexity. Maintenance of the infrastructure components of the AHS involves both prevention and malfunction services. Systems will require designs which incorporate graceful operation under routine maintenance as well as during repair of malfunctions. RSC 1 has the lowest effectiveness in this category because it requires the highest degree of infrastructure maintenance with a corresponding impact to traffic flow and it is slightly more difficult to maintain than RSC 3 because it has entry/exit control in the infrastructure.

Emergency Service

The effectiveness of the AHS configuration in providing emergency service is given a priority rating of 2. All three RSC's have moderate ratings in this category because each RSC is capable of providing priority access to emergency vehicles and supporting emergency modes of operation. RSC 1 and 2 are limited in their capacity to decrease the transit time of emergency vehicles in a single lane AHS. The AHS lane must be cleared of entire platoons to allow emergency vehicles to pass, which is plausible but has a significant impact on throughput. Another factor in emergency service is that either the queue must be cleared at check-in or a lane must be dedicated for emergency and enforcement vehicles. RSC 3 does not have dedicated check-in lanes, limiting access to emergency vehicles behind other cars, but the emergency vehicle cannot reach the AHS lane across non-AHS traffic if the non-AHS lanes are blocked.

Vehicle Cost

The cost of vehicle equipment has a relative importance of 9 in the urban environment, reflecting the impact huge quantities of vehicles will have on implementation costs. Infrastructure platoon and space/time slot control both will have some degree of vehicle costs stemming from communications and lateral control electronics. Vehicle-centered platoon control has a high vehicle cost rating because its control philosophy is vehicle-intensive, adding a potentially significant increase to AHS vehicle price tags.

Infrastructure Cost

The cost of infrastructure instrumentation has a relative rank of 5 in the urban environment, significantly lower than vehicle costs because the number of freeway kilometers is limited. Infrastructure platoon control has the highest potential infrastructure cost because its control philosophy is infrastructure-intensive. Space/time slot control has a slightly lower infrastructure cost primarily because entry/exit barriers are eliminated. Vehicle-centered platoon control has lowest infrastructure cost because its control is largely in the vehicle and infrastructure equipment is required only for wayside sensing.

Rural Environment Analysis

The results of evaluating the operational requirements for each of the RSC's in terms of the rural environment are summarized in table 4. The analysis is performed in much the same manner as the urban trade-off. Many of the operating requirements are evaluated the same across the RSC's in both environments. The discussions below highlight the major differences and provide rationale for the relative weight of each operating requirement.

Table 4. RSC's versus Operating Requirements in Rural Environment

Operational Requirement Weight		RSC 1 Infrastructure Platoon Control	RSC 2 Vehicle-Centered Platoon Control	RSC 3 Space/Time Slot Control
Capacity	1	High	High	High
Travel Time	8	Better	Best	Better
Operator Interface	4	Good	Fair	Better
Deployment	9	Complex	Complex	Complex
Operating Environ-ment	3	Well Suited	Well Suited	Not Well Suited
Efficiency	5	Better	Good	Better
Safety	10	Safer	Safer	Safe
Reliability	6	Higher	High	Highest
Maintainability	6	More Difficult	Not Difficult	Less Difficult

Emergency Service	2	Good	Good	Good
Vehicle Cost	5	Medium	High	Medium
Infrastructure Cost	9	Higher	Medium	High

Capacity

Capacity has the lowest relative weight (1), reflecting the view that traffic density is not a driving force toward AHS in the rural environment. All three RSC's have high effectiveness in terms of meeting the capacity requirements of the rural AHS.

Travel Time

Point-to-point travel time is rated at 8 in relative importance in the rural environment. Infrastructure and vehicle-centered platoon control both have the same effectiveness score as the urban scenario. Both RSC 1 and 2 do not include heavy trucks or buses, so the travel time will not be limited by maximum speeds of slower traffic. RSC 2 is judged to have the shortest potential travel times, since it supports high-performance vehicles. Space/time slot control is capable of providing passing lanes on grades in the rural countryside where land use is not an issue. The impact of mass transit vehicles and trucks on travel time is reduced for RSC 3 on rural highways, making its travel time effectiveness better than in the urban environment.

Operator Interface

The AHS vehicle user interface is rated at 4 in relative importance in the rural environment. The effectiveness of each RSC is unchanged from the urban environment. The driver perception may be improved in the platoon control RSC's in cases where traffic density allows single-car platoons. The overall rating is not improved, however, because the potential for close spacing between vehicles is inherent in the design.

Deployment

Ease of implementation and transition to AHS is rated at 9 in relative importance in the rural environment. Deployment of AHS infrastructure and vehicles has higher significance in the rural environment for two reasons. The impact of infrastructure complexity is greater on rural highways due to the greater distances involved. The deployment of AHS vehicles is an issue because the level of patronage must be high enough to justify implementation of the system. The relative ranking of each RSC is unchanged in considering deployment tradeoffs. RSC 1 and 3 increase in complexity in terms of impact to the infrastructure, but RSC 3 has a corresponding impact to transition to AHS from the vehicle perspective.

Operating Environment

The effectiveness of the AHS configuration on both urban and rural freeways is given a priority rating of 3. Both infrastructure and vehicle-centered platoon control are well suited to urban implementation, since they support higher vehicle densities. Space/time slot control is not as well suited to the urban environment as it is to rural because its maximum density is limited. None of the RSC's is best suited in both environments due to the attributes assigned in their definition.

Efficiency and Support of Alternative Propulsion

Reduction of fossil fuel consumption is rated at 5 in relative importance in the rural environment due to larger travel distances. Infrastructure platoon control is less effective in the rural environment because the complexity involved in providing alternative fuel support is prohibitive over long distances. Improvements in fuel efficiency may be realized on a greater scale in space/time slot control because this RSC supports mass transit and trucks, facilitates travel at fuel-efficient speeds, and can minimize inefficient stops for rest by relieving drivers of vehicle control.

Safety

Safety has the highest relative weight (10), indicating that it is the highest priority requirement for AHS in the rural environment. All three RSC's have similar potential safety, since spacing can be optimized for safety under lower traffic densities. The proposed AHS design must be safer to travel than existing freeways for the concept to receive broad-based support. Any AHS implementation will be required to meet certain safety standards. The feasibility of meeting safety standards in a given configuration is similar for RSC's 1 and 2. Space/time slot control has the lowest rating because there is no barrier between AHS and non-AHS lanes, corresponding to a greater potential for accidents due to human error.

Reliability

Reliability is closely tied to maintainability in the rural environment and is given a relative weight of 6. Decreased traffic density causes malfunctions to have a less immediate impact on safety and a greater impact on maintainability over greater highway kilometers. There is no change in the effectiveness scoring of the three RSC's, since their relative impact on equipment reliability is independent of the environment.

Maintainability

The maintainability of the infrastructure and vehicle electronics is rated at 6 in relative importance in the rural environment. Greater quantities of infrastructure equipment will require service due to longer highway lengths, but the logistics of accessing the equipment for maintenance will be less complex when disruption of traffic flow is less of an issue. One factor in judging the complexity of maintenance will be the locations of AHS service facilities for vehicles in rural areas. Infrastructure facilities may be combined with existing highway departments, but service stations may not be qualified to maintain AHS vehicle equipment in every population center in the short term.

Emergency Service

The effectiveness of the AHS configuration in providing emergency service is given a priority rating of 2. All three RSC's have good effectiveness in this category because each RSC is capable of meeting the requirement of providing priority access to emergency vehicles and supporting emergency modes of operation. None of the RSC's is derated in this environment because the lower densities of the rural highways enhances the flexibility of the RSC configuration.

Vehicle Cost

The cost of vehicle equipment has a relative importance of 5 in the rural environment, because the density of vehicles is much less than the urban environment. The relative ranking of the RSC's is unchanged.

Infrastructure Cost

The cost of infrastructure instrumentation has a relative rank of 9 in the rural environment, reflecting the significantly large number of freeway kilometers involved. The relative ranking of the RSC's is unchanged.

Conclusions

The primary results of this analysis show that the operating requirements must be balanced to determine the best system configuration. Any system design can be made as safe and reliable as any other, but the cost, complexity, and possibly capacity must be considered in the trade off. The best configuration will allow the highest-priority operating requirements to be met while realizing a system that minimizes complexity of implementation.

Task 2. System Element Characteristics

The characteristics of AHS are discussed in terms of the similarities and differences associated with operation in the urban and rural environments. The focus of this analysis is to identify common system elements for the purpose of developing a cost-effective system approach capable of adapting to various operating requirements. The characteristics are analyzed from the perspective of vehicle subsystems, infrastructure deployment, operator interface, and communications and infrastructure electronics. The implications of similarities and differences as they are related to the RSC's are discussed in Task 3.

Vehicle Characteristics

The characteristics which pertain specifically to the vehicle are discussed in this subsection. Table 5 summarizes the relative importance of these factors. The vehicle design column relates the degree of importance of each factor to the other factors in that column. The urban column is relative to the rural column. This subsection provides further explanation of the entries in this table.

Environmental

Environmental factors such as air pollution, noise pollution, and fuel consumption are similar concerns for both environments. However, regulations may differ, thus affecting vehicle requirements and design. Vehicle noise and air pollution controls (including for electric vehicles) are more critical for urban users, due to greater population density. Existing and emerging regulations aimed at reducing passenger vehicle pollution in urbanized areas is an important aspect manufacturers must consider in vehicle development. On the other hand, vehicle design to reduce fuel consumption is more important for the rural user, because of greater travel distances.

