Precursor Systems Analyses of Automated Highway Systems

RESOURCE MATERIALS

Check-In Activity

U.S. Department of Transportation
Federal Highway Administration

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FOREWORD

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

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

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

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

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

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EXECUTIVE SUMMARY

Activity Area Description

The check-in activity is one of 16 areas addressed as part of the "Precursor Systems Analyses of Automated Highway Systems (AHS)" study. The objective of this activity area is to identify major requirements, issues, and risks associated with ensuring that a vehicle and its operator can safely enter the AHS. In addition, the results of this precursor analysis provide insights into the technologies, design, deployment, operation and practicality of the automated check-in element of an AHS.

Study Focus

The focus of this study is on identifying the requirements, issues and risks associated with alternative approaches for performing automatic check-in to an AHS. The purpose of the check-in process is to ensure safe entry onto the AHS and safe and efficient operation while on the highway. An understanding of the information required at check-in to make these determinations was developed, and the potential system approaches for obtaining this information were investigated as a means for identifying potential requirements, issues, and risks. Special emphasis is placed on evaluating aircraft flight test technology and check approaches analogous to systems for AHS check-in.

Overall Approach

The overall approach to this task is centered on developing an evaluation matrix that combines the vehicle functions, vehicle characteristics, and operator characteristics required to be checked for safe AHS entry and efficient operation with alternate methods for obtaining the necessary information and performing the checks. Analyses of this matrix identified the requirements, issues and risks associated with the check-in activity.

Guiding Assumptions

A series of assumptions was made to support this analysis. These can be broken into three categories: 1) general assumptions, many of which were given in the Precursor Systems Analysis of AHS Broad Agency Announcement; 2) Representative System Configurations (RSC) for the implementation of an AHS; and 3) the manner in which the AHS may evolve over time.

Study Flow/Tasks

The precursor analysis for automated check-in consisted of five tasks: 1) define information requirements; 2) define check-in alternatives; 3) define evaluation criteria; 4) develop the evaluation matrix; and 5) determine requirements, issues, and risks.

Methodologies

The analysis performed for this study includes employment of four key methodologies: 1) Quality Function Deployment (QFD); 2) user acceptance surveys; 3) simulation; and 4) parametric cost analysis. The use of QFD was instrumental in developing an understanding of the information requirements associated with checking-in the vehicle. The use of simulation provided means for understanding the impacts of check-in design factors such as time required to check-in and number of check-in stations. The use of focus groups provided insights into the feelings of potential AHS users to ensure that we understood the issues as viewed by the user. Cost will be a key factor in the success, development timing, and approach to the implementation of an AHS. To address this key area, various cost analysis techniques were employed to give a first order feel for key issues arising from the ability to fund AHS development.

QFD Results

The QFD analysis was performed in four steps. Step one developed a list of information that may need to be obtained at check-in. Step two rated this information in terms of importance in relation to vehicle check-in. The third step included researching and developing a list of information acquisition approaches. Finally, step four determined the matches between the needed information and the information acquisition methods by assigning ratings of strong, moderate, weak, or no relationship. These relationships are captured in a matrix called the QFD "House of Quality." The QFD focus team used to perform this analysis included members of the Northrop Grumman Corporation flight test, avionics, human factors, advanced technology, and reliability and maintainability technical staffs, and the systems and cost analytical staffs.

Advanced Aircraft Health Monitoring and Flight Test Systems

There are direct correlations between verifying the readiness of an aircraft to fly a planned mission and validating whether an automobile is safe to enter and operate on an automated highway. Preparation of a complex advanced technology aircraft for flight is a "check-in" process that involves disciplined testing of aircraft subsystems, meticulous review of aircraft inspection and configuration records, and strict application of mandated maintenance procedures. Study of the methodology, procedures, and processes involved in an ongoing development test program for a complex military aircraft indicates a strong correlation between aircraft test philosophy and test techniques with those that would be associated with checking an automobile into an automated highway system.

Although the majority of flight preparation effort appears to occur within the hours just preceding a flight, the groundwork for preflight acceptance is laid in the in-depth inspections and systems certifications that are accomplished on a continuing basis throughout the active life of the aircraft. Performed on the basis of flight hours accumulated or on calendar time elapsed, periodic off-line inspections and testing establish the basic health credentials for an aircraft. During these inspections, the aircraft is subjected to microscopic inspections of critical parts, tear-down of mechanical components, such as flight control actuators, application of non-destructive inspection methods and test equipment to rule out incipient failures in highly stressed composite structures, and chemical analysis of lubricants and liquid coolants. For aircraft subsystems disrupted during the inspection or affected by software configuration changes, system re-tests are performed to verify performance to the baseline requirements.

Approaches to advanced aircraft check-in make maximum use of existing onboard information, relying on Built-In Test (BIT) for system validation. Periodic comprehensive reviews of aircraft systems to validate total system performance is performed. Real time data monitoring to continually validate vehicle performance is employed. This is equivalent to a check-in system approach that uses periodic vehicle inspections, relies heavily on vehicle self-test capability where critical system status information is broadcast to the "control center," and continues to use this self-test capability to provide a real-time assessment of the vehicles and driver's ability to operate safely.

Automotive Technology Assessment

Discussions were held with elements of five automobile manufacturers to gain an understanding of current automotive design and future trends. The companies contacted were Chrysler Corp., Ford Motor Corp., General Motors Corp., Honda Corp., and Toyota Corp. The primary elements contacted were R&D centers whereby we gained general knowledge on the directions of automotive system design and dealer service facilities. Through the latter, access was gained to detailed service manuals that provide insight into current automotive system design.

These discussions highlight the fact that automotive companies are proceeding down the developmental path the aerospace industry followed, especially in the direction of digital serial line communication systems. The vehicle systems clearly show the trend within the automotive industry to increase on-board system monitoring for purposes of maintenance, safety, and engine monitoring associated with emissions. It also confirms that the number and sophistication of system test and monitoring capability are growing and will continue to grow.

Advanced aircraft sophistication notwithstanding, current generation automobile technology matches current military aircraft technology virtually feature for feature, varying only in scale, maintainability, reliability, and cost. Multiple dedicated digital processors communicating on serial digital buses, built-in test, fault sensing, indication and recording, automated controls, and augmented steering are either baseline elements or optional features in today's automobiles. As a result, there is significant fall-out from aircraft technology and flight test instrumentation design practices which can benefit the planning and design of vehicles for automated highways:

1. Industry standards are vital to the integration of on-board vehicle systems with external supporting systems. These include:
    a. Serial bus communication protocol and software governing data word lengths, frame structure, engineering units algorithms, and synchronization strategy.
    b. RF communication standards.
    c. Standards for pressure, position, and temperature sensors.
    d. Standards for vehicle design that affect system safety and vehicle certification.

2. Utilization of existing vehicle diagnostics and status reporting features can provide rich resources for external monitoring and control of onboard systems, with minimum impact on vehicle design.

3. Test-unique sensors are employed when the required data cannot be obtained from the vehicle subsystems.

4. Programmability of on-board systems to support evolution and modification of vehicle and external support systems.

5. Modularity of system components enhances troubleshooting and maintenance.

User Acceptance Survey

As a means to gain insight into issues associated with user acceptance of various AHS check-in approaches, a survey was conducted. This survey was designed to take advantage of focus-group-style discussions where the groups consist of approximately 8-10 people and several one-on-one sessions. These smaller sessions targeted individuals who drive as part of their living as opposed to the commuters who dominate the larger focus groups. In addition, we contacted a Caltrans district traffic engineer and asked the same questions of him to get an expert's opinion. The survey focuses on six categories: check-in scenarios (i.e. station, transition lane); entrance criteria (i.e. driver's license, AHS training, maintenance requirements); information (i.e. privacy); driver interaction; equipment and associated costs; and a summary section.

Prior to attending the focus groups, participants were sent a brief introduction on the concept of an AHS. Additionally, participants were asked to complete a personal data questionnaire to identify their driving characteristics and to link unique concerns to specific focus groups. Instructions for the survey were presented to the focus group followed by a brief description of AHS check-in and some possible scenarios. The survey was administered and results were tabulated.

Simulation

In order to assess the effect that check-in time may have at an AHS entry point in terms of queue length and vehicle time in system, a simple queuing simulation was constructed and exercised. Depending on the number of vehicle systems and driver functions that must be interrogated prior to entering the AHS, the time required to actually perform the check-in can vary and consequently have a significant impact on the flow of vehicles through the AHS entry point. This analysis complements the QFD analysis by providing an idea of what, where, and how items are checked and the implications of associated check-in time requirements on traffic performance.

AHS check-in can potentially occur in several ways depending on the structure of the highway where an AHS entry point may exist. For this queuing analysis, we chose to focus on the check-in station rather than the transition lane, primarily due to the scope of this effort and the current stage of model development. However, in terms of resultant delays from vehicle queuing, the check-in station represents the most critical case since it is assumed that vehicles would not stop while on a transition lane. This queuing model can currently be used to perform sensitivity analysis on arrival times, check-in times, and number of check-in stations.

Measures of performance obtained from the check-in simulation include the following:

- Average time the vehicle spent in the system
- Average number of vehicles waiting to be checked
- Percentage of time that the check-in station(s) is occupied
- Percentage of time that the check-in station(s) is idle

Cost Analysis

The objective of this analysis was to establish relative magnitudes of life cycle costs (LCC) to the user, business, government, and public. Top-level analysis was performed to give a first-order look at the relative cost distribution for a concept among the user, business, government, and public by LCC phase. In addition, risks were identified in terms of the inclusion of systems or approaches which are high cost drivers, and the potential impact on the likelihood of implementation based on these risks.

AHS Check-In entry options are itemized into required components or technologies for implementation; software requirements were also approximated. When major components were identified, various methods were considered to generate relative magnitudes of cost. For components classified as individual pieces of equipment for the users or for the AHS Check-In site, parametric analysis, estimates by analogy, and literature searches were the primary methodologies used to estimate LCC magnitudes. LCC includes the development, production, and operations and maintenance phases of a system. Parametric analysis is generally used in cases where the minimal detail information is available such as an envisioned technology with a rough sizing of the system. Minimal design details are required when using parametric analysis. Northrop Grumman possesses multiple models to assist in performing parametric analysis which are accepted for use by government and industry, including PRICE, SEER, REVIC, and Cognition. Estimating by analogy is used when a technology or similar component exists and can be applied with minor modifications. The existing component is adjusted by a complexity factor determined by the designer which characterizes the relative additional or reduced complexity of the new conceptual design. Literature searches are used when a specific component is known to exist and is specifically required to be part of the system. Literature searches also supplement analogous estimates by providing information on existing component performance and costs to enable a determination of a complexity factor adjustment to account for current AHS concepts.