Table 5. Factors Affecting the Vehicle Design for Urban and Rural Environments

Importance of Factor...	...On Urban	...On Rural	...On Vehicle Design (Relative)
Environmental	Higher	Lower	Higher
Cost	Lower	Higher	Higher
User Perceptions/ Public Acceptance	Lower	Higher	Lower
Safety	Higher	Lower	Higher
Reliability	Higher	Lower	Higher
Liability	Higher	Lower	Lower
Physically Disadvantaged	Equal	Equal	Lower
Alternate Transportation Systems	Higher	Lower	Lower
Parking/Vehicle Storage	Higher	Lower	Lower
Other Technical Issues	Lower	Higher	Lower

Costs

The funding base of a rural project will be different from that of the urban base. The dispersed rural population may be unable to generate a tax base to support an advanced highway system. Businesses and residences tend to locate in areas to minimize the cost of transportation. Businesses have historically been located in the urban area to be near other required services and to have ease of access to suppliers, labor, and other products. Workers have moved into urban areas (or nearby suburbs) to minimize travel times to jobs. Benefits of reliable travel times may make AHS-specific vehicle costs more palatable for urban travelers facing increasing commute times.

User Perceptions/Public Acceptance

Choice of transportation mode is often based on factors including cost per kilometer traveled, convenience of door-to-door travel, and overall trip time for both workday commutes and leisure trips. The automobile is a carapace, unique to the individual whether in a rural or urban environment, and provides a high degree of user comfort in comparison with other mass transit alternatives. The automobile will continue to be the preferred mode for many trips that air, rail, or bus do not conveniently serve, making AHS travel attractive for both urban and rural users. Vehicle designers and highway planners must consider the fact that rural routes are also utilized for leisure activities by those living in both environments. The advantages of automated travel may be less obvious to the rural user, since the AHS is often viewed as focused primarily on reducing congestion and increasing capacity. Small-town residents feel remote from the external authorities whose actions affect their lives, creating an additional obstacle to acceptance by rural travelers. There is also the general feeling that the benefits of AHS to suburban commuters are greater than for inner city urbanites, causing concern that the AHS will serve an elite minority of travelers. The absence of congestion on rural highways may reduce the perceived need to upgrade large sections, making it more difficult to sell the AHS concept nationwide. Designing a vehicle for both environments will make AHS more desirable by increasing the potential market penetration and taking advantage of the benefits of volume production.

Safety

The AHS is a natural upgrade of the interstate highway system. As such, any successful AHS must achieve a level of safety at least equal to that of existing freeways. Present limited-access freeways have the lowest fatalities per vehicle kilometer of any highway category. Indeed, the fatality rate has a long-term trend of decreasing, due to improved vehicle design and safety equipment, increasing public concern about and action against drunk driving, and improvements to the freeway system to remove isolated instances of less than ideal design for safety. Comparing urban and rural freeways, the present urban system has a somewhat lower fatality rate. However, the number of fatalities occurring on rural freeways represents a small fraction of the total of all highway fatalities. It is very likely that the public will begin to perceive the goal of increased safety on the freeway system or its AHS replacement as an instance of diminishing return on investment. This is seen as likely because the present freeway fatality rate of about one fatality per hundred and sixty million vehicle kilometers translates into one chance in ten thousand of being a fatality for each year of sixteen thousand kilometers of freeway driving. Assuming a lifetime of eighty years, this represents one hundred and twenty-five lifetimes. Vehicle-related safety equipment may be perceived as being less beneficial to the rural user due to the low average traffic density, regardless of the fact that the higher travel speeds typically found in rural areas increase the risk of injury or death in collisions. The urban user tends to see more accidents because of the much higher traffic density and thus could be expected to continue to place a greater premium on increasing levels of highway safety. However, AHS vehicles (which may be used in either the rural or urban environments) must be designed to provide a high level of safety in all applications.

Reliability

Vehicle reliability will be more critical in the urban environment with its increased capacity burden. Vehicle wear tends to also be greater in the urban environment, due to shorter trips and the correspondingly frequent starts and stops. System failures will affect the speed profile and travel times particularly for the urban traveler. A somewhat mitigating characteristic is that service facilities qualified to maintain specialized AHS vehicle equipment would likely be more accessible for urban users as compared to rural users.

Liability

AHS-related vehicle equipment will increase the urban vehicle liability factors more significantly than for the rural case. This is due to the increased traffic density and correspondingly more stringent control requirements which must be achieved in an urban environment to achieve the high level of safety expected. The manufacturer may pass this increased cost along to the vehicle owner.

Physically Disadvantaged

An AHS vehicle should be designed to allow physically disadvantaged rural users to travel further distances (such as to an urban area) and allow similar urban users to travel more often. Thus no meaningful difference is seen relative to urban and rural.

Alternate Transportation Systems

Mass transit systems are more prevalent in large cities and will have a greater impact on the urban configuration. Transit vehicles traveling in high-occupancy-vehicle lanes which give users a time advantage during rush hour may not serve all commuters conveniently in some urban areas, due to excessive residential sprawl or diverse clusters of employment centers. The AHS may offer equivalent time savings at a reasonable benefit-to-cost ratio for the majority of commuters in certain urban areas. An AHS design which supports mass transit vehicles in addition to passenger vehicles may provide the greatest utility.

Parking/Vehicle Storage

Many urban areas have goals of reducing the number of vehicles on the streets and do not plan on increasing the availability of parking. The successful implementation of an AHS would only tend to exacerbate this situation. Thus in urban areas, vehicle design should account for the increased number of vehicles to be driven on streets and parked due to the enhanced capacity of an AHS. Vehicles may be designed more compactly or standardized for stacking more efficiently. AHS may also evolve to include the use of multi-user vehicles which serve the denser portions of the urban areas. Users would park their normal vehicle outside the central urban area, ride these multi-user vehicles into the core cities, exit the vehicle, and the vehicle would continue on as a transit type vehicle.

Other Technical Issues

The types of roadway obstacles will vary between the urban and rural cases. Vehicle obstacle detection systems must consider these differences. There will be differences in the number of entrances and exits, thus affecting the complexity of the system and its response times, which will be more critical in the urban case. Refueling assumptions of urban and rural environments are similar; however, refueling must also be accounted for. This may lead to an advantage for electric vehicles in the urban setting. The concentration of commercial vehicles will differ between the two environments. The vehicle capacity may be identical during certain operating regimes; however, the capacity profiles will differ between the rural and urban environments. Ride characteristics and entertainment features are more important for the long-distance rural traveler. The complexity of demand on the driver is typically less for the rural environment, hence a decreased value of AHS for the rural user.

Notwithstanding all these vehicle considerations, the vast majority of automobiles are and need to be used in both urban and rural applications. Thus, the vehicle must be designed and certified to meet the most demanding combination of requirements. Exceptions to this are small and/or specialized vehicles intended only for urban commuting. These represent a small but emerging market segment and also are the likely first application of alternative propulsion systems. Another exception is mass-transit vehicles designed for urban use.

Infrastructure Deployment Characteristics

The American Association of State Highway and Transportation Officials' (AASHTO) standards which define rural versus urban areas are based on population. The differences between urban and rural freeway systems from an infrastructure perspective can be classified into several categories, which are discussed in the following text. However, there are major elements of freeway design that are common regardless of environment. Horizontal and vertical alignment of the roadway is a function of vehicle speeds and providing adequate sight distance. Maximum and minimum values for these particular elements are the same regardless of environment and set the stage for designing these facilities.

Common design processes used on both rural and urban freeways result in different impacts on implementation and will be addressed as they directly affect AHS. Urban and rural freeways have distinct operational considerations as well. The effects of operational characteristics are discussed in terms of how they impact AHS implementation in the urban and rural environments.

Topography

Rural highway design is concerned with topography issues to a greater extent than urban freeways. Typical urban freeways are not concerned with topography, due to the location of urbanized areas and the limited physical extent of freeway deployment. The majority of urban freeways are on relatively flat terrain and do not traverse mountain ranges and canyons, with notable exceptions such as Albuquerque or the Los Angeles area. Rural freeways routinely must account for grade differences which affect both design and operation. Rural AHS lanes will require the design of vertical grades so that vehicle speeds, headway, and platoon spacing may be maintained in the AHS lane. The steepness of the grades used on AHS lanes may be limited to optimize the ability to maintain consistent speeds and vehicle spacing.

Number of Lanes

The number of lanes provided differs greatly in urban and rural settings. The number of lanes is based on providing an adequate level of service for the anticipated vehicle volume per hour which will not be exceeded very often or by very much. The theoretical vehicle volume per hour represents a twenty-year horizon from the completion of the freeway. Urban freeway design is based on providing the required number of lanes to allow for a specific level of service. Public agencies commonly specify an acceptable level of service based on anticipated volume. Rural freeways are typically designed to meet a certain level of service, and provide for two lanes in each direction divided by a wide median. Urban freeway sections are typically multi-lane (three or more) divided by a median that provides a physical barrier between directions of travel.

Cross-Sectional Features

Roadway cross-sectional features such as lane width, shoulder width, center median, and right-of-way all vary from urban to rural environments. Lane widths tend to be wider, while shoulder widths are sometimes narrower, in rural freeways. Center median and right-of-way are generally larger in a rural environment as a result of availability and lower cost of land.

Most urban sections provide minimum median width. Minimal width would include a shoulder and a median barrier between directions of travel. Typically, side slopes in fill sections are steep, or retaining walls are used to reduce right-of-way costs. Room for expansion of an existing urban freeway is typically not available without exercising eminent domain. The implementation of AHS in an urban setting may require occupying or replacing an existing freeway lane, high occupancy vehicle (HOV) lane, or shoulder. Rural freeways offer more potential for adding a lane to the existing cross-section.

Interchange Spacing

Density of freeway or traffic interchanges is much higher in an urban setting than in a rural. Interchange spacings of 1.6 kilometer in densely populated areas is common, whereas rural freeways can exhibit spacing of over sixteen kilometers. This difference will affect access/egress point spacing for the AHS. Urban settings will provide more flexibility for closer AHS point spacing if the existing infrastructure is used. Closer interchange spacing corresponds to a greater number of access/egress points, which will result in higher costs per unit length in the urban setting.

Pavement/Structure Design

The design of a freeway pavement section or bridge is based on several factors. Type and volume of traffic is a significant consideration in this process. Average daily traffic (ADT) and percentage of trucks is converted to equivalent single-axle loads. The percentage of trucks using the facility will have a large impact on AHS lanes. Truck traffic as a percentage of total traffic tends to be higher on rural freeways than on urban sections. This difference may be balanced by the significantly greater overall volume of traffic each day on urban freeways in terms of single-axle loads. Total equivalent axle loads are used as a design criteria; however, the heaviest axle loads are a significant factor in the construction and maintenance of the pavement. Truck traffic requires greater pavement strength to increase the durability of lanes subjected to truck use.

Security Measures

Methods of prohibiting unauthorized pedestrian and animal access to the freeway vary between urban and rural locations. Urban freeways are typically less accessible than rural freeways by virtue of their design. Limited access stems in part from the tight right-of-way constraints imposed on urban freeways. Noise walls, barriers, retaining walls, and access control fencing pose formidable obstacles to pedestrians in urban areas. Provisions for urban freeway pedestrian crossings are typically provided, eliminating the need to mix vehicular and foot traffic.

Rural freeways often have fencing only at the right-of-way limits, designed to prevent domestic livestock from entering the freeway. Pedestrians and non-domestic animals such as deer, coyote, and antelope can breach the fence without much effort. Long distances of rural freeways have no barriers in place to restrict animal or pedestrian traffic, creating a potential for accidents which may be alleviated by AHS obstacle detection and avoidance.

Capacity versus Travel Time

The intention of freeway design in both environments is to accommodate future traffic demands, and specific differences in operational features must be taken into account. Urban freeways must support peak-hour traffic, which can be 8 to 12 percent (or more) of the total daily traffic. The urban demand in the peak hours thus represents two to three times the average volume. Rural freeways do not typically experience short peak flows, with the exception of vacation routes and resort areas. Many urban freeways presently operate at or in excess of planned capacity during peak periods.

Travel time is important to both rural and urban environments; however, increasing or improving the capacity is typically of greater importance than reducing travel time to transportation funding agencies in the urban area. Rural freeways rarely operate at capacity, and therefore the overriding factors for these facilities are safety, comfort, and travel time.

Operating Speeds

Urban and rural freeways typically have different operating speeds, especially during urban peak hours. Rural freeways usually operate at higher travel speeds, due to less congestion and fewer entry/exit/weaving operations. Urban freeways operate at speeds from approximately 40 to 56 km/h under capacity volumes during peak-hour conditions. There is greater ramp volume and weaving movements in an urban setting. These differing operating characteristics provide various issues concerned with mixing AHS and non-AHS traffic.

AHS may operate at higher average speeds than present freeways, ranging anywhere from 96 to 144 km/h. The disparity between AHS speeds and existing freeway operating speeds introduces a safety consideration where mixing traffic is concerned. Urban settings may favor an AHS system which supports separate dedicated facilities for AHS vehicles, reducing the potential for accidents introduced by non-AHS drivers.

Surrounding Land Use

Surrounding land use varies drastically between urban and rural settings. Land use near urban freeways varies from higher density residential to commercial/industrial. Land uses in the urban environment typically generate much higher traffic volumes than those found in a rural environment. Urban areas also contain extensive surrounding roadway networks, impacting modification of the existing interchanges. Rural freeways are often surrounded by agricultural, undeveloped, or government land. Land required for expansion of the freeway is typically less expensive and more accessible in a rural setting. Right-of-way in urban settings is more costly and usually more difficult to obtain. Rural freeways have a limited network of interconnecting roadways, due to the land use associated with rural areas.

Facility Maintenance

Maintenance activities performed on freeways are similar between urban and rural environments. There are differences between settings with regard to the number of maintenance workers, maintenance budgets, location of maintenance resources, and vehicle repair facilities.

Maintenance crews are typically larger for urban areas, due to the amount and complexity of the infrastructure. Urban settings generally have maintenance facilities and resources located in close proximity to the roadway, and are capable of quicker response on high-priority items than in rural areas. Maintenance priorities instituted in rural settings are similar, but often have much greater distances and travel times to respond to maintenance requirements. Rural areas may also have more than one organization responsible for maintenance activities on the same roadway, depending on the length of the route and the proximity of maintenance facilities to the repair location. The locations of service stations available for emergency vehicle repairs are less frequent in the rural environment. Service locations for AHS vehicles, which may require specialized facilities, may be considerably less convenient in the rural environment.

Cost

The capital costs associated with implementing infrastructure improvements tends to be greater in urban areas than in rural areas. The primary contributors to the cost differential are the cost of right-of-way, maintenance, protection of traffic flow during construction, and the relocation of utilities (although utility costs are highly variable depending on prior rights classification). Actual material costs can be higher for rural sections, depending on how close a material source is to the project. Construction methods also affect construction costs. Work areas are confined in urban areas due to surrounding developments, and certain cost-saving methods cannot be utilized as they can be in rural areas.

Operator Interface Characteristics

Operator Competence Verification

The process used to determine operator competence to access the system will be similar in the urban and rural environments. The check-in procedure will verify driver characteristics such as licensing, toll accounts, and insurance status. The check-out procedure will verify visual acuity, alertness, and manual response of the driver. The majority of verification procedures will be required in the urban and rural environments, allowing the operator interface to be designed effectively for both.

Emergency Maneuvers

The operator interface will incorporate a method of alerting drivers to system malfunctions or hazards. The ability to provide information to the driver in emergency situations will be necessary in both the urban and rural environments. The implementation of the user interface which provides these capabilities will be similar in both environments.

Operator Comfort

The operating environment as it is perceived by the user will be significantly different in the urban and rural environments. The urban environment will involve significantly greater vehicle densities, with a corresponding impact on the spacing of vehicles. The rural environment may support higher travel speeds, but the perception of safe operation will not be affected as profoundly. The urban operator interface may require a method for adapting the user's perception of travel in the system. Options may include entertainment or modification of the windshield transmissivity to alter the driver's visual environment. The rural operating environment will be affected to a greater extent by the distances traveled. The driver may be offered the option to read or sleep during long-distance rural travel. The effect of operator comfort on design of the operator interface will be dissimilar in the urban and rural environments, reducing potential commonality.

Destination Information

The urban environment has a multiplicity of destination and route options. Modification of destinations and routes is quite likely for a typical urban traveler who may decide on the spur of the moment to run an errand on the way home from work. The spacing of entry/exit points on rural highways reduces the options significantly for the rural traveler. Modification of destination or route will be highly unlikely. The most frequent input to the system during rural travel is expected to be requests for rest stops. The operator interface design will have dissimilar requirements in the two environments for this category. The complexity of the interface will be affected if urban route modifications are incorporated into the design.

Communications Characteristics

Capacity

The number of users requiring access to a single communications service within the system may be significantly different in the urban and rural environments, which has an impact on communications design requirements. The specified capacity of the system to handle entry/exit information and infrastructure-based position guidance will be determined by the density of traffic. The difference in traffic volume will cause a dissimilarity in maximum communications capacity requirements in the two environments.

Throughput

The quantity of information per vehicle which is handled by the message formats is not greatly affected by the operating environment. The amount of information will be similar in urban and rural, and may include vehicle location, entry/exit qualifications, and system control data. The size of the information messages will not have a significant effect on design characteristics in the two environments. The approach to assigning message protocols will not be significantly affected by the setting.

Contention

The method used to assign users access to the network will be influenced by the number of users in the system. Typical analog configurations which assign different channels to adjacent users may be sufficient in the rural environment. The urban environment will require more sophisticated methods to support the higher user densities by implementing digital multiple access techniques or equivalent contention resolution schemes.

Network Configuration

The configuration of the network to serve the system requirements may be different in the two environments. In the urban environment, the density of users and grid layout of the infrastructure may favor a multi-point to multi-point or cell-based reconfigurable network. The long linear distances in the rural environment may favor a point-to-multi-point or satcom-based network configuration. The ideal network approach is likely to be different in the urban and rural environments based on the disparity between physical architecture of the highways and required communications paths.

Error Rate

The error rate of the communications link is a factor in the system reliability of the AHS. Error rates are affected by frequency-selective multipath fading, which is common in urban environments where structures, overpasses, underpasses, and other vehicles cause reflections of radio waves. Modulation schemes can be implemented to combat fading and improve bit-error rates. The techniques employed to meet urban operating requirements may not be necessary in the rural environment to achieve similar error rates.