Assessments/Analysis

Many information acquisition approaches for obtaining vehicle and driver information at AHS check-in were assessed on their individual merits. These approaches include BIT, driver supplied data transfer, certifications stations, encoded data with scanners, imaging sensors, instrumentation, and driver physiological sensors. Assessment of each approach includes a system description, technology maturity evaluation, strength and weakness descriptions, and cost analysis.

AHS Check-In Options

Alternate integrated systems approaches were developed for a mature (circa 2010) AHS from extensive assessments based on the QFD analysis. The baseline and six alternate systems are shown in the figure 1. In order to perform an analysis of the merits of each approach, an operational context is needed. The operational context in this case is the manner in which the highway entry point will be implemented.

In general, each alternate system has increased capability, in terms of advanced technology, as you move down the figure 1. With these advances come cost, time, safety, and technological maturity tradeoffs. These tradeoffs, applied to each alternate system, are shown in figure 2. In order to select which check-in concept is the most appropriate for AHS needs, these four aspects (cost, time to check-in, safety, and technology assessment) must be carefully considered along with the preferred AHS infrastructure concept.

Option	BIT	Certif. Station	Operator Keys	Add-On Instrumentation	Smart Card	Driver Interaction	ROM	Physical Condition Sensor	Unique Physical Signature	Audio Input	IR Sensors
Baseline	X	X	X	X (w,t,h)	X	X					
Alt 1	X	X	X (i)	X (w,t,h)	X (i)	X (i)					
Alt 2	X	X	X	X (w,t,h)	X	X	X				
Alt 3	X	X	X	X (w,t,h)	X	X	X	X			
Alt 4	X	X	X	X (w,t,h)	X	X	X	X	X		
Alt 5	X	X	X	X (w,t,h)	X	X	X	X	X	X	
Alt 6*	X		X	X (w,t,h,p)	X	X	X				X

(i) = Infrastructure
(w) = Vehicle Weight Measurement
(t) = tire pressure
(h) = hitch and chain
(p) = Pressure Transducer, Strain Gauge, and Accelerometer to Obtain Component Data
* Obstacle course required

Figure 1. Baseline and Six Check-in Alternatives

Conclusions

A sophisticated AHS check-in system is technologically feasible by the year 2010 considering the types of technologies currently available and other emerging technologies applicable to automated check-in. A review of the philosophies, methodologies, procedures, techniques, and processes involved in the flight testing of advanced air vehicles suggests application to AHS check-in of ground vehicles. Lessons learned from flight test programs, advanced aircraft data systems, instrumentation, and data acquisition technologies can be instrumental in the development of smart car systems.

Maximal use should be made of existing vehicle capabilities and trends in automobile design. Currently, on-board vehicle health monitoring systems appear to be the trend, which would facilitate a smooth transition of vehicles in becoming AHS compatible. The retrofit of existing vehicles that are not AHS compatible should be available by 2010, thus opening the AHS to "used" vehicles as well.

The time required to check-in will be critical in terms of traffic flow efficiency, user acceptance, and safety. Ideally, check-in should be as transparent to the operator as possible, and therefore, functions assessed by AHS that require additional operator tasks or actions beyond current driving requirements should be minimized. Utilizing technologies such as ROM, audio input, and smart card can significantly increase the safety of the system as well as reduce the time required for a vehicle to check-in.

Option	Cost*	Time to Check-In (sec) Min./Max.	Safety	Technology Assessment	Comments
Base-line	1.3B	2.02/15.02	• Too much driver interaction • Deficiency in checking driver alertness	• Only technology not mature is smart cards • Certification station can be developed off existing systems	
Alt. 1	1.2B	15.02/15.02	• Full stop transition lane may back up onto freeway	• Same as the baseline, but technology is placed in the infrastructure	• Only feasible with a check-in station • Check-in time penalty (all checks occur at a check-in station)
Alt. 2	1.4B	2.02/12.06	• Use of ROM decreases required driver interaction	• ROM is a fully mature tech-nology	• ROM adds level of security by being a tamper resistant form of data storage
Alt. 3	1.8B	1.0/10.22	• Reliable check of driver condition by physical condition sensor	• A physical condition sensor should be avail-able by 2010.	• Some concern with cost, size, and acceptance
Alt. 4	1.9B	1.0/10.42	• High confid-ence of driver identification	• Unique physical signature systems are in develop-ment.	• Privacy issues are a major concern with positively identifying the driver
Alt. 5	2.8B	1.0/7.41	• Audio input decreases driver distraction	• Audio input and voice rec-ognition is in development for continuous dictation.	• Audio input supports check-in on-the-fly • Cost concern
Alt. 6	1.1B	5.0/15.0	• Full obstacle course checks AHS systems	• IR sensors are in development today for vehicle identification	• Only available with a check-in station

* Life Cycle Cost (LCC) to the user, business, government, and public. LCC includes development, production, operations and maintenance phases of a system.

Figure 2. Alternate Check-In System Comparison

Several issues and risks associated with AHS check-in were identified during this study. In requiring a certification station, an issue arises concerning training and regulation necessary to operate these "service" stations to ensure system safety checks are performed in a consistent and legal manner. Standardization is also a problem that must be addressed since it could affect several aspects of AHS operation including communication, interstate AHS compatibility, individual vehicle performance capability, data protocol, and vehicle BIT systems. Tamperproof on-board and off-board equipment is also crucial in preventing unsafe vehicles and drivers from accessing the AHS.

Testing the driver impairment and/or alertness via a physical condition sensor may have a high cost since the technology is still in a developmental stage. However, if driver interaction was used to accomplish this function, the possibility of driver distraction may present a safety problem. An audio input device must be able to account for fluctuations in audio delivery (different accents, etc.), clutter, and hearing impaired drivers.

There is also the issue of privacy of information. To what extent should the system be able to access a driver's personal information, such as retrieving the address from the driver's license, determining travel origins and destinations, or identifying an impaired driver? Whatever is decided, the public should be informed of the information that might be accessed so that there is a choice whether to use the AHS.

SECTION 1

INTRODUCTION FOR ACTIVITY AREA

1.1 ACTIVITY AREA DESCRIPTION

The automated check-in activity is one of 16 areas addressed as part of the "Precursor Systems Analyses of Automated Highway Systems (AHS)" study. The objective of this activity area is to identify major requirements, issues and risks associated with ensuring that a vehicle and its operator can safely enter the AHS. In addition, the results of this precursor analysis provide insights into the technologies, design, deployment, operation and practicality of the automated check-in element of an AHS. Northrop Grumman was assisted in this effort by the Partners for Advanced Transit and Highways (PATH), who provided guidance and expert opinion concerning advanced transportation systems.

1.2 STUDY FOCUS

The focus of this study is on identifying the requirements, issues and risks associated with alternative approaches for performing automatic check-in to an AHS. Some of the issues addressed in this report by Northrop Grumman are shown in figure 1-1, which is MITRE's automated check-in issues matrix. The issues to be addressed by other contractors are shown as well.

The purpose of the check-in process is to ensure safe entry onto the AHS and safe and efficient operation while on the highway. An understanding of the information required at check-in to make these determinations was developed and the potential system approaches for obtaining this information were investigated as a means for identifying potential requirements, issues, and risk. Special emphasis was placed on evaluating aircraft flight test technology and health monitoring approaches as analogous systems for AHS check-in.

Issue	Calspan	Delco	Honeywell	Northrop[1]	Raytheon
Vehicle functions to be tested	Yes	Yes, includes special service vehicles.	Yes, includes software testing and certification	Yes	Yes
Operator characteristics to be tested	Yes	Yes	Only minimally considered due to the extensive effort by the Human Factors Program.	Yes	Yes, special emphasis on the role of the driver. Various levels of automation.
Seriousness of the function or characteristic	Yes	Yes	Yes, will depend on the established system safety requirement. Will drive the priority of the malfunction management strategy.	Yes, hierarchy of failure of a function. Information requirements.	Yes
Current and projected state-of-the-art in vehicle design and manufacture		Yes, will incorporate input from GM into projected AHS relevant technologies.	Yes, projected system configuration mechanization will be addressed.	Yes	Yes. Insight from Ford with respect to projected technology will be incorporated.
Infrastructure requirements		In Exit/Entry	Minimal, will only consider the roadside equipment.		Yes
Effect of failure advisories			Data required for operator display, and that required for malfunction management.	Yes	
Acceptability of the approach	Yes, impact on roadway and vehicle design.			Yes	Yes, including liability and safety issues.
Major alt. ways to ensure safe and efficient operation	Yes, broad overall approach.	Yes, broad overall approach.	Yes, part of overall Health Management System.	Yes, incorporation of aircraft diagnostic systems.	Yes
Component check upon start up		Continuous in-vehicle?	Yes	Yes, Built-In Test (BIT)	Yes
Component check on non-AHS roads		In-vehicle?	Yes	Yes - BIT	Yes. This is a strong emphasis area.
"On the fly" check in	Yes, emphasis area.	Dynamic check-in	Yes	Yes - AHS Traffic Permitting.	Yes
Comm. link requirements	Yes	Yes, incorporate comm. expertise of Hughes.		Yes	Yes
Built-in vs. dynamic tests	Yes	Implicit	Yes	Yes - Special BIT Program.	Yes
Early deploy. and distant future needs		Yes			Yes. Evolutionary Approach.

[1]Establish a command center for the infrastructure-Management Plan: 1) Computer Complex; 2) Software Specifications; 3) Communications Center. Note: Privatization could be the answer for AHS. This was suggested for Air Traffic Control to expedite upgrades and development - a czar to head it up.

Figure 1-1. Automated Check-In Issues Matrix

1.3 OVERALL APPROACH

The overall approach to this task is centered on developing an evaluation matrix that combines the vehicle functions, vehicle characteristics, and operator characteristics required to be checked for safe AHS entry and efficient operation with alternate methods for obtaining the necessary information and performing the checks. Analyses of this matrix identified the requirements, issues and risks associated with the check-in activity. The approach for this analysis is depicted in figure 1-2.