Susceptibility to Jamming

Urban environments have a higher incidence of radio-wave interference than the rural environment. The communications system design in the urban environment will be required to provide higher jamming margin.

Infrastructure Electronics Characteristics

Availability of Utilities

Infrastructure control components will require a supply of primary power. The availability of power sources exists to a greater extent in the urban environment. Both environments may require addition of utility or wired communications infrastructure. The impact to the rural AHS development is potentially greater, due to the greater lengths of roadways between population centers.

Spacing of Traffic Operations Centers

Traffic Operations Centers (TOC's) may be required in both environments to support regional coordination of communications and traffic management. TOC's designed for urban capacity requirements may have more functionality than the rural environment dictates. An alternative would be to increase the spacing of TOC's in the rural environment to allow the loading of rural centers to reach the level of a typical urban center. The spacing of TOC's in the rural environment will impact the communications system design to support distances which are significantly greater than the equivalent urban configuration.

The cost of implementing TOC's in the rural environment may prove prohibitive. Other options in the rural setting include maintaining communications with a single central TOC via satellite communications or implementing distributed intelligence across the system and eliminating the TOC in the rural configuration.

Task 3. Design Considerations

The implications to AHS development are evaluated with respect to the contrasts and commonalities among urban and rural characteristics developed in the preceding sections. The tradeoff analysis and the characteristics identified in Task 2 are viewed as they impact the defined RSC's. Preliminary design consideration are developed in the categories of vehicle subsystems, infrastructure deployment, operator interface, and communications and infrastructure electronics. The goal of this section is to compile a set of factors which can influence the design of AHS and provide a basis for a cost-effective, readily acceptable system that meets the major system performance goals.

Vehicle Issues

A list of vehicle related implications is presented in table 6. The particular RSC and the region of major impact are also identified. The categories discussed in the following paragraphs explain the primary impacts of urban and rural considerations on specific system configurations.

Table 6. Vehicle-Related RSC Implications

Implications	Main RSC	...On Urban	...On Rural
Vehicle Content	2	Low	High
Propulsion	1	High	Low
Cost	2	Low	High
Maintainability	2	High	High
Operator Interface	1,3	High	Low
Check-In/Check-Out	1,3	High	Low

Reliability	2	High	Low
Safety	3	High	Low

Vehicle Content Considerations

RSC 2 is intended to place the maximum practical system content in the vehicle, which will increase vehicle equipment costs and maintenance responsibilities. This increase will have the greatest implication for the rural user, who typically travels the furthest and may need to purchase equipment with capabilities only partially used in lower-capacity rural environment. Although it is desired to minimize the differences in equipment between the urban and rural environment, some items may be extraneous. Certain types of detection equipment may be utilized in one and not the other. Equipment to support platooning or closer vehicle spacing may be less important in the rural environment. Furthermore, if an electric vehicle system is designed for the urban environment, the rural user may be required to purchase more expensive equipment to provide compatibility. Instead of a binary decision (include/not include), these may be viewed as cost/performance trade-off requirements which will affect the RSC’s.

Propulsion Considerations

RSC 1 includes electric propulsion as an option, making it the most environmentally desirable from a pollution and noise standpoint and allowing for the future possibility of roadway power, especially in the urban environment. This would also allow for a hybrid propulsion system — electric in urban areas, internal combustion engine (ICE) in rural. Subsystems designed for the ICE vehicle will be applicable to the electric vehicle. In fact, a hybrid system may be most beneficial. The myriad ramifications of a hybrid vehicle are beyond the scope of this task. The inclusion of hybrid capabilities would not be beneficial to the rural user in cases where the vehicle cost is increased to provide alternate propulsion which is supported only in urban areas.

Cost

RSC 1 is the least expensive vehicle configuration and RSC 2 is the most expensive, making it less desirable from the user standpoint. This is especially true in the rural environment, as noted in Vehicle Content.

Maintainability

RSC 2 requires more user vehicle maintenance responsibility, which also degrades reliability. Both the urban and rural user would be adversely affected by this aspect.

Operator Interface

The operator/vehicle interface will be designed for ease of use in all cases. RSC 1 and 2 support platoons and thereby maximize throughput on the AHS lanes. RSC 2, with its larger platoon sizes, will have the greatest capacity and correspondingly less potential for queued check-ins. RSC 1 and 3 have more of a potential for queued check-ins in an urban environment, which could increase the user's responsibilities and require more feedback from the driver. In general, the urban environment with its higher vehicle density will require more user interaction.

Check-In/Check-Out

Check-in points in the urban environment may become subject to unreasonable queuing and congestion with RSC 1 and 3, as mentioned previously, thereby nullifying some of the AHS advantages such as lower vehicle maintenance requirements and ease of use. RSC 1 vehicles, which may be electric/hybrid, would require additional equipment to handle check-in/check-out. RSC 3, which allows for a mixed vehicle-type scenario, will also require additional equipment and subsequently increased check-in/check-out verification procedures, which will affect vehicle hardware/software requirements.

Reliability

Additional soft-fail capabilities will need to be built into each vehicle for RSC 2, since it is vehicle-control intensive. These capabilities will be especially crucial for the high-capacity urban areas.

Safety

RSC 3 uses normal highway lanes to achieve entry into the AHS exclusive lanes, thus making it less safe than the other configurations with respect to interference from non-AHS vehicles in the urban environment. This will tend to increase vehicle safety costs, such as vehicle occupant protection and insurance.

Infrastructure Deployment Issues

Topography

Sustained upgrades are found more frequently in rural areas, and while upgrades have minor effects on passenger car speeds, the impact on truck speeds can be severe. RSC 3 supports heavy truck traffic, and provision for AHS truck bypass lanes would be required to maintain desirable passenger car operations on upgrades in the presence of truck traffic.

Truck arrestor beds, a design feature on conventional rural freeways, accommodate occasional truck brake failures on sustained downgrades. RSC 3 will require implementation of arrestor beds, unless trucks with the potential for brake failure can be detected at the check-in point and denied access to the AHS. RSC's 1 and 2 will obviate this need by denying trucks access to AHS lanes through the check-in procedure.

The implications of topography on the RSC's is not expected to be significant in the urban environment, except from the standpoint of land use. Land usage is addressed in a following paragraph.

Number of Lanes

The number of lanes provided for a freeway varies for urban and rural environments. The implication of this relates to how the AHS lane(s) are implemented, either as a new lane or occupying an existing lane. In rural settings, an AHS lane will most likely be constructed as a new lane, leaving the same number of non-AHS lanes. RSC 1 is most compatible with the construction of new lanes from an incremental cost standpoint. RSC 2 includes greater infrastructure content associated with vehicle control. It is expected that the difference in cost to include AHS instrumentation during construction of new lanes would be less than the cost to retrofit existing lanes with equipment associated with RSC 1. This premise holds for each of the RSC's, but with the large extent of infrastructure instrumentation in RSC 1, the potential savings of implementation during new construction could be the most significant of the three RSC's.

Most rural freeways provide two lanes per direction of travel, and if an AHS lane occupies an existing lane, it will severely impact non-AHS freeway operation. The ability to pass slower traffic, and handle traffic during an accident or maintenance will be greatly impacted.

Restriction of lanes available to non-AHS traffic has the potential of encouraging more violations by non-authorized vehicles using the AHS lane where no barrier is provided between AHS and non-AHS lanes, such as RSC 3.

The multilane facilities associated with urban areas can more easily accommodate an AHS lane within the existing lane configurations provided the demand to use the AHS lane outweighs the loss of capacity to the non-AHS facility due to the loss of the lane. Latent demand of the non-AHS facility will also affect whether the AHS lane will be a new lane or occupy an existing freeway lane. Latent demand is more of a factor in an urban setting than in a rural environment. RSC’s 1 and 2 both provide the greatest capacity for increasing traffic density through platoons, and the tradeoffs associated with dedicating an existing lane to AHS traffic may be best served.

Cross-Sectional Features

Acquisition of land in urban areas is typically more complicated and more expensive than in a rural area. Construction of new facilities in an urban area is more difficult and more expensive than in rural areas, due to constraints associated with the density of development near urban freeways.

Therefore, there are many more implications of implementing a dedicated AHS facility in an urban environment, especially if it is implemented on a separate alignment from the non-AHS freeway. All social, legal, environmental, and economic impacts associated with new non-AHS freeways will also apply to new AHS freeways. Construction of an entirely new facility in a rural environment is more practical than in an urban area. Although the same impacts apply to a rural freeway, these impacts are typically much less severe and less costly.

RSC’s 1 and 2 are dedicated facilities, which may require a larger extent of additional right-of-way than RSC 3, since it is a mixed-use configuration.

Interchange Spacing

Due to check-in and check-out procedures of the AHS, interface point spacing will have a dramatic effect on AHS operation. Each entry-exit maneuver will have an associated delay relating to the check-in and check-out procedure. The closer the interchange spacing, the more opportunity to distribute the AHS traffic. This will be easier to achieve in an urban environment. Closer spacing of AHS access/egress points has the potential to degrade AHS operation unless traffic entering and leaving the facility is matched to the flow capabilities. The system will be required to adjust platoon/vehicle spacing and speed to provide gaps for new vehicles entering the system. The closer the entry/exit spacing, the less opportunity to make these adjustments without severely degrading AHS operation. This will have a greater impact in urban areas, where interchange locations are typically closer together.

Balancing the impacts to the AHS lane operations and the accessibility of AHS interface points and surrounding non-AHS roadways will be more significant in an urban setting than in a rural environment. Point spacing impacts dedicated facilities more than mixed systems. Therefore, RSC 1 and 2 are affected more by interchange spacing than RSC 3.

Pavement/Structure Design

The definition of RSC's 1 and 2 limits heavy vehicles to separate facilities; therefore, new roadway sections or structures designed to accommodate only passenger cars and light trucks will have reduced weight-bearing requirements. This reduction could result in less cost to implement new AHS infrastructure in terms of pavement design factors. RSC's 1 and 2 could utilize existing freeway facilities and expect reduced structural maintenance costs due to the absence of heavy trucks. RSC 3 supports heavy vehicles mixed with passenger vehicles, and any new AHS infrastructure implemented for this configuration must be designed to accommodate truck traffic. RSC 3 could also be implemented on existing freeway sections; however, it is anticipated that RSC 3 would require more pavement maintenance due to truck traffic.

AHS trucks may operate within a narrower lane than driver-controlled trucks, increasing the effective axle loading of the pavement and structures. The identification, evaluation, and mitigation of this effect may be an important design issue for AHS pavement design where trucks are present. Implementation of separate lanes for truck traffic as in RSC's 1 and 2 may be economically beneficial in urban settings where many lanes are instrumented. RSC 3 would require all ten lanes to be designed to accommodate trucks, for instance, whereas in RSC's 1 and 2, eight lanes could have reduced design requirements for light vehicles, and only two lanes designed to truck traffic requirements.

RSC 3 is more compatible for rural implementation because it accommodates heavy vehicles, which make up as much as 20 to 30 percent of the traffic mix on typical rural freeways.

RSC's 1 and 2 exclude heavy vehicles and are better suited to an urban environment. Truck traffic is approximately 5 to 10 percent of the total traffic mix in urban areas and even less during peak hours; therefore, the impact of excluding trucks and buses from the AHS is less in urban areas.

Security Measures

The potential for vehicle collisions with pedestrians or animals is similar in each of the RSC's. Although there is a greater opportunity for pedestrian and animals to encroach on rural freeways, the urban areas may be at greater risk of collisions due to the far greater numbers of vehicles. RSC's 1 and 2 have the potential for involving larger numbers of vehicles when an accident occurs, due to the close spacing of vehicles within the platoons. The potential for vehicle collisions with unauthorized vehicles traveling in the AHS lane is greatest in RSC 3, since it does not support dedicated lanes and provides enforcement as the only barrier. This factor greatly impacts the safety of implementing RSC 3 in the urban setting, due to the significantly higher traffic densities.

Capacity versus Travel Time

Table 7 provides a comparison of travel speed versus capacity of a lane given a platoon size of 15. The capacities calculated assume a one-meter separation between vehicles within a platoon, and AASHTO braking distance between platoons. The table is based on the assumption that a platoon might instantaneously stop and that the following platoon is capable of coming to a coordinated stop within AASHTO braking distances for the given speeds. Deceleration rates are approximately 0.3g for these speeds and braking distances.

For these assumptions, capacity is maximized at about 80 km/h, since the braking distance is a function of the square of the vehicle velocity. It is not suggested that the "brick wall failure" assumption be adopted as a specific design value for AHS; however, some safety factor will be required. The table illustrates that maximizing capacity does not necessarily minimize travel time. Further study shows that higher capacities are associated with larger platoon sizes when maintaining the safe braking distances between platoons.

Table 7. Comparison of Travel Speed versus Capacity of a Lane Given a Platoon Size of 15

AASHTO Design Speed (km/h)	Space Between Platoons (m)	Density (vehicles per km)	Capacity (Vehicles per Hour) for Traffic at:						
			48 km/h	64 km/h	80 km/h	96 km/h	112 km/h	128 km/h	144 km/h
48	26	127	6,155						
64	51	106	5,088	6,784					
80	85	85	4,111	5,481	6,851				
96	126	69	3,328	4,437	5,546	6,655			
112	178	56	2,691	3,588	4,485	5,382	6,279		
128	241	45	2,180	2,906	3,633	4,360	5,086	5,813	
144	317	37	1,776	2,368	2,960	3,552	4,143	4,735	5,327

Capacity is the primary issue in the urban environment, with reduced or more consistent travel times the result of alleviation of congestion. Rural travelers are not affected by congestion to the same extent, but may benefit by significantly reduced travel times. The long-haul trucking industry is a prime example of a user that has a great potential benefit in shorter trip times.

RSC’s 1 and 2 have the greatest potential for maximizing throughput on the AHS lanes, since they support platoons. RSC 2 has the best potential capacity, since it contains larger platoon sizes than RSC 1. RSC 3 does not provide for platooning of vehicles and would therefore provide the least potential improvement to capacity. All three RSC’s have similar potential for improving travel times, since each can support AHS operating speeds, which are higher than existing freeway travel speeds.

Transition to AHS

AHS and non-AHS traffic are mixed in a non-dedicated configuration such as RSC 3. AHS traffic enters the freeway at interface points or interchanges used by non-AHS traffic. AHS traffic then maneuvers to the AHS lane. The difference in operating speeds between the AHS lane and a typical freeway lane operating at capacity during peak hour could be 64 to 96 km/h in the urban setting. The transition between non-AHS lanes and AHS lanes will require merge lanes or ramps to allow AHS vehicles to match the speed of non-AHS traffic. The merge lane will reduce the overall capacity of the freeway unless the existing right-of-way is widened or the lane structure is modified to support more lanes. Adding a merge lane will not increase cross-sectional capacity, since it is used for transition to the AHS. The impact of transitioning to the AHS may be less severe in the rural environment, since lower traffic volumes may allow candidate vehicles to accelerate or decelerate safely in non-AHS lanes.

RSC's 1 and 2 provide a dedicated facility for the AHS lane and would support the greatest delta in operating speeds between AHS lanes and non-AHS lanes, at the expense of providing a merge lane to allow AHS vehicles to accelerate to match the speed of the platoons. RSC 3 provides a non-dedicated AHS facility in which AHS vehicles merge directly from non-AHS lanes into the AHS lane. This setting will not safely support a large differential in operating speeds between adjacent lanes unless the space/time slot spacing is large enough so that a slower-moving car can accelerate to AHS speed before the following slot catches up.

Alternatively, an AHS without a dedicated merge lane might operate by allowing the system to maintain a maximum speed differential between the AHS and the adjacent mixed traffic lane. The speeds and vehicle spacing within the AHS lane could be altered to provide a gap for the merging vehicle, an approach which could severely limit the capacity of the lane. The operating speed in the AHS lane would be modified to allow vehicles to merge safely without requiring excessive acceleration or deceleration. The advantages of this concept over the use of a merge lane include the following: 1) a lower speed differential between the AHS and adjacent mixed traffic lane has a lower likelihood of catastrophic accidents, and 2) the absence of the buffer lane reduces the width requirement of the overall freeway, including mixed and AHS lanes.

This alternative is plausible in RSC 3, due to the requirement that this configuration be tolerant of unauthorized vehicles. The higher speeds and close spacing of platoons supported in RSC's 1 and 2 are not likely candidates for this scenario.

<u>Surrounding Land Use</u>

RSC 3 may be implemented without additional right-of-way acquisition, since it is not a dedicated facility. It may be developed by converting existing HOV lanes, shoulders, or the left travel lane to AHS use. This conversion may not be practical in the rural environment, since it would affect a proportionately higher percentage of the available travel lanes. RSC's 1 and 2 will require the greatest investment in additional land, since these configurations require separate facilities, including check-in plazas and storage areas at exit ramps for vehicles which fail check-out requirements. RSC 1 and 2 may require prohibitive amounts of additional right-of-way in the urban environment. In the rural environment, it may be more advantageous to build additional facilities, allowing any of the three RSC's to be implemented.

Maintenance of Facilities

All three RSC's contain some degree of infrastructure elements. RSC 1 is heavily infrastructure dependent and will require the greatest level of preventive and corrective maintenance in terms of the roadway, especially over long distances of rural freeway. Its infrastructure elements include wayside sensing, communications, entry facilities, and a physical barrier to prevent unauthorized access. RSC 2 incorporates entry facilities and markers in the roadway for lateral control, requiring a somewhat lower level of infrastructure maintenance. Maintenance of any AHS equipment installed within travel lanes will be affected by the urban setting in terms of accessing the equipment without disrupting traffic flow. RSC 3 incorporates wayside sensing and communications in the infrastructure, but maintenance of entry facilities is eliminated.

Cost

The determination of a favored approach in terms of cost is dependent on the distribution of costs. Implementation costs which are spread amongst the users may be readily divided in a vehicle-based system such as RSC 2, especially in the urban environment where the potential number of users is high. Implementation costs which are subsidized by fuel taxes and infrastructure development funds are well suited to infrastructure-based systems such as RSC's 2 and 3, and may be more suited to rural areas where the number of users per lane kilometer is much lower but the fuel usage may be higher. Costs which are recouped via a toll can be implemented most easily in RSC's 1 and 2 through entry/exit deployment features. This approach can be implemented in either environment, but may be subject to avoidance by alternate routes more often in rural areas.

Operator Interface Issues

Operator Competence Verification

Operator competence verification will be implemented differently depending on the system configuration. Infrastructure-based platoon control (RSC 1) and vehicle-based platoon control (RSC 2) incorporate barriers to prevent unauthorized entry to the AHS. Both RSC's include dedicated lanes for check-in which allow non-AHS drivers to be excluded through the verification process. Space/time slot control (RSC 3) does not provide a barrier mechanism to prevent unauthorized access, and transition to the AHS lane is directly from non-AHS lanes rather than through a check-in facility.