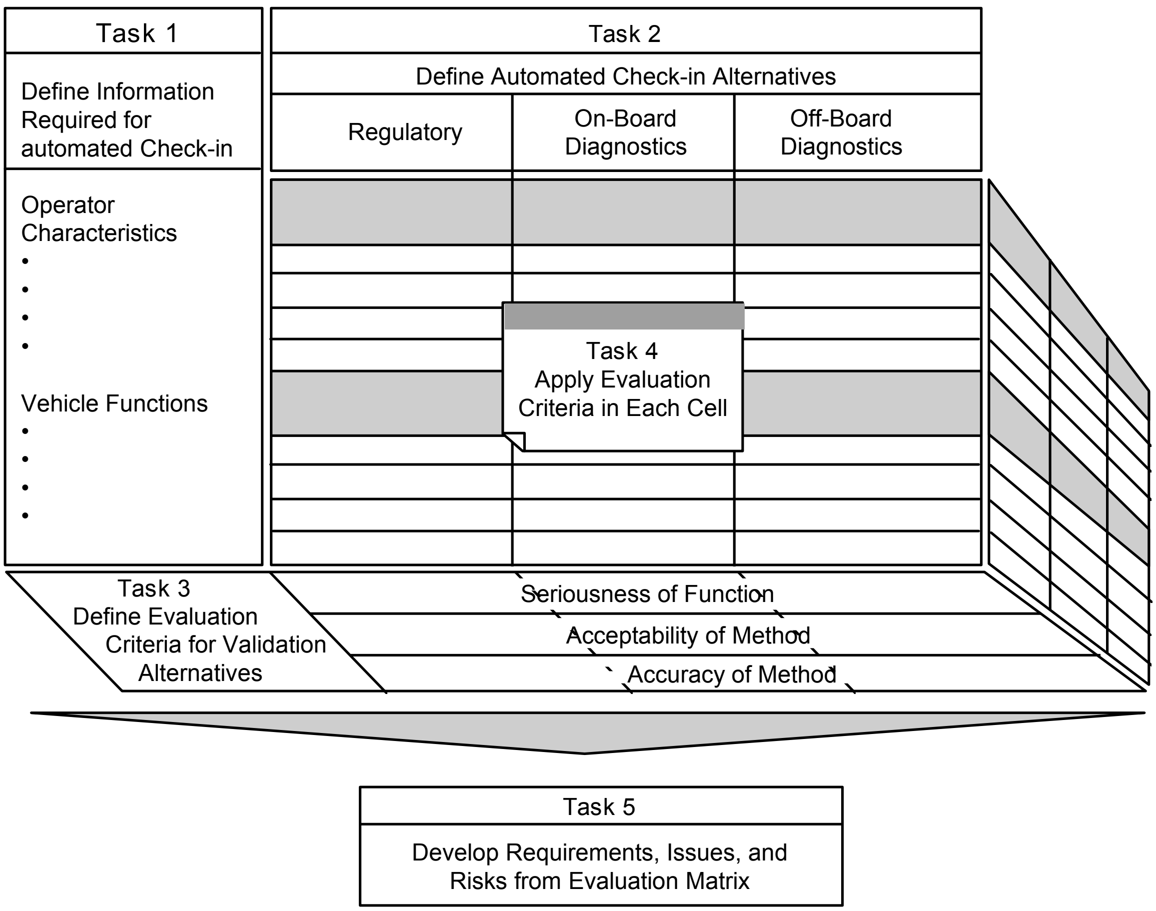


Figure 1-2. Automated Check-In Analysis Tasks

1.4 GUIDING ASSUMPTIONS

A series of assumptions was made to support this analysis. These can be broken into three categories: 1) general (many of which were given in the Broad Agency Announcement [BAA]); 2) Representative System Configurations (RSC) for the implementation of an AHS; and 3) the manner in which the AHS may evolve over time. These assumptions are addressed in the following sections.

1.4.1 General

The following assumptions were used for this study:

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

2. The vehicles will contain instrumentation that will allow the AHS to control the vehicle while operating on instrumented segments of the roadway.

3. Not all vehicles will be instrumented and not all roadways will be instrumented:
   - Instrumented vehicles will be able to operate on non-instrumented roadways.
   - Only instrumented vehicles will be allowed to operate on instrumented roadways.
   - Non-instrumented vehicles can be instrumented on a retrofit basis.

4. Operation on a freeway (as defined by the American Association of State Highway and Transportation Officials [AASHTO]) type of roadway is assumed.

5. The AHS will operate in a wide range of weather conditions typical of the continental United States.

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

7. Vehicle and driver inspection must not create a significant impact on the efficiency of either automated or conventional highways.

8. No hazards shall be induced due to the inspection process.

1.4.2 Representative System Configurations (RSC)

A multitude of RSC's have been proposed, which mix and match system elements, i.e., roadway infrastructure, degree of centralization of command, control, and communications, and types of vehicles. These RSC's focus on the overall operation of an AHS and therefore yield many variations. However, a review of the possible RSC's shows that the range of probable options associated with check-in is much smaller, as depicted in a simple matrix in figure 1-3. Figure 1-3 specifically addresses checking the vehicle at entry to the AHS, whether through a check-in station or transition lane, as well as assessing a vehicle's approach speed. This matrix represents all the check-in options associated with the complete set of RSC's.

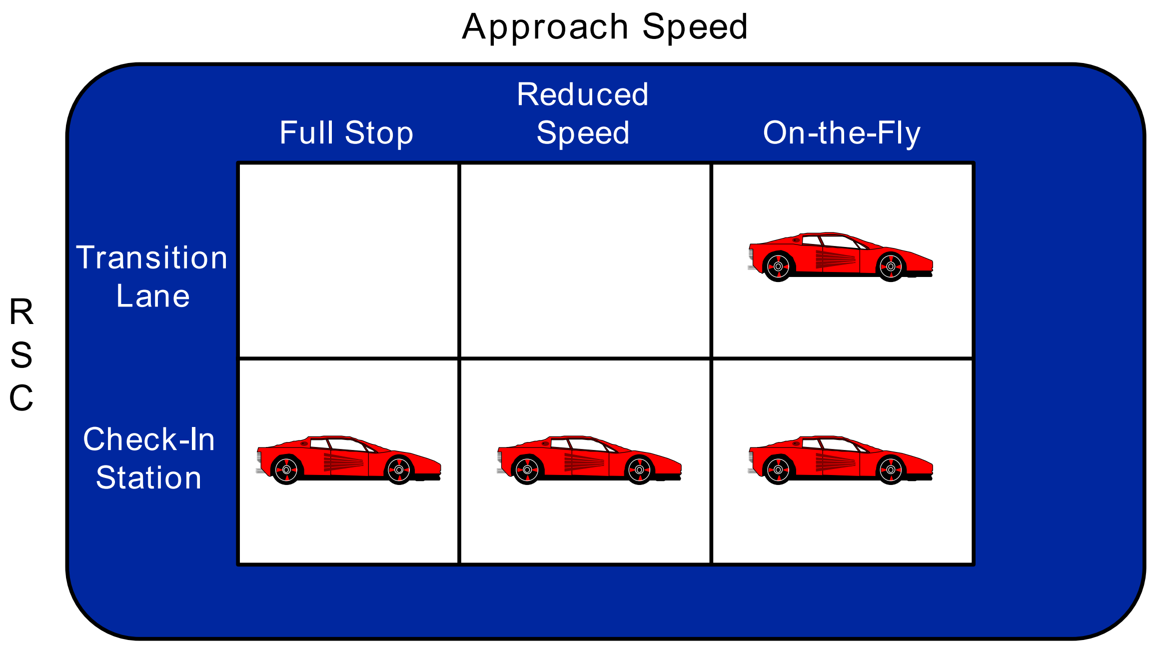


Figure 1-3. Range of Check-in Approaches

These AHS entry options can accommodate all vehicle types, including electric vehicles, as illustrated in some of the proposed RSC's. Any of these options can be combined with a requirement for regular certification checks. In addition, an "obstacle course" could be added to permit stimulation of vehicle systems to ensure proper function of the systems and software (figure 1-4). It is assumed for the obstacle course that a roadside control center would transmit a set of instructions commanding the vehicle to perform a series of maneuvers designed to generate the necessary data to check safety critical functions.

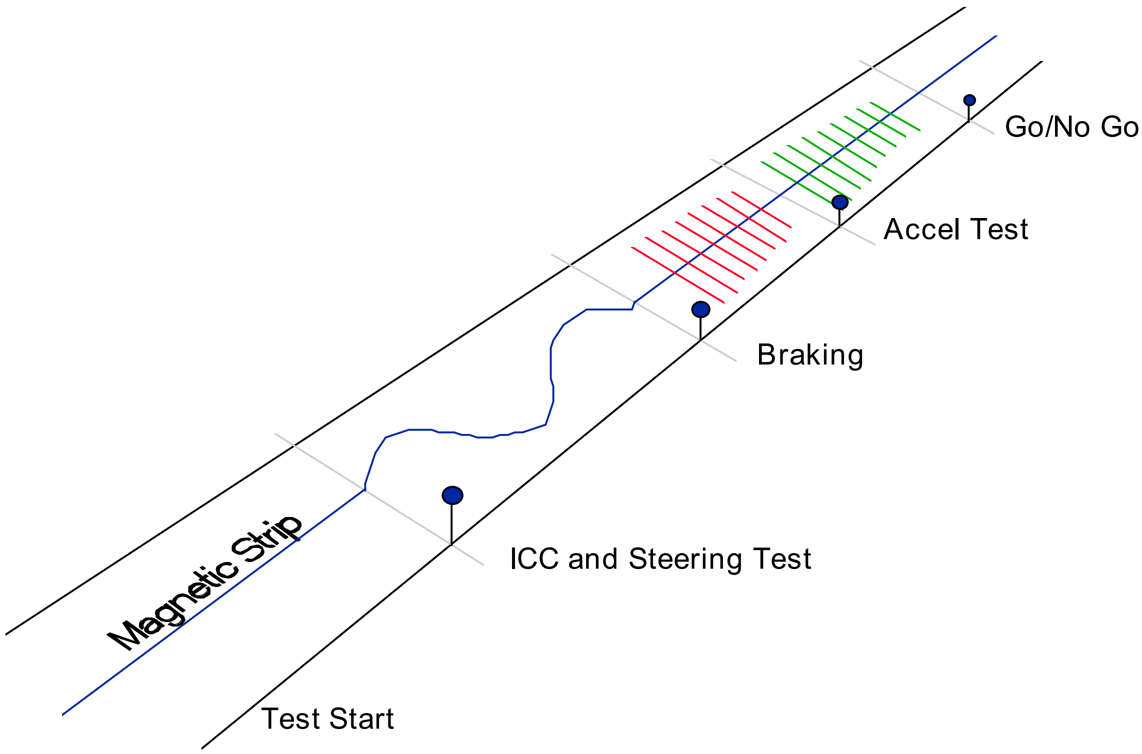


Figure 1-4. Obstacle Course

1.4.3 Evolution

A key factor that will influence how the check-in system is implemented will be the evolution of the overall AHS. Several evolutionary paths have been proposed, including those by the University of Southern California Center for Advanced Transportation Technologies[1], developed as part of the PSA studies. The primary interest for this study is how the AHS evolution will influence the requirements for the check-in system. As a starting point for this study, a reduced version of the USC proposed evolution was adopted (figure 1-5).