The implications of the two approaches to the task of operator competence verification are extensive. The verification process can be highly complex in the case of RSC's 1 and 2, possibly including verification of licensing, toll accounts, and insurance status as well as physical characteristics. The operator interface in these two RSC's may provide sensors for measuring such attributes as visual acuity, alertness, and manual response of drivers. RSC 1 and 2 may also include voice or text interactive messaging that allows the system to inform the driver of passage or failure of the entry/exit criteria.

The verification criteria in RSC 3 may be quite simple, to the point of not requiring measurement of any physical characteristics or assessment of financial responsibility. The operator interface may be significantly less complex in RSC 3, since the primary barrier against unauthorized use is enforcement and fines, similar to existing HOV lanes. This approach may not be sufficient in the urban setting, however, since safety may be compromised if no barriers to unauthorized users are implemented.

Emergency Maneuvers

Several aspects of emergency maneuvers may be different among the RSC's, including the source and frequency of incidents, the degree of operator interaction required, and the method in which information is relayed to the driver. RSC 3 may require the system to detect and warn AHS operators of non-AHS vehicles infringing on the AHS lanes. RSC 1 and 2 are not readily accessible by unqualified drivers, reducing the need for this type of emergency notification and management. System malfunctions within the infrastructure control of RSC 1 and 3 may affect all vehicles where the incident occurs, requiring coordinated action to be taken. System malfunctions within the vehicle control in RSC 2 may be more likely to affect a single vehicle within the platoon, although the actions of other vehicles may be impacted; a single driver may be required to take manual control of a function such as lateral position.

Operator Comfort

Disparities in the operating environment as it is perceived by the user will be similar to those discussed with respect to the urban and rural environments. RSC 1 and 2 both incorporate platoons, which entail close spacing of vehicles when traffic density increases. The perception of safety will be more greatly affected in RSC 2 during high speed travel. User perception of safety in RSC 3 will not be affected negatively because the spacing is comparable to gaps drivers commonly use. The operator interface in platoon control configurations may require a method for adapting the user perception of travel in the system, while perception is less of an issue in space/time slot control.

Destination Information

The effect of destination and route options on the complexity of the operator interface will not be affected by the system configuration to a great extent. Modification of destinations and routes would be entered by the user in a similar manner in platoon or space/time slot control RSC's. The primary impact to route modifications among the RSC's will be in terms of vehicle control and will not impact the design of the operator interface.

Communications Issues

Capacity

Overall capacity of the communications system is a primary design issue, and the impact of the system configuration will be assessed. Capacity is a measure of the total number of users a system can support. The capacity of the system to handle entry/exit information and infrastructure-based position guidance will be determined by the density of traffic. Communications within platoons will not be subjected to capacity limitations, since the platoon sizes are no greater than fifteen. Vehicle-centered platoon control has the largest potential traffic volume in terms of entry/exit, since it supports the highest traffic density by virtue of larger platoons, corresponding to the greatest communications user capacity requirements. Infrastructure-centered platoon control and space/time slot control, respectively, have less potential traffic density, yet communications are infrastructure-intensive. The capacity requirements will be a tradeoff between the various communication methods within each RSC, since each incorporates more than one mode of information transfer.

Throughput

The quantity of information handled by the message formats is a major factor in the varying system configurations. Throughput is a measure of the total amount of data that must be transferred in a given time frame. Data transfers will include information such as vehicle location, entry/exit qualifications, and system control data. The size of the information messages may vary significantly between the three RSC's. The amount of information contained in a single message is related to how the communications tasks are divided. Heavily infrastructure-dependent configurations such as RSC 1 and 3 may combine several tasks in a single communications technique. RSC 2 combines vehicle-to-vehicle communications within the platoon with roadside-to-vehicle communications for transfer of entry/exit data. The sum total of data in RSC 2 may be the greatest, but it may be partitioned in a way that relieves the stringency of throughput requirements on a single communications path.

Contention

A primary consideration in avoiding contention among adjacent users will be the proximity of vehicles in the system configuration. Both platoon-based RSC's have higher potential densities for users of communications resources, which will impact the allocation design. Frequency channel selection may not provide enough diversity to support large numbers of adjacent users in RSC 1 and 2 without introducing a high degree of complexity and corresponding cost. Alternative solutions include digital multiplexing techniques, which may not be necessary in RSC 3 unless the deployment of AHS highways creates demand in excess of the capabilities of low-cost alternatives.

Network Configuration

A major factor in determining network configuration in terms of vehicle communications will be the vehicle control arrangement. Tightly spaced vehicles traveling at high speeds must receive position control and braking commands nearly simultaneously in some situations. To relieve data rate requirements, it may be necessary to specify point-to-multipoint communications within platoons in RSC 1 and RSC 2. Point-to-point communication may be adequate in the space/time slot configuration.

Error Rate

The effect of error rates on the communications system reliability will be an issue among the RSC's. Error rates are affected by frequency-selective multipath fading, which may be more common where closely spaced vehicles can cause multiple reflections of radio waves. Modulation schemes can be implemented to combat fading and improve bit-error rates. The communication techniques employed to meet the operating requirements of each RSC will be dependent on the minimum acceptable error rates for the type of information transferred. Examples include vehicle control data, which must be updated rapidly and accurately and will be less tolerant of errors, and entry/exit data, in which case re-transmission can be utilized to defeat errors without adversely affecting overall performance.

Susceptibility to Jamming

The effect of radio-wave interference on communications will be different among the three configurations. Both RSC 1 and RSC 2 incorporate platoons in their control definition. The potential for receiving in band signals is much greater when a high number of radiators are operating in close vicinity using the same modulation techniques. Space/time slot control may have a slight advantage in this category, benefiting from reduced jamming margin requirements.

Infrastructure Electronics Issues

Availability of Utilities

Infrastructure control components will require a supply of primary power. The availability of power will have a greater impact on RSC's 1 and 3 than on RSC 2, due to the extent of infrastructure electronics defined in those configurations. The cost of providing power may be an issue, especially over long distances or in areas where disruption of traffic flow is a consideration. RSC 2 concentrates the majority of its control within the vehicle, reducing dependence on power supplied along the roadside.

Design of TOC's

Traffic Operations Centers will be required to support regional coordination of traffic management in all three RSC's. The primary function of TOC's is traffic management (ATMS) and traffic information (ATIS). AHS will use the information gathered by the TOC's such as accidents, lane closures, and alternate routing to determine the speeds and capacities which will be allowed in various segments of the AHS. All of the RSC's will require this information, and differences in how the information is transferred from the TOC to the vehicle will be a function of the communications subsystem design, independent of the RSC design.

Infrastructure Electronics

The quantity, complexity, and positioning of infrastructure electronics will vary as a function of the RSC design. For RSC 1, the control loop for both lateral and longitudinal positioning is closed within the vehicle. The infrastructure electronics will primarily support communications to the vehicles. The spacing of the infrastructure electronics will be determined by the range of the communications system.

RSC 2 and RSC 3 will close the control loop closed in the infrastructure. This design places the controller as well as the sensors in the infrastructure. The vehicle will receive corrections to its lateral and longitudinal position from the infrastructure. Close spacing of infrastructure electronics will be required in order to measure the vehicle's position. Spacing of infrastructure electronics is a greater issue in the rural environment, since longer lengths of roadway are involved. The infrastructure electronics will consist of sensors to measure the position of vehicles, controllers to calculate the corrections, and communications equipment to send the corrections to each vehicle every 10 to 50 ms.

Task 4. Urban/Rural Issues And Risks

This task evaluates the issues and risks associated with designing, deploying, and operating an AHS under three scenarios. These include an AHS which is specific to an urban environment, one which is specific to a rural environment, or one which addresses the urban/rural combination. This evaluation focuses on those issues and risks which are related to the fundamental differences between an urban and a rural environment. Each issue will be discussed as it pertains to the urban and rural environments. The urban/rural issues and risks are summarized in table 8.

Table 8. Urban/Rural Issues and Risks

Issue/Risk	Urban Considerations	Rural Considerations
Utilization of TOC's	TOC's utilized effectively	TOC's underutilized
Communications	Cost effective, readily available	Expensive, often not available
Vehicle Equipment	AHS vehicles equipped for urban	Potential for over-equipped vehicles
Emergency Services	Available within reasonable time	Often located at great distances
Malfunction Management	Easily detected, good redundancy	Hard to detect, no redundancy
Operational Cost	Easily spread over large number of urban users	Small number of users makes funding difficult; AHS will be avoided if too expensive
Congestion Reduction	Included in AHS design, but may require specific congestion reduction equipment in the roadway and the vehicle	Rural roadways/vehicles do not normally need congestion reduction equipment
Deployment	Deployment issues far different than in rural environment	Deployment issues far different than in urban environment
Check-Out	Closely spaced storage areas, but may be expensive to procure right-of-way	Storage areas located at great distances, but right-of-way not expensive

Utilization Of Traffic Operations Centers

The increased use of ITS concepts will result in a proliferation of TOC's. These TOC's will provide essential environmental information such as weather, congestion, and incident notification to the AHS. It is likely that the TOC's will play a major role in AHS, perhaps as the regional or zone controller of the system. The need for a TOC as part of the AHS is present in all three RSC's. TOC's will be heavily utilized in urban areas where traffic densities warrant constant observation of the highway system. In rural areas, TOC's have a more limited role, which includes the monitoring of weather, road condition reporting, and occasional incident detection and response. These rural TOC's will be underutilized due to the low volume of traffic on rural highways. Since the underutilization of TOC's is strictly a rural phenomenon, it is considered an urban/rural issue.

Communications

Communications is an issue in rural areas due to the lack of existing communications and power infrastructures. The AHS will require roadside communications electronics as part of the infrastructure. This communications system is required to support both the short-range vehicle-to-infrastructure RF link as well as the communications between infrastructure elements. The emergence of ITS services in urban areas may make access to a variety of communication options for regional and controller-to-controller links straightforward. The existence of some level of broad area coverage may enhance the ability to support this subset of AHS communications requirements more cost effectively in the urban environment. There is usually no existing communications system which can be used to support AHS in rural areas. Therefore, whatever electronics and power are required to support communications must be installed as part of the AHS. This could cause significant cost differences between the urban and rural implementation of AHS.

Vehicle Equipment

Any implementation of AHS will require AHS-specific equipment in the vehicle. The urban AHS may require a higher level of vehicle equipment to support platooning or closer spacing of vehicles. This may lead to a situation where vehicles which operate strictly in a rural area are over-equipped. Excess equipment affects both purchase price and maintenance costs. An AHS design which requires the same vehicle equipment for urban and rural operation would be ideal from a design standpoint, but may not be practical from an implementation perspective. This will be discussed in the context of several vehicle characteristics:

Safety

Vehicle-related safety equipment may be perceived as being less beneficial to the rural user with the low freeway accident rate statistics and reduced traffic density. However, AHS vehicles (which may be used in either the rural or urban environments) must be designed to provide equal or improved levels of safety to those of present-day freeway systems.

Cost

It is uncertain whether the projected decrease in vehicle electronics costs over one or two decades can make AHS cost-effective, or if the improved performance of electronics equipment can make the system reliable enough for public use. Continued development and testing is the only completely reliable means to determine this issue. Costs incurred by the state to provide transportation services and facilities for the rural environment are typically greater than the taxes collected from them (state gasoline tax). Although additional funding may be available for the urban environment, there are other costs, such as those for relocation due to freeway lanes and infrastructure facilities. In both cases, there will be additional vehicle equipment costs required to implement AHS.

Environmental

Air pollution and noise abatement features on vehicles will be important in both the rural and urban environment; however, both will be more of an issue in the highly congested urban areas. Reduced fuel consumption would lead to a reduction in air pollution; however, increased capacity will minimize this advantage in the urban case. Electric vehicles could be especially advantageous for the urban environment.

Vehicle Design

Reduced fuel consumption could lead to smaller fuel tanks and reduced vehicle weight. A high-quality ride is essential if popular use of any system is to be maintained for travel greater than two hours (i.e. rural) affecting roadway and vehicle design. Goals of the AHS include reducing fatigue on long trips and allowing drivers to engage in tasks other than driving during long commutes to the workplace.

Liability

An automated system in which a commercial or government sponsored agency operates a controlled driving environment raises the issue of fault assignment. Vehicle manufacturers may be reluctant to support development of AHS-specific instrumentation if required to shoulder a share of the responsibility for system failures. Liability concerns are applicable to both the urban and rural environments; however, in the urban case with its higher traffic density, the debate over fault responsibility may occur more frequently.

Reliability

Soft-fail capabilities will be especially critical in the urban areas to handle vehicle/roadway failures. As mentioned previously, it is uncertain whether the projected improved performance of electronics equipment can make the system reliable enough for public use.

Parking/Vehicle Storage

As AHS increases the vehicle capacity, parking and vehicle storage in the urban environment (for example, from failed check-in/check-out) will become over-saturated. Vehicle design will be required to maximize space utilization.

Increased Highway Capacity

Additional freeway capacity has been built to accommodate peak highway traffic in the rural environment at the expense of construction on other rural traffic routes. People can commute longer distances in the same amount of time. This means greater employment opportunities in metropolitan areas for people in outlying communities and greater distances they will be able to travel for other purposes. This will affect vehicle maintenance and reliability.

Tax Base

In urban areas, the lost tax base in urban areas due to such aspects as usage of land for freeways will require the user to accept a greater cost burden either through increased taxes, vehicle license fees or tolls. In rural areas, the same will hold true due to the dispersed population.

Emergency Services

The level of emergency services is expected to improve in any AHS design. The ability of an emergency vehicle to arrive on-scene in a shorter time is one of the benefits of AHS. This shortened response time is due to both faster detection of a condition which requires an emergency vehicle and the potential speed increases (compared to non-AHS highways) which an AHS can support for emergency vehicle operation. The level of emergency services in the rural areas will improve dramatically with the introduction of AHS, although the challenges of rural emergency services are great. At issue in the rural environment are the long distances which an emergency vehicle may have to travel from qualified service stations. This could lead to the perception of excessive delays between the detection of an incident and the arrival of emergency vehicles. Depending on the minimum response time dictated by AHS operating requirements, emergency vehicle support may be supplemented by air response to relieve spacing of stations.

Malfunction Management

The AHS requirements will include malfunction detection and backup for failed components within the system. Common techniques for malfunction management include spacing infrastructure components at intervals which allow the operation of the AHS in the event of failure of one or perhaps two consecutive infrastructure components. The issue with this approach is the expense of infrastructure redundancy in rural areas. Alternately, if a rural highway is designed without redundancy, there are risks associated with both the malfunction itself and with the detection of the malfunction. The unit cost of preventive maintenance of infrastructure components will be proportionately higher in rural areas, due to the distances which must be traveled to get to the components and the lower vehicle density, assuming costs are distributed evenly among the users.

Operational Cost (Financing)

The cost of operating an AHS may be financed through fees collected from users of the AHS. The large number of vehicles and existing congestion in most urban areas will generate a demand for the AHS, even if user fees are charged. In rural areas, there will be significantly fewer vehicles from which fees can be collected. Also, in the absence of congestion on rural highways, drivers may choose to save money by not using the AHS. Financing alternatives to usage fees or methods of distributing fees collected over all areas should be considered.

Congestion Reduction

Congestion is predominately an urban problem. AHS will help to relieve congestion by increasing the highway lane density. Rural AHS will not focus on congestion reduction, since the typical traffic densities are low, although there are situations which do produce congestion in rural areas. For example, highways leading to and from vacation locations may be subject to significant congestion during the summer months or on long weekends. It is likely that the AHS will require either different equipment or closer spacing of equipment in the infrastructure to support congestion reduction. Decisions concerning which rural roadways benefit most from congestion specific equipment then become an issue. If additional vehicle equipment is required to support congestion reduction, at issue will be whether to equip all vehicles or only those vehicles intended for use in the urban environment. This creates an additional problem regarding whether to equip family vacation vehicles which may pass through a number of urban areas.

Deployment

The deployment issues of an AHS vary greatly between urban and rural environments. In a phased deployment, a subset of the final capability will be fielded first, giving the users some benefit while allowing the developers time to fully test the features of the mature system. A subset which addresses lateral and longitudinal control in order to improve safety but does not address the congestion problem would be adequate for a rural environment but insufficient for an urban environment. Similarly, a subset which addresses the congestion problem by providing higher vehicle densities in AHS lanes but does not address heavy trucks would be effective in an urban environment but would not be well suited to a rural environment.

Initial deployment of AHS exclusively in urban environments would not be acceptable to rural residents if the costs of AHS-specific equipment is included on all new cars. Similarly, initial deployment of AHS exclusively in rural environments would provide a small number of people the benefits of AHS at a higher cost per user. The challenge of deploying the AHS in urban and rural environments is balancing the capabilities of a phased deployment between the needs of urban and rural drivers as well as balancing the mix of urban and rural highways which will get initial AHS capability.

Check-Out

AHS design may include a storage area where vehicles can be parked if either the driver or the vehicle becomes incapable of manual operation. The spacing of these storage areas and the time lost due to diversion to one of the storage areas must be addressed in the AHS design. Reasonable spacing of storage areas from a cost and land use perspective may cause a vehicle to be diverted farther than the driver would like. Population centers may be spaced hundreds of kilometers apart in rural areas. Spacing of facilities may be even greater if locations are limited to centers with medical emergency facilities. It is unacceptable to divert a vehicle 100 kilometers or more. Storage areas with ramps from/to a parking facility may require significant space. The procurement of land for the storage areas should not be a problem in rural areas where land is available, but may be cost-prohibitive in urban areas.

User Perceptions

An overview of general issues and risks that influence user perceptions is provided in table 9. The vehicle design column relates the degree of importance of each factor to the other factors in that column. The urban column is relative to the rural column.

Highway systems have in the past received broad community support because of the perception that they would reduce congestion on local streets, reduce noise and air pollution, provide better access to recreational facilities, and increase economic levels. For rural communities in particular, they have served to upgrade educational facilities, improved vocational training possibilities, and made medical care more accessible. Other advantages have included increased accessibility to shopping and recreational facilities and an increased standard of living.

There has been the expectation of rural users that a highway system would benefit their area by allowing residents to commute to jobs in urban areas. It would reverse the flow of people to crowded urban centers and restore economic vitality to rural America. There would be positive effects for the physically and mentally disadvantaged with better access to urban services (e.g., health care and social and rehabilitation services) with a system like AHS. Specific to the vehicle, an AHS system needs to provide for these disadvantaged citizens.