The first step in this evolutionary process focuses on intelligent cruise control (ICC) with a dedicated lane for ICC-equipped vehicles. A dedicated lane is needed primarily due to safety reasons; collision avoidance capability is not implemented in this stage, although the technology is advancing rapidly. Sensors are used to determine traffic flow and identify vehicles in the blind spot. Additionally, communication is established between the vehicles and the roadway.

No Automation (Today)	Dedicated ICC Lane
• HOV Lanes • Traffic Warning & FreewayCondition Signs • Ramp Metering	• Communication between Vehicles and the Roadway • Driver Steers the Vehicle • Sensors for Traffic Flow • Lateral Blind Spot Sensor
Multiple ICC Lanes	**Fully Automated**
• Vehicle-to-Vehicle Communication • "Hands Off" Steering in a Single Lane • Longitudinal Collision Avoidance • Sensors Provide Lateral Collision Warnings • Look-Ahead Data Required by Sensors or Transponders on the Roadway	• Vehicle Enters Lane and Merges Automatically • Vehicles can Change Lanes with Automated Lateral Collision Avoidance • Vehicles Treated as "Packets" • Vehicle Routed by Roadway • Vehicle Tells the Roadway Position and Speed

* MAIN SOURCE: Data here is primarily from "AHS Evolution", USC Center for Advanced Transportation

Figure 1-5. Possible AHS Evolution

In the next step (see figure 1-5), multiple ICC lanes exist now that communication is established between vehicles and collision avoidance is operational. Finally, the AHS transitions into a fully automated system with vehicles merging into the lanes automatically and changing lanes automatically as well.

These evolutionary steps are important not only from a technology availability perspective, but also from an acceptance issue by potential AHS users. Such a complex system will have to be introduced in stages so that users become familiar and comfortable with the operation of an AHS to ensure its maximal use.

SECTION 2

ANALYTICAL APPROACH

2.1 STUDY FLOW/TASKS

The precursor systems analysis for automated check-in was accomplished in three phases. The first phase consisted of tasks related to the QFD analysis while the second phase assessed information acquisition and evaluation approaches. This second phase included queuing analysis accomplished using simulation as an analysis tool. Finally, the third phase evaluated integrated check-in system alternatives in order to determine system requirements, issues, and risks. This study flow is depicted in figure 2-1.

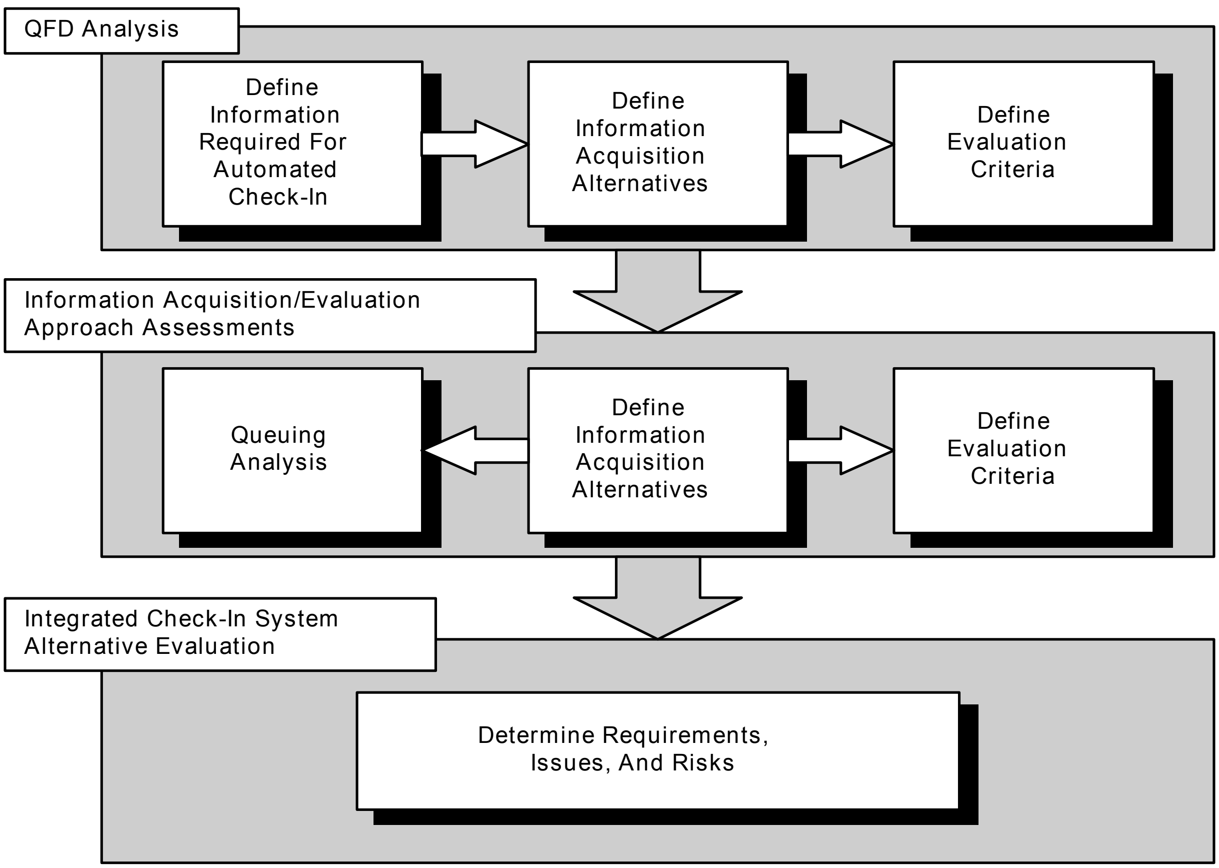


Figure 2-1 Study Flow

2.1.1 Define Information Required for Automated Check-in.

The objective of this task was to identify the information required for evaluation at check-in to ensure both the vehicle and operator can safely enter and operate on the AHS. This was accomplished by performing a functional analysis to systematically establish the vehicle systems and operator qualifications, capabilities, and status which must be checked prior to permitting AHS entry.

2.1.2 Define Automated Check-in Alternatives.

The objective of this task was to define alternative means to obtain and validate information regarding the vehicle functions and operator characteristics.

2.1.3 Define Evaluation Criteria.

The objective of this task was to define the criteria for evaluating the information requirements and alternative check-in system approaches.

2.1.4 Develop Evaluation Matrix.

The objective of this task was to define the relationships between information developed in the first two tasks to provide the basis for determining requirements, issues and risks. Northrop Grumman used the Quality Function Deployment (QFD) methodology to prioritize the information requirements and relate the alternative means for obtaining and validating vehicle check-in information to the information requirements. The QFD methodology is discussed in section 2.2.1.

2.1.5 Develop Requirements, Issues, and Risks.

The objective of this task was to develop requirements, issues, and risks based on the analysis of alternate integrated check-in system approaches. These alternatives were developed from the results of the QFD exercise.

2.2 METHODOLOGIES

The analysis performed for this study includes employing four key methodologies: 1) QFD; 2) focus group surveys; 3) simulation; and 4) parametric cost analysis. The use of QFD was instrumental in developing an understanding of the information requirements associated with checking-in a vehicle. The use of simulation provides means for understanding the impacts of check-in design factors such as time required for check-in and number of check-in stations. The use of focus groups provided insights into the feelings of potential AHS users to ensure that we understood the issues as viewed by the user. Cost will be a key factor in the success, development timing, and approach to the implementation of an AHS. To address this key area various cost analysis techniques were employed to give a first order feel for key issues arising from the ability to fund AHS development.

2.2.1 Quality Function Deployment (QFD)

QFD is a structured methodology that systematically and logically organizes information to improve decision making. It uses a set of matrices that organizes and documents conventional wisdom and technical know-how. The primary matrix relates the needs or requirements that must be satisfied (the "Whats") to the methods and concepts that can be used to satisfy the needs (the "Hows"). The relationships are weighted using a strong, medium, weak, or no-relationship-with approach. By assigning values to these relationships and to the importance of the "whats," an absolute rating and relative ranking for each of the "hows" can be developed.

2.2.2 User Survey

A survey was conducted as a means to gain insight into issues associated with user acceptance of various AHS check-in approaches. This survey was designed to take advantage of focus-group-style discussions where the groups consist of approximately 8-10 people, plus several one-on-one sessions. These smaller sessions targeted individuals who drive as part of their living as opposed to the commuters who dominated the larger focus groups. In addition, we contacted a Caltrans district traffic engineer and asked the same questions of him to get an expert's opinion.

For the survey, open-ended questions were developed around a broad range of issues to identify user perceptions and needs including human factors design. The following assumptions were utilized for question development:

1. The larger focus groups were homogeneous, i.e. members of each group shared similar driving patterns and experiences.
2. Most of the subjects had little or no knowledge of AHS.
3. Subjects had some prior knowledge of current California highway systems (e.g. ramp metering, carpool lanes) and driver requirements (e.g. driver's license, smog certification, insurance).

The survey focuses on six areas: check-in scenarios (i.e. station, transition lane); entrance criteria (i.e. driver's license, AHS training, maintenance requirements); information (i.e. privacy); driver interaction; equipment and associated costs; and a summary section. Categories were arranged to represent the information flow of check-in as well as to facilitate the transition of responses from one category to the next. Additionally, questions within each category were arranged to lead discussions to the next question. This allowed the survey to more closely reflect a conversation thus encouraging the flow of ideas.

Prior to attending the focus groups, participants were sent a brief introduction (see appendix B) on the concept of an AHS so that we could concentrate on the check-in aspect of an AHS during the actual focus group and minimize the number of questions regarding AHS in general. In addition, participants were asked to complete a personal data questionnaire to identify their driving characteristics and to link unique concerns to specific focus groups. Instructions for the survey were presented to the focus group followed by a brief description of AHS check-in and some possible scenarios. In addition, a brief description was provided at the beginning of each category.

2.2.3 Simulation

In order to assess the effects that check-in time may have at an AHS entry point in terms of queue length and vehicle time in system, a simple queuing simulation was constructed utilizing a simulation language called SIMAN. Depending on the number of systems that must be interrogated prior to entering the AHS, the time required to actually perform the check-in can vary and consequently have a significant impact on the flow of vehicles through the AHS entry point. This analysis complements the QFD analysis by providing an idea of what, where, and how items are checked and the implications of associated check-in time requirements on traffic performance.

AHS check-in can potentially occur in several ways depending on the structure of the highway where an AHS entry point may exist. For this queuing analysis, we focused on the check-in station rather than the transition lane primarily due to the scope of this effort and the current stage of model development. However, in terms of resulting delays from vehicle queuing, the check-in station represents the most critical case since it is assumed that vehicles would not stop while on a transition lane.

Currently the model follows the algorithm depicted in figure 2-2. The arrival time to the check-in point is based on an exponential distribution with a mean arrival rate and the actual check-in time is assumed to be constant. When the vehicle is released, it is assumed that the ramp leading to the actual AHS is clear (i.e. no additional queue develops).