Other perceptions are not as favorable to an AHS system. Local merchants in a rural area have suffered because of the decreased travel time to a nearby metropolitan area. There has been the fear that new industrial developments will move to the rural areas and displace local workers. Outsiders with greater capital resources could move into a rural area and benefit from the best opportunities to the disadvantage of local investors. And prices will rise as outside investors become interested in local sites for development and those who wished to relocate will be priced out of the land market.

Table 9. Potential Impacts of AHS on Urban and Rural Environments

Potential Impacts	...On Urban	...On Rural	...On Vehicle (Relative)
Perceptions of Implementation	Low	High	Low
Access to Emergency Services	Low	High	Low
Access to Recreational Sites	High	Low	Low
Equity of Representation	High	Low	Low
Vehicle Wear	High	Low	High
Noise Pollution	Low	High	High
Air Pollution	High	Low	High
Water Pollution	Low	High	High
Accident Rate	High	Low	High
Complexity of Demands on Driver	High	Low	High
Flow Congestion	High	Low	High
System Efficiency	High	Low	High
Serving Maximum Population	High	Low	Low
Park Land Taken	Low	High	Low
Vacant Land Taken	High	Low	Low
Access to Employment Opportunities	Low	High	Low
Access to Educational Opportunities	Low	High	Low
Displacement of Persons And Businesses	High	Low	Low
Effect on Welfare and Unemployment Costs	High	Low	Low
Effect on Commercial Property Value	Low	High	Low
Effect on Residential Property Value	Low	High	Low
Tax Gain through Increase in Land Value	Low	High	Low
Tax Loss through Displacements	High	Low	Low
Right-of-Way Costs	High	Low	Low
Facility Construction Costs	Low	High	Low
Vehicle Costs	Low	High	High
Fuel Consumption	Low	High	High
System Operating Costs per Kilometer (Labor)	High	Low	Low
System Operating Costs per Kilometer (Materials)	High	Low	Low
User Trip Time	High	Low	Low
User Trip Cost	High	Low	High
Weather Reliability	High	Low	Low
Comfort to Users	High	Low	High
Multiple Use of Space	High	Low	Low
Congestion on Neighboring Streets	Low	High	Low
Regional Growth and Development	Low	High	Low
Access to and Egress from Roadways	Low	High	Low
Changes in Retail Market area	Low	High	Low
Disruption Caused by Construction	High	Low	Low
Integration with Existing Transportation Facilities	Low	High	High
Community Development and Growth	Low	High	Low
Neighborhood Cohesion	Low	High	Low
Preservation of Historic And Cultural Sites	High	Low	Low
Conservation of Natural Resources	Low	High	High

CONCLUSIONS

The primary results of Activity Area A — Urban and Rural AHS Comparison indicate that the goals of urban and rural AHS are not compatible. The impetus towards increased automation in the urban setting is to improve traffic flow and reliability of travel times, while in rural areas the main advantage of automation is reduced travel times and ease of travel. The challenge of the AHS design will be to develop a configuration which addresses both environments. The major topics summarized from this report include the division of AHS instrumentation between the vehicle and the infrastructure, the effective utilization of AHS functions, balancing user costs with benefits, feasibility of evolutionary deployment, and availability of a communications backbone.

The division of instrumentation between the infrastructure and the vehicle must be determined by system-level design considerations which take into account the complexity, testability, reliability, and maintainability of the system. The design complexity and testability of the control loop system is directly affected by the placement of the equipment. One example of the effect of systems design considerations on this trade-off is the steady-state control loop system. This system is comprised of four major elements: the sensors, the communications, the processor, and the actuators. The sensors may be placed in the vehicle or the infrastructure, communications must be in the vehicle to support close vehicle following and may also be in the infrastructure, the processor may be in the vehicle or in the infrastructure, and the actuators must reside in the vehicle.

The control loop processor will accept inputs from the sensors and the communications, perform a calculation, and send the results in the form of commands to the actuators. This process may be repeated 20 to 50 times per second to support tight headway maintenance requirements. The design complexity and testability of the control loop system is directly affected by placement of the equipment. The scope of the roadside processing task can be appreciated using a numerical example. Typical figures proposed in related analyses project 4,000 vehicles per hour throughput at speeds of 100 km/h. These figures correspond to vehicle densities of 40 vehicles in one km of freeway at a single instant of time, assuming a single lane of traffic. Roadside processors spaced at one km intervals must be capable of receiving sensor inputs, performing calculations, and transferring actuator commands to 40 vehicles at a minimum update rate of 20 Hz. A single processor must also accept control of one vehicle per second and transfer control of one vehicle per second, coordinating with two adjacent controllers. The ability to uniquely identify position-related information for 40 individual vehicles is another significant task. Precise timing for each vehicle is extremely complex. The capacity of the communications system is proportional to the processing requirements, since 40 vehicles must receive actuator commands at least 20 times per second, corresponding to 800 messages per second. The testability of the system is difficult, since end-to-end testing cannot be completed until system integration. Finally, reliability is a concern, since failure of an infrastructure component affects transfer of control of 40 vehicles in this example.

Implementation of the vehicle control loop within the vehicle simplifies the timing of inputs to the processor, allows testing prior to system integration, and improves reliability in the sense that a failure affects a single vehicle only. Alternative infrastructure-based configurations which reduce the individual processor load will increase the quantity of roadside processors and increase the complexity of coordination among processors. Infrastructure placement is not considered practical for the vehicle control loop function.

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

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

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

The goals of evolutionary deployment of AHS functions are different in urban and rural scenarios. A subset of the capabilities may be fielded first in a phased deployment, providing users initial benefits while allowing developers time to fully test the features of the mature system. Adaptive cruise control combined with lane-keeping instrumentation are candidates for early AHS deployment which can provide safety benefits for travelers and trucks making long-distance trips. This capability is compatible with a rural environment, but may not provide throughput benefits in an urban environment in which the majority of drivers continue to weave, preventing effective use of automated headway control. Similarly, a subset which addresses the congestion problem by providing higher vehicle densities in AHS lanes but does not address heavy trucks would be effective in an urban environment but would not be well suited to a rural environment.

The AHS will require roadside communications electronics as part of the infrastructure to support dissemination of regional traffic coordination data. The potential disparity in the available communications backbone will affect the proportional cost of urban and rural instrumentation. Access to a variety of communication options such as traditional telephone lines or similar services are often available in urban areas. The lack of an existing communications system in rural areas may require installation of electronics and power as part of the AHS deployment. This could cause significant cost differences between the urban and rural implementation of AHS.

The results of the urban and rural comparison indicate that a system configuration which places responsibility for the vehicle control loop dynamics in the vehicle is the most feasible. The conclusion is drawn that while the evolutionary deployment of incremental AHS capabilities may provide limited safety and convenience benefits to some users, considerable throughput improvements cannot be achieved without full automation of vehicle control functions. It is recommended that the initial proof of concept be targeted to specific user requirements in a congested urban environment, with funding designed to include usage-based fees to establish operational capabilities prior to wide-scale deployment in connecting rural areas.

BIBLIOGRAPHY

Bates, John W., et al, "Effect of Fare Reduction on Transit Ridership in the Atlanta Region: Summary of Transit Passenger Data," Travel Demand, Mode Choice, and System Analysis, Transportation Research Record 499, Transportation Research Council, 1974.

Bishop, Richard J. Jr., "Precursor System Analysis of an Automated Highway System," IEEE Vehicular Technology Conference 1993, IEEE, 1993.

Curry, David, Richard Carlson, Clark Henderson, Thomas Mandel, Arnold Mitchell, Randall Pozdena, Peter Schwartz, et al, Transportation in America's Future: Potentials for the Next Half Century, Parts 1&2, Stanford Research Institute, 1977.

Delco Systems Operations, Precursor Systems Analyses of Automated Highway Systems, Activity D — Lateral and Longitudinal Control Analysis, Interim Results, May 1994.

Delco Systems Operations, Precursor Systems Analyses of Automated Highway Systems, Activity H — AHS Roadway Deployment Analysis, Draft Report, Interim Results, March 1994.

Farness, Donald H., et al, Cost-Benefit and Other Economic Analyses of Transportation, TRR, Transportation Research Board, 1974.

Geometric Design of Highways and Streets, American Association of State Highway and Transportation Officials (AASHTO), 1990.

Hill, Morris D., A Method for the Evaluation of Transportation Plans, Highway Research Record 180, Highway Research Board, 1967.

Huddleston, John, and C. Michael Walton, Interurban Transportation Policy and the Rural Community, TRR, Transportation Research Board, National Academy of Sciences, 1976.

Hudson, W. Ronald, and C. Michael Walton, Transportation to Fulfill Human Needs in the Rural/Urban Environment, Society of Automotive Engineers, Inc., 1974.

Manheim, Marvin L., Fundamentals of Transportation Systems Analysis, Volume 1: Basic Concepts, MIT Press, 1979.

Skorpa, Lidvard, Richard Dodge, C. Michael Walton, John Huddleston, Transportation Impact Studies: A Review with Emphasis on Rural Areas, Council for Advanced Transportation Studies, The University of Texas at Austin, 1974.

Stevens, William B., The Automated Highway System Concepts Analysis, MTR 93W0000123, Mitre, August 1993.

Walton, C. Michael, et al, Transportation Planning for Small and Medium-Sized Communities: Proceedings of a Workshop, Transportation Research Board, National Academy of Sciences, 1980.