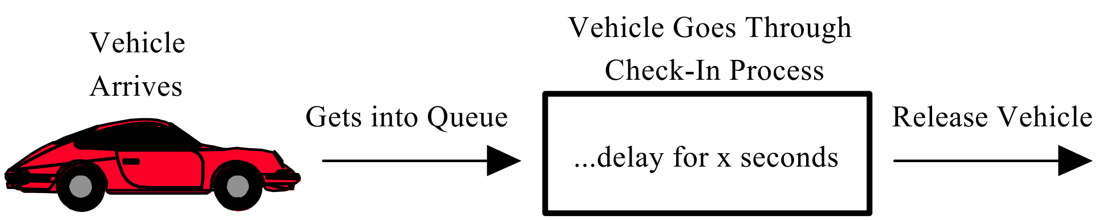


Figure 2-2. Model Algorithm

In all likelihood, there would not be two queues for the vehicle to pass through (i.e. before and after the check-in process) because of the inefficiency in traffic flow and driver irritation that would result. It was assumed that the vehicle would be held at the station, if necessary, until a successful merge with the AHS traffic flow could be made. Therefore, one can think of the delay time incurred during the actual check-in process as including a time factor for safe access to the AHS considering aspects such as traffic flow and safety. A delay time of zero implies that check-in was on-the-fly and the vehicle is permitted to immediately merge onto the automated highway. Measures of performance obtained from the simulation include the following:

- Average time the vehicle spent in the system (i.e. check-in procedure and release)
- Average number of vehicles waiting to be checked (i.e. queue length on on-ramp)
- Percentage of time that the check-in station(s) is occupied
- Percentage of time that the check-in station(s) is idle

2.2.4 Cost Analysis

The objective of this analysis was to establish relative magnitudes of life cycle costs (LCC) to the user, business, government, and public. User is defined as the operator of the AHS vehicle. Business encompasses entities which will produce or integrate equipment required to achieve a full AHS check-in function. Government includes agencies responsible for procuring and maintaining the AHS check-in functions. The last sector, public, encompasses the total population, including the user, affected both directly and indirectly by the installation of an AHS check-in system.

Top-level analysis was performed to provide a first-order look at the relative cost distribution for a concept among the user, business, government, and public by LCC phase. LCC includes the development, production, and operations and maintenance phases of a system. In addition, risks were identified in terms of the inclusion of systems or approaches which are high cost drivers, and the potential impact on the likelihood of implementation based on these risks.

The approach to this analysis is shown in figure 2-3. AHS check-in entry options (see section 3.3) were divided into required components or technologies for implementation, and software requirements were estimated. When major components were identified, various methods were considered to generate relative magnitudes of cost. For components classified as individual pieces of equipment for the users or for the AHS check-in site, parametric analysis, estimates by analogy, and literature searches were the primary methodologies used to estimate LCC magnitudes. Parametric analysis is generally used in cases where the minimal detail information is available such as an envisioned technology with a rough sizing of the system. Minimal design details are required when using parametric analysis. Northrop Grumman possesses multiple models which are accepted for use by government and industry, (e.g.., PRICE, SEER, REVIC, and CostAdvantage) to assist in performing parametric analysis. Estimating by analogy is used when a technology or similar component exists and can be applied with minor modifications. The existing component is adjusted by a complexity factor, determined by the designer, which characterizes the relative additional or reduced complexity of the new conceptual design. Literature searches are used when a specific component is known to exist and is specifically required to be part of the system. Literature searches also supplement analogous estimates by providing information on existing component performance and costs to enable a determination of a complexity factor adjustment to account for current AHS concepts.

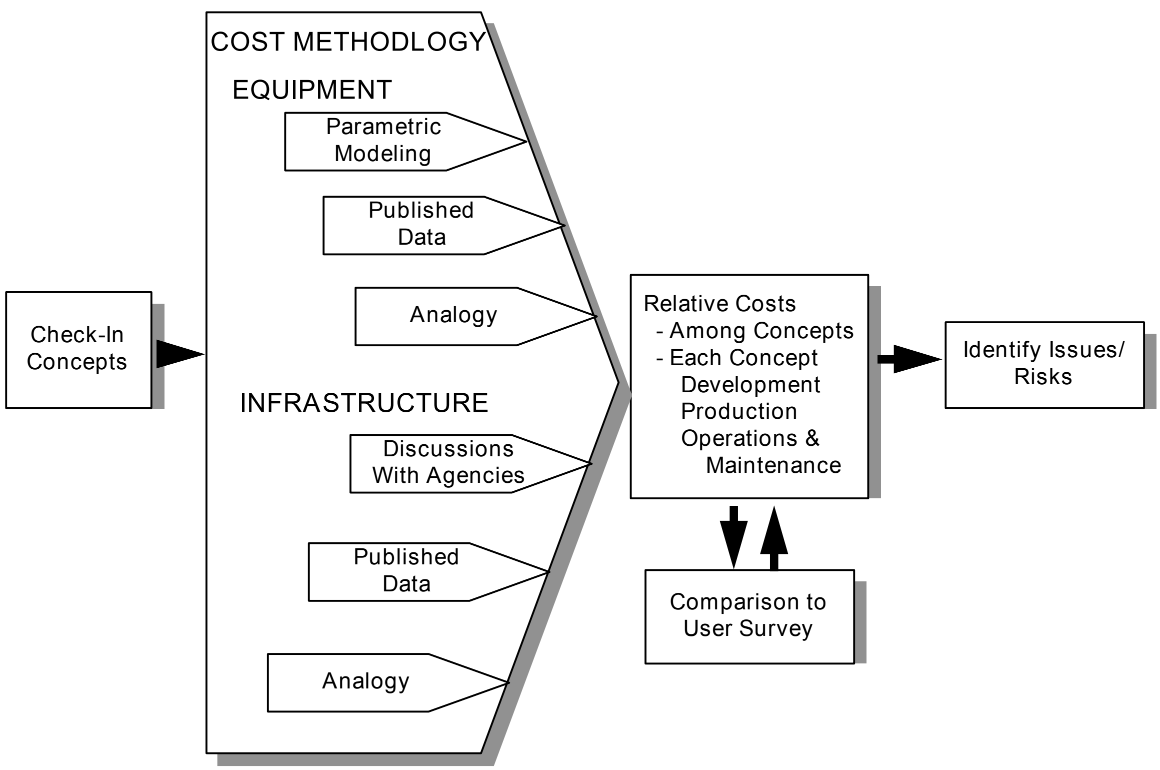


Figure 2-3. Cost Analysis Methodology

For items considered part of the AHS check-in infrastructure, primarily the Command Control Center, estimates by analogy and literature search were the primary methods of estimating. Parametric analysis could not be used because a database is not available. However, as data is obtained in the future, it will be entered in a database for use in subsequent parametric analysis. An important method of estimating costs of infrastructure is discussions with agencies with similar set-ups. Adjustments for system complexity to AHS concepts are also accounted for when applicable.

A combination of the methods described above were used throughout the cost analyses. Literature searches and discussions with manufacturers generally provided prices for equipment, but not development costs. The PRICE H parametric model (described in appendix) was selected to estimate development costs based on its ability to translate product characteristics using weight and costs into a product manufacturing complexity factor. It was also selected due to its use in government and industry. The translation process of product characteristics to a manufacturing complexity factor is referred to as calibration. The model allows a calibrated factor to be input along with associated programmatic information such as number of prototypes, schedules, and product design maturity to estimate development costs based on Cost Estimating Relationships (CER) resident in the model. All calibrated product complexity factors were examined for reasonableness by comparing them to the model's database values for similar products and technologies.

While this model was selected for use mainly to estimate development costs, it was also used to project production costs. The model is also capable of projecting changes to cost using a technology improvement curve with respect to time. Since prices used in these analyses generally characterize current technology, the PRICE model was used to provide a projection of these products' costs in the future assuming technology improvements. Similar to the generation of development estimates, production programmatic information such as quantity of systems, schedule, and calibrated product complexity factor were input to estimate production costs based on CER's resident in the model.

The PRICE model was also used to estimate integration costs of the AHS vehicle subsystems and the check-in site subsystems.

Resultant costs were used to generate ratios distributing their contribution to each sector, i.e., user, business, government, public, by life-cycle phase. For each concept, high cost drivers were identified along with any perceived risks. Estimated user costs were compared to survey results relating to affordability to determine potential success among users. This is discussed in section 3.4.

Since limited official groundrules and guidance were available, estimates were based on assumptions deemed reasonable by Northrop Grumman's cost analyst to bound the scope of the study. Where actual statistics were not available, assumptions were made and noted. Each check-in design option was estimated based on the required hardware and software as described in Sections 3.3.3 and 3.4. Costs were totaled and are shown as a distribution by life cycle phase by sector. Costs were summarized as a relative magnitude rather than as an absolute value since the concepts are still being studied and quantified. The basis of estimate for each hardware, software, or infrastructure item is shown in Sections 3.2.1 and 3.4. Future refinements to these data should be made as better information becomes available and as different scenarios are defined.

General groundrules and assumptions governing the generation of all cost estimates for this study are shown below. Specific assumptions for items reside within their respective sections.

1. Los Angeles county is characterized in these cost estimates.

2. The number of drivers assumed to exercise the AHS initially is 550,000, derived from 10 percent of LA County drivers. According to the California Highway Patrol, there are 5,509,100 licensed drivers in Los Angeles County. The percentage selected was based on the assumption that AHS will initially be similar to luxury electronic options on cars. Ward's 1993 Automotive Yearbook shows percent usage on domestic cars of options such as anti-theft, suspension controls, and head lamp timers to be 7.9, 8.6, and 14.1, respectively. Ten percent was selected as representative of the number of the people willing to choose an AHS Smart Vehicle option package.

3. The actual number of existing metered on-ramps was not available as a basis for the number of AHS check-in sites. Therefore, the number of check-in ramps was assumed to be a function of the number of freeway kilometers in the LA Metro area. The California Automobile Club (AAA) cites 850 freeway kilometers (528 miles) in LA County. Assuming an AHS check-in site would be available every 4.8 kilometers (three miles) to provide convenient access to AHS drivers, 176 check-in sites were used. A single check-in lane per site is also assumed.

4. LA Department Of Transportation has a Command Control Center monitoring intersections for traffic flow control that covers 130 square kilometers (50 square miles). The number of command control centers required was based on an assumption that the control center's coverage is configured to receive signals in an area that is approximately 27 kilometers long by 5 kilometers wide. The 27 kilometer length is related to an equivalent stretch of freeway. For this analysis, the 850 freeway kilometers mentioned above will require thirty one command control centers for each concept to cover the LA County area.

5. Time span of the operations and maintenance (O&M) analysis covers two years. This time span was selected to enable an estimate for user vehicle certifications and infrastructure maintenance without introducing more vehicles onto the AHS since a profile of number of users over time is not currently available.

6. Users would certify their vehicles semi-annually at an approved station to pass AHS checks.

7. As a result of semi-annual certification, 1,435 stations were assumed to be required to handle the quantity of vehicle AHS systems used in this analysis. The number of stations were based on the assumption that they would operate six days/week for eight hours/day. It was also assumed that time to test each vehicle would be one-half hours, or 16 vehicles per day per station.

8. Maintenance costs for the Smart Vehicle were assumed to be 5 percent of the AHS equipment purchase price per year that will cover equipment safety adjustments, recalibration, and repairs. This factor was based on Northrop Grumman cost analyst experience, and further validated by discussions with drivers knowledgeable about vehicle maintenance.

9. Maintenance costs of the roadside equipment and Command Control Center were assumed to be 20 percent per year of the total purchase price. This factor was based on statistics that quantify transit maintenance expenses at 19 percent and facilities maintenance at 10 percent of annual operating expenses. Although operating expenses do not correlate exactly to capital expense (purchase price), the 20 percent factor was used in this analysis as the best data available.

10. Twenty prototypes per equipment item was used in the PRICE H model. This number was based on Northrop Grumman cost analyst experience of development hardware requirements for military electronic systems.

11. AHS vehicle equipment was characterized as a mobile commercial platform, and roadside equipment was characterized as a ground commercial platform in the PRICE H model.

12. Each cost analysis covers a single design concept. No mixing of concepts were analyzed for this study.

13. Costs obtained through quotes from manufacturers or literature searches were adjusted when possible to account for the quantities outlined in this study.

14. Initial deployment was assumed to be the year 2010 based on the AVCS Technology Development Timeline (see References).

15. PRICE H model schedules assumed development start to be January 1996. The production schedules were assumed to start in January 2005 to allow adequate time to manufacture the quantity of AHS systems assumed above to meet the initial deployment date.

16. PRICE H model calibration cost values used equipment prices less 30 percent for general and administrative fees and profit.

17. All cost estimates (including profit) are shown as 1994 dollars. The terms "cost" and "price" are used interchangeably in this analysis even though they are defined differently from a finance perspective. "Price" accounts for mark-ups and profit while "cost" does not. When a term is meant explicitly, it is noted.

SECTION 3

TECHNICAL DISCUSSIONS

3.1 Quality Function Deployment Results

The QFD analysis was performed in four steps. Step one developed a list of information ("What's") that may need to be obtained at check-in. Step two rated the "What's" in terms of importance. A five level rating scale was employed, i.e. critical, desirable, useful, ambivalent, and unimportant. The third step included researching and developing a list of information acquisition approaches. The last step determined the matches between the "What's" and "How's." The matches were rated as strong, moderate, weak, or no relationship. The QFD "House of Quality" developed from this exercise is included in appendix A. The QFD focus team used to perform this analysis included members of the Northrop Grumman Corporation flight test, avionics, human factors, advanced technology, and reliability and maintainability technical staffs, and the systems and cost analytical staffs.

3.1.1 Information Requirements

A list of information that may be of use for the check-in process was developed by the QFD focus team. This list represents the potential information "needs" associated with the development of the check-in system and driven by overall AHS implementation. This effort was intentionally performed independently of any potential implementation approach for an AHS. The QFD focus group then assigned an importance rating to each information item. A five level rating scale was used ranging from critical to unimportant. The basis for assigning these values were:

- Contribution to Ensuring Safe Operation
- Required for Operation on the System
- Required for Efficient AHS System Operation

The results of this effort are summarized in figure 3-1. Key factors for determining these ratings are summarized in appendix A. A quick consensus was generally reached on the items listed as "critical" and "unimportant." In one case, the information items were the obvious key factors for ensuring safe operations on the highway. In the other case,

	CRITICAL	DESIRABLE	USEFUL	AMBIVALENT	UNIMPORTANT
Automated Control Systems (Including Steering and Braking)	• Brake System • Steering System • Actuators • Computer System • Comm. Equipment • Operator Interface • Sensors • System Integration				
Propulsion & Drive Train	• Tire Pressure and Condition		• Engine Performance • Fuel Level • Charge (Elect. Vehicle)	• Oil Press. • Wheel Align./Balance • Cool. Temp and Level • Alt. and Elect. Sys • Suspension	• Transmission Fluid Pressure
Driver Information Systems	• Enunciator Panel			• Gauges • Speedometer	
Emergency Incident Response					• Spare Tire • Flares/Reflect. • Fire Extinguisher • First Aid Kit • Comm.
Trip Plan		• Destination • Selected Route • Preferred Route • Time of Arrival	• Est. Fuel Req.		
Driver Qualifications	• Driver's License and AHS Training • Impaired/Alertness				• Outstanding Tickets or Tolls
Vehicle Characteristics	• Vehicle Type • Entry Weight • Dimensions		• Cargo Type • Weight Distrib.	• Fuel Type	• Occupancy
Vehicle Regulatory	• AHS System Cert.	• Schedule Maint.Cert.	• Annual Safety Check		• Registration • Insurance • Smog Certification • Law Enforcement Rprt. • Permits
Safety Systems	• Hitch and Chain • Warnings and Advisories • BIT System	• Lights • Wipers			• Doors Ajar • Emergency Exits • Windshield Visibility • Airbags • Mirrors • Seatbelts

Figure 3-1. Information Requirements Summary

the items were easily identified as not contributing to any of the key factors. This included items which are easily observed by the driver as unsafe conditions and items that were assessed to have a very low probability of occurring.

For the items in the other three categories, a consensus was much more difficult to obtain. The items listed under "desirable" tended to be those that the team members felt were important to obtain, but not necessarily critical to safe and effective operation on the highway. Many of these items fell into the "efficiency" category, such as destination. Pre-selecting a destination is not required for an AHS to operate but would support efficient operations by optimizing routing of each vehicle.

Items in the "useful" category tended to be ones that members of the group felt could add some value to operation on the AHS, but in general were not overly concerned if they were deleted. Most of the items in the "ambivalent" category fell into two areas: 1) easily observed by the driver or 2) low probability of failure. However, there was some concern on the part of the team relative to these items and to the extent that the driver should be trusted, which kept them out of the unimportant category.

In general, the focus team felt that check-in should include the items on the critical and desirable lists, with some limited flexibility to drop some desirable items. The addition of the useful information should be a goal since these would add capability and potentially some small advantage regarding safety. However there is much more flexibility in trading off these items especially if they are major cost drivers. As in the lower rating category, many of the useful items were traded off due to the feeling that they are easily monitored by the driver and the driver/owner should ensure their proper operation. There was a strong feeling within the group that the driver/owner should maintain some responsibility for the condition of the vehicle as opposed to placing trust entirely in an "omnipotent" check-in system.

As the rating categories imply, no effort should be expended in trying to obtain the information in the ambivalent and unimportant categories. The ambivalent information was considered only if it was a natural fallout of the design approach. There should also be no significant increase in operational and maintenance costs associated with their inclusion in the check-in process. In addition, some of the information in the unimportant category may fall in the undesirable category, such as outstanding tickets and tolls, since it raises serious privacy issues and is of no direct value to AHS goals (i.e., traffic throughput, reduced emissions, safety, etc.).

3.1.2 Alternate Information Acquisition/Evaluation Approaches

Research was conducted to identify potential means for obtaining the desired information for check-in. The approaches identified range from the use of smart cards to sophisticated Built-In-Test (BIT). Matches between the information needs and the acquisition approaches are rated as strong, medium, and weak. The QFD analysis only includes the top four information categories. The "unimportant" information was dropped from further consideration. Results of this effort are summarized in figures 3-2a through 3-2e.

The information database used to identify the potential approaches for obtaining and evaluating the necessary check-in information includes aircraft health monitoring and flight test approaches and supporting systems, and information gained through research into the current state of automotive system design and trends for the future. This background information is discussed in sections 3.1.2.1 and 3.1.2.2, respectively.

Figure 3-3 lists the approaches in the order of their QFD scores. The score was obtained by summing the products of the rating for a particular information item and the ability of the approach to obtain that information (Strong = 9, Moderate = 3, Weak = 1). The highest score was for the use of Built-In-Test (BIT). A high score indicates an approach which can be used for multiple purposes and generally supports obtaining the information falling in the highly rated categories. One approach, inductive loop, was eliminated based on this analysis since there were no strong connections.

Also shown on this chart is the percent of information obtained based only on the "strong" connections between an approach and a particular information item. Two values are shown for each information category. The first value, "alone," is the percent of the information items the approach can be used to obtain by itself. The second value is the cumulative percentage of the information that can be obtained as each approach is added. The bold lines on this chart indicate when 100% of critical, desirable, useful, or ambivalent information can be checked by the candidate technologies above the line. For example, all critical information can be checked by the first ten technologies listed on this chart. Note, since there are multiple approaches to obtaining any given information item the cumulative value only increases when an approach is added that can obtain information that the prior approach cannot.

Information Needed		Acquisition Approach Relationship: Strong	Acquisition Approach Relationship: Moderate
Driver Qualifications	• Driver's License and AHS Training	Smart Card Operator Keys Unique Physical Signature Sensor On or Off-Board Bar Code Scanner	Optical Scanner
	• Impairment/Alertness	Driver Interaction Physical Condition Sensor	Audio Input
Vehicle Characteristics	• Vehicle Type	Read Only Memory (ROM) Smart Card Operator Keys Off Board Bar Code Scanner Optical Scanner	Driver Interaction Audio Input
	• Entry Weight	ROM Smart Card Add-On Instrumentation Off Board Bar Code Scanner Optical Scanner Scale/Skid Plate	Operator Keys Audio Input
	• Dimensions	ROM Smart Card Operator Keys Optical Sensor (Image Processor) Off Board Laser Off Board Radar	Driver Interaction Audio Input
Vehicle Regulatory	• AHS System Cert.	Read Only Memory Smart Card Optical Scanner Off-Board Bar Code Scanner	Operator Keys
Safety Systems	• Warning and Advisory Systems	Built In Test Driver Awareness	Add-On Instrumentation
	• Hitch and SafetyChains	Built In Test Add-On Instrumentation Optical Sensor (Image Processor)	Driver Awareness Off-Board Laser IR Sensors Inductive Loop
	• BIT System	Certification Station	
Steering and Braking	• Braking System	Built In Test Certification Station Add-On Insturmentation IR Sensors Off Board Radar Scale/Skid Plate	Driver Awareness
	• Steering System	Built In Test Certification Station Add-On Instrumentation Magnetic Sensor	Driver Awareness Scale/Skid Plate

Figure 3-2a. Critical Information Acquisition Approach

Information Needed		Acquisition Approach Relationship: Strong	Acquisition Approach Relationship: Moderate
Automated Control Systems	• Actuators	Built In Test Certification Station Add-On Instrumentation	Standard Vehicle Instrumentation
	• Sensors	Built In Test Certification Station	
	• Communication Equipment	Built In Test	Certification Station
	• Operator Interface	Built In Test Certification Station Driver Interaction	
	• Computer Systems	Built In Test Certification Station	
	• System Integration	Built In Test Certification Station	
Propulsion and Drive Train	• Tire Pressure and Condition	Certification Station Add-On Instrumentation Driver Awareness Off Board Laser Optical Sensor (Image Processor)	Radar IR Sensor
Driver Information Systems	• Enunciator Panel	Built In Test Driver Awareness	Add-On Instrumentation Certification Station

Figure 3-2b. Critical Information Acquisition Approach

Information Needed		Acquisition Approach Relationship: Strong	Acquisition Approach Relationship: Moderate
Trip Plan	• Destination	Operator Keys Audio Input Driver Interaction	
	• Selected Route	Operator Keys Audio Input Driver Interaction	
	• Preferred Route	Operator Keys Audio Input Driver Interaction	
	• Time of Arrival	Operator Keys Audio Input	
Vehicle Regulatory	• Scheduled Maintenance Certification	Read Only Memory (ROM) Smart Card Optical Scanner Off-Board Bar Code Scanner	Operator Keys
Safety Systems	• Lights	Built In Test (BIT) Driver Awareness IR Sensors Optical Sensor (Image Processor)	
	• Wipers	Built In Test (BIT) Driver Awareness Optical Sensor (Image Processor)	

Figure 3-2c. Desirable Information Acquisition Approach

Information Needed		Acquisition Approach Relationship	
		Strong	Moderate
Trip Plan	• Estimated Fuel Requirement	Operator Keys	
Vehicle Characteristics	• Cargo Type	Ready Only Memory Smart Card Bar Code Scanner	Operator Keys Driver Interaction
	• Weight Distribution	Add-On Instrumentation Scale/Skid Plate	
Vehicle Regulatory	• Annual Safety Check	Read Only Memory Smart Card Optical Scanner Bar Code Scanner	
Propulsion & Drive Train	• Engine Performance	Certification Station Built In Test Standard Vehicle Instrumentation	Driver Awareness
	• Fuel Level	Standard Vehicle Instrumentation	
	• Charge (Elect. Vehicle)	Built In Test	

Figure 3-2d. Useful Information Acquisition Approach

Information Needed		Acquisition Approach Relationship	
		Strong	Moderate
Vehicle Characteristics	• Fuel Type	Ready Only Memory Smart Card Driver Interaction Off-Board Bar Code Scanner Optical Sensor (Image Processor)	Operator Keys On or Off-Board Audio Input
Propulsion & Drive Train	• Wheel Alignment/Balance	Certification Station Driver Awareness Laser Scale/Skid Plate	
	• Suspension	Certification Station Add-On Instrumentation	Built In Test Driver Awareness Laser
	• Coolant Temperature/ Level	Standard Vehicle Instrumentation IR Sensor	
	• Alternator & Electrical System	Certification Station Built In Test	
	• Oil Pressure	Standard Vehicle Instrumentation	
Driver Information Systems	• Gauges	Built In Test Driver Awareness	Certification Station
	• Speedometer	Built In Test	Certification Station

Figure 3-2e. Ambivalent Information Acquisition Approach

QFD Score	Candidate Technology	% Critical Alone	% Critical Cum	% Desirable Alone	% Desirable Cum	% Useful Alone	% Useful Cum	% Ambivalent Alone	% Ambivalent Cum
1197	Built-in-Test (BIT)	0.58	0.58	0.29	0.29	0.29	0.29	0.38	0.38
950	Certification Station	0.47	0.68	0.00	0.29	0.14	0.29	0.38	0.63
654	Operator Keys	0.16	0.84	0.57	0.86	0.14	0.43	0.00	0.63
621	Add-On Instrumentation	0.32	0.89	0.00	0.86	0.14	0.57	0.13	0.63
618	On-Board Smart Card	0.26	0.95	0.14	1.00	0.29	0.86	0.13	0.75
618	Off-Board Smart Card	0.26	0.95	0.14	1.00	0.29	0.86	0.13	0.75
546	Read Only Memory	0.21	0.95	0.14		0.29	0.86	0.13	0.75
528	Driver Awareness	0.16	0.95	0.29		0.00	0.86	0.25	0.75
504	Off-Board Bar Code Scanner	0.21	0.95	0.14		0.29	0.86	0.13	0.75
480	Driver Interaction	0.11	1.00	0.43		0.00	0.86	0.13	0.75
432	Off-Board Optical Sensor	0.16		0.29		0.00	0.86	0.13	0.75
383	On-Board Audio Input	0.00		0.57		0.00	0.86	0.00	0.75
383	Off-Board Audio Input	0.00		0.57		0.00	0.86	0.00	0.75
378	Optical Scanner	0.16		0.14		0.14	0.86	0.00	0.75
270	Scale/Skid Plate	0.11		0.00		0.14	0.86	0.13	0.75
243	IR Sensors	0.05		0.14		0.00	0.86	0.13	0.88
225	Off-Board Laser	0.11		0.00		0.00	0.86	0.13	0.88
192	Off-Board Radar	0.11		0.00		0.00	0.86	0.00	0.88
171	Standard Vehicle Instrumentation	0.00		0.00		0.29	1.00	0.25	1.00
81	Unique Physical Signature Sensor	0.05		0.00		0.00		0.00	
81	Physical Condition Sensor	0.05		0.00		0.00		0.00	
81	On-Board Bar Code Scanner	0.05		0.00		0.00		0.00	
81	Magnetic Sensor	0.05		0.00		0.00		0.00	
27	Inductive Loop	0.00		0.00		0.00		0.00	

Figure 3-3 QFD Matrix - Strong Connections Only

Using a ground rule which says that at a minimum the check-in system should obtain the information included in the "Critical" and "Desirable" categories, an integrated check-in system can be designed which uses the top five approaches (BIT, Certification Station, Operator Keys, Add-On Instrumentation, and On or Off-Board Smart Card) plus the tenth rated item, Driver Interaction. In this case, the Add-On Instrumentation would be for the purposes of obtaining vehicle entry weight, tire pressure, and, for vehicles towing a trailer, a hitch and safety chain check. A system which combines these information acquisition approaches will be the baseline for the analysis that follows. A system based on these approaches will also permit 86 percent of the information included in the "Useful" category to be obtained and assessed and 75 percent of the "Ambivalent" category, without any additional system capability required. In addition, since the "Standard Vehicle Instrumentation" will be present and the outputs can be easily collected and evaluated on-board as part of the BIT or sent to the infrastructure, these numbers would increase to 100 and 88 percent, respectively.

Driver awareness of the condition of his vehicle should always occur and influence the driver's decision whether to enter the AHS. However, as would be expected, there is a highly divergent opinion on how much the driver can be trusted to gain and maintain the necessary awareness of his vehicle's condition and make the appropriate decisions. For this reason, driver awareness will not be used as the primary means to check any item, but will be considered a dual check in conjunction with the primary method.

Read Only Memory (ROM) and Off-Board Bar Code Scanner are both highly rated approaches, but as can be seen in figure 3-3 they duplicate functions performed by the top four approaches and hence add no primary capability to the system. However, there may be reasons to prefer these approaches for obtaining a given information item. Whether this is the case will be investigated in section 3.2.1, Check-in Information Acquisition/Evaluation Approaches Assessments or by introducing the approach in an alternate check-in system integration approach. Similarly, other information acquisition approaches may be determined to be desirable for a preferred system. This may be due to its ability to provide higher accuracy information, lower cost, or more convenience to the user.

As a point of interest, figure 3-4 shows the QFD results if both the strong and moderate matches between information needs and approaches are included. This did not change the results in terms of the approaches needed to obtain both the "critical" and "desired" information other than the desired capabilities can now be covered by the top three approaches alone. However, using the "'moderate"' capability may not provide the precision and accuracy desired to ensure the vehicle can safely operate. These results are of more interest in terms of defining potential "graceful" degradation approaches, which

Candidate Technology	% Critical Alone	% Critical Cum	% Desirable Alone	% Desirable Cum	% Useful Alone	% Useful Cum	% Ambivalent Alone	% Ambivalent Cum
Built-in-Test (BIT)	0.58	0.58	0.29	0.29	0.29	0.29	0.50	0.50
Certification Station	0.58	0.68	0.00	0.29	0.14	0.29	0.63	0.63
Operator Keys	0.26	0.95	0.71	1.00	0.43	0.71	0.13	0.75
Add-On Instrumentation	0.42	0.95	0.00		0.14	0.86	0.13	0.75
On-Board Smart Card	0.26	0.95	0.14		0.29	0.86	0.13	0.75
Off-Board Smart Card	0.26	0.95	0.14		0.29	0.86	0.13	0.75
Read Only Memory	0.21	0.95	0.14		0.29	0.86	0.13	0.75
Driver Awareness	0.32	0.95	0.29		0.14	0.86	0.38	0.75
Off-Board Bar Code Scanner	0.21	0.95	0.14		0.29	0.86	0.13	0.75
Driver Interaction	0.21	1.00	0.43		0.14	0.86	0.13	0.75
Off-Board Optical Sensor	0.16		0.29		0.00	0.86	0.13	0.75
On-Board Audio Input	0.21		0.57		0.00	0.86	0.13	0.75
Off-Board Audio Input	0.21		0.57		0.00	0.86	0.13	0.75
Optical Scanner	0.21		0.14		0.14	0.86	0.00	0.75
Scale/Skid Plate	0.16		0.00		0.14	0.86	0.13	0.75
IR Sensors	0.11		0.14		0.00	0.86	0.13	0.88
Off-Board Laser	0.16		0.00		0.00	0.86	0.25	0.88
Off-Board Radar	0.16		0.00		0.00	0.86	0.00	0.88
Standard Vehicle Instrumentation	0.05		0.00		0.29	1.00	0.25	1.00
Unique Physical Signature Sensor	0.05		0.00		0.00		0.00	
Physical Condition Sensor	0.05		0.00		0.00		0.00	
On-Board Bar Code Scanner	0.05		0.00		0.00		0.00	
Magnetic Sensor	0.05		0.00		0.00		0.00	
Inductive Loop	0.05		0.00		0.00		0.00	

Figure 3-4. QFD Matrix - Strong and Moderate Connections

would let the entry point continue to admit cars to the highway by using alternate means for obtaining the necessary information until the primary mode is returned to operation.

Section 3.2 looks in detail at each of the information acquisition approaches and the pros and cons of including them in an integrated check-in system. Section 3.3 evaluates a baseline and six alternate integrated check-in system approaches based on the results of the QFD work and approach assessments.

3.1.2.1 Advanced Aircraft Health Monitoring and Flight Test Systems

An element of this assessment was to review advanced aircraft health and flight test monitoring approaches and technologies in light of the Check-in Requirements. Current generation aircraft are a complex integration of sophisticated flight controls, aircraft management systems, offensive and defensive avionics, and weapons management systems, supported by a network of high-speed digital processors and serial bus communications systems. With all its complexity, the aircraft and its subsystems are easily managed by a single person air crew. Onboard diagnostic instrumentation and an intelligent warning/caution advisory panel continuously apprise the air crew of system failures or degradation. Built-in test (BIT) diagnostics in major subsystem elements perform self-test functions upon system initialization and/or periodically during ground and flight operations. Ergonomically designed controls and displays and automated aircraft management tools reduce air crew workload, freeing the air crew to concentrate more on mission-related tasks and less on air vehicle management. A maintenance recorder logs anomalies and generates out-of-tolerance reports for post flight review by ground crew personnel.

There is a direct correlation between verifying the readiness of an aircraft to fly a planned mission and validating whether a vehicle is safe to enter and operate on an automated highway. Preparation of a complex advanced technology aircraft for flight is a "check-in" process which involves disciplined testing of the aircraft subsystems, meticulous review of aircraft inspection and configuration records, and strict application of mandated maintenance procedures. Study of the methodology, procedures, and processes involved in an ongoing development test program for a large military aircraft indicates a strong correlation between aircraft test philosophy and test techniques with those that would be associated with checking a vehicle into an automated highway system. It should be noted, however, that the complexity of advanced aircraft systems and, consequently, tests of those systems, are beyond the scope and scale of ground vehicle system testing. The pre-flight or check-in process for a recent high-technology aircraft takes place in four segments as shown in figures 3-5 and figure 3-6.

Although the majority of flight preparation effort appears to occur within the hours just preceding a flight, the groundwork for preflight acceptance is laid in the in-depth inspections and systems certifications which are accomplished on a continuing basis throughout the active life of the aircraft. Performed on the basis of flight hours accumulated or on calendar time elapsed, periodic off-line inspections and testing establish the basic health credentials for an aircraft. During these inspections, the aircraft is opened up for literally microscopic inspections of critical parts, tear-down of mechanical components, such as flight control actuators, application of non-destructive inspection methods and test equipment to rule out incipient failures in highly stressed composite structures, and chemical analysis of lubricants and liquid coolants. For aircraft subsystems disrupted during the inspection, or affected by software configuration changes, system re-tests are performed to verify performance to the baseline requirements.

The hours immediately preceding a flight are devoted to performing operational checks of communications, navigation, and offensive/defensive avionics. These checks utilize a combination of built-in or self-test test capabilities, supported by specialized ground test equipment for signal stimulation or simulation. Crew arrival initiates a final visual inspection of the aircraft, followed by power-up of the aircraft and the electrical/ avionics subsystems. Pre-taxi cockpit activity completes the activation and setup of flight avionics and communications systems and the loading of flight planning information. Engine-running checks of the generator and hydraulic systems are followed by a twenty minute self-test sequence for the flight control system. The crew continues to check aircraft systems during taxi to the active runway by exercising steering, brakes, engine throttles and flight control surfaces and by monitoring crew station displays.

CATEGORY	VERIFICATION METHOD
Periodic (Time-Compliant Inspections)	
•Flight crew certification	•Physical exams, proficiency tests
•Brakes	•Tear-down maintenance
•Filters	•Clean/replace
•Fluid Contamination	•Chemical analysis
•Critical Structure	•Visual, sonic, dye penetrant
•Flight Controls	•Actuator maintenance
•Mechanical Systems	•Tear-down maintenance
Pre-Flight	
•Flight plan	•Mission tape load, preflight brief
•Structure	•Visual
•Equipment installations	•Visual
•Fluids	•Visual
•Tires	•Visual, pressure check
•Air data systems	•Pressure stimulation test
•Navigation system	•Operational test
•Communication radios	•Operational test
•Avionics	•BIT and operational test
Pre-Taxi	
•Crew walk-around inspection	•Visual
•Power-up checks	•Cockpit indications
•Radio checks	•Functional operation
•Engine checks	•Cockpit display indications
•Flight control checks	•BIT and functional tests
•Inertial Nav alignment	•BIT and cockpit display indications
•Warning/Caution and Advisories	•Flight manual reference for go-no-go decision
•Misc. initiated BIT tests	•Cockpit display indications
Taxi	
•Infrastructure coordination	•Airfield ground control clearances
•Braking tests	•Functional
•Steering checks	•Functional
•Engine throttle checks	•Functional and cockpit indications
•Warning/Caution and Advisories	•Flight manual reference for go-no-go decision

Figure 3-5. Air Vehicle Check-In Process: Baseline Procedures

CATEGORY	VERIFICATION METHOD
Periodic (Time-Compliant Inspections)	
•Engine maintenance runs	•Performance and vibration limit checks
•Software configuration changes	•Operational test of affected subsystem
•Test instrumentation calibration	•Physical stimulation or signal simulation
Pre-Flight	
•Crew/test support team briefing	•Flight plan and test procedure review
•Test instrumentation checks	•Normal indicated values for selected measurands
•Structure	•In-range indications for 1g load condition
•Fluids	•Normal indications for fuel, oxygen, coolant levels
•Air data system	•Normal indication of ambient conditions
•Navigation system	•Normal indication of heading, lat-long
•Avionics	•Fault indication monitoring, limit checking of key parameters
Pre-Taxi	
•Infrastructure checks	•Tracking radar lock-on, test range clearance verification
•Power-up electrical checks	•Limit checks for monitored systems after power-up
•Instrumentation checks	•Telemetry signal quality, mission control display indications
•Communication radios	•Verification of HF, VHF, UHF transmit/receive functions
•Engine checks	•Limit checks on propulsion system RPM, temps, pressures
•Hydraulics	•Limit checks on system pressures and temperatures
•Flight controls	•Monitoring of stop-to-stop controls, inputs, and responses
•Navigation system	•Correlation of inertial, GPS, and surveyed aircraft location
•Warning/Caution and Advisory	•Correlation of indicated failures with monitored data to support go-no-go decision process
•Misc. initiated BIT	•Correlation of BIT system indications with monitored data
Taxi	
•Braking tests	•Limit checking of test sensor pressure and temperature data
•Steering checks	•Correlation of steering response with commanded inputs
•Propulsion system checks	•Correlation of engine response data with throttle commands

Figure 3-6. Air Vehicle Check-In Process: Flight Test Monitoring and Recording

For aircraft in the development stage, these baseline pre-flight check-in activities are enhanced and supplemented by special instrumentation added specifically for flight test data acquisition. Developmental flight testing of a new aircraft creates a requirement for thorough check-out of the aircraft and its subsystems before take-off and throughout the flight. To support this checkout, to provide documentary data for verification of system performance, and to provide for monitoring of critical aircraft functions, test sensors are installed throughout the aircraft subsystems to measure strain, vibration, temperature, vibration, aircraft motion, pressure, acceleration, and flow. Additional data is collected by special interfaces with the aircraft's serial digital communication buses. Digital data formatters integrate, encode, and format the bus and sensor data into serial streams for on-board tape recording and for telemetry transmission to ground based work stations where test engineers and technologists monitor the test in progress. Air vehicle preflight, or check-in, is accomplished with greater confidence with the broader coverage and deeper insight provided by the flight test instrumentation.

In a recent program for an advanced military aircraft, approximately 8,000 active test measurands were continuously captured for telemetering and on-board recording. In early flight test aircraft, with emphasis on envelope expansion and propulsion/airframe testing, approximately 25% of the measurements were acquired with dedicated flight test sensors to obtain pressure, strain, temperature, acceleration, and various analog signals, with the remaining 75% of test measurand requirements being met by the selective capture of information from multiple separate aircraft serial digital data bus systems (up to 17 in one case), or multiplex ("mux") buses. In later flight test aircraft where testing concentrates on avionics and weapons systems development, serial data buses provide up to 90% of the required test data. Of special interest here is that, except for the electrical interfaces, the data collection for test purposes is totally transparent to the operational hardware/software systems supplying the data.

A significant portion of flight test instrumentation technology has direct application to check-in designs for AVCS vehicles. A major premise of flight test instrumentation philosophy is to capitalize on the air vehicle's on-board data resources to supply required test data, and install dedicated test sensors only when data is unavailable from the operational systems. Additionally, it is desirable that the test data system acquire its information from the system under test in a processed, rather than raw signal form. This avoids the potential of introducing noise into or electrically loading the monitored system. Data collection is facilitated in both aircraft and automobiles by the widespread use of serial digital communication buses ("mux buses") by the on-board systems. In present generation military and commercial aircraft, mux buses are designed to industry standards (MIL-STD 1533 and ARINC 429, respectively) which define items such as bus control protocol, data word length, and synchronization strategy.

Additionally, the electrical interface ports designed into aircraft and automobile mux bus systems for vehicle maintenance and diagnostic testing provide non-intrusive access to those systems for data monitoring and recording. However, the automobile manufacturers thus far have not adopted operating standards for their systems, thus presenting a challenge for interfacing individual vehicle makes with IVHS infrastructure nodes in a common format. This challenge has already been addressed in both military and commercial aerospace vehicles, especially pre-production prototype vehicles, which have contained inter-generational avionics sub-systems with serial buses designed to a variety of different protocols. One recent prototype aircraft contained several avionics buses, each conforming to one of five different serial bus communication standards: ARINC 420, IEEE-488, RS-422, RS-232, and MIL STD 1553B. The problem was solved in the test data acquisition system by implementing bus data collectors which reformatted the captured data into a commonly used standard format, thus normalizing the output data product to a form acceptable to the affected contractor and government test facilities. This normalization approach would offer a method for interfacing AVCS autos with non-standardized serial bus systems to the IVHS infrastructure during the evolutionary stages of highway automation.

Additional test information must be acquired from the smart vehicle sensors and processors to support check-in activities. This can be accomplished in a manner similar to the flight test approach, by merging data selectively captured from the AVCS system with that acquired from the vehicle's on-board operating systems within the AVCS computer.

To summarize, figure 3-7 shows the basic air vehicle flight test check-in process. The advanced aircraft check-in approach makes maximum use of existing onboard information, relying on BIT for system validation. Periodic, comprehensive reviews of aircraft systems to validate total system performance are performed. Real time data ing to continually validate vehicle performance is employed. This approach is the equivalent to a check-in system approach which uses periodic vehicle inspections, relies heavily on vehicle self-test capability with critical system status information broadcast to the "control center," and continues to use this self-test capability to provide a real-time assessment of the vehicles and driver's ability to operate safely.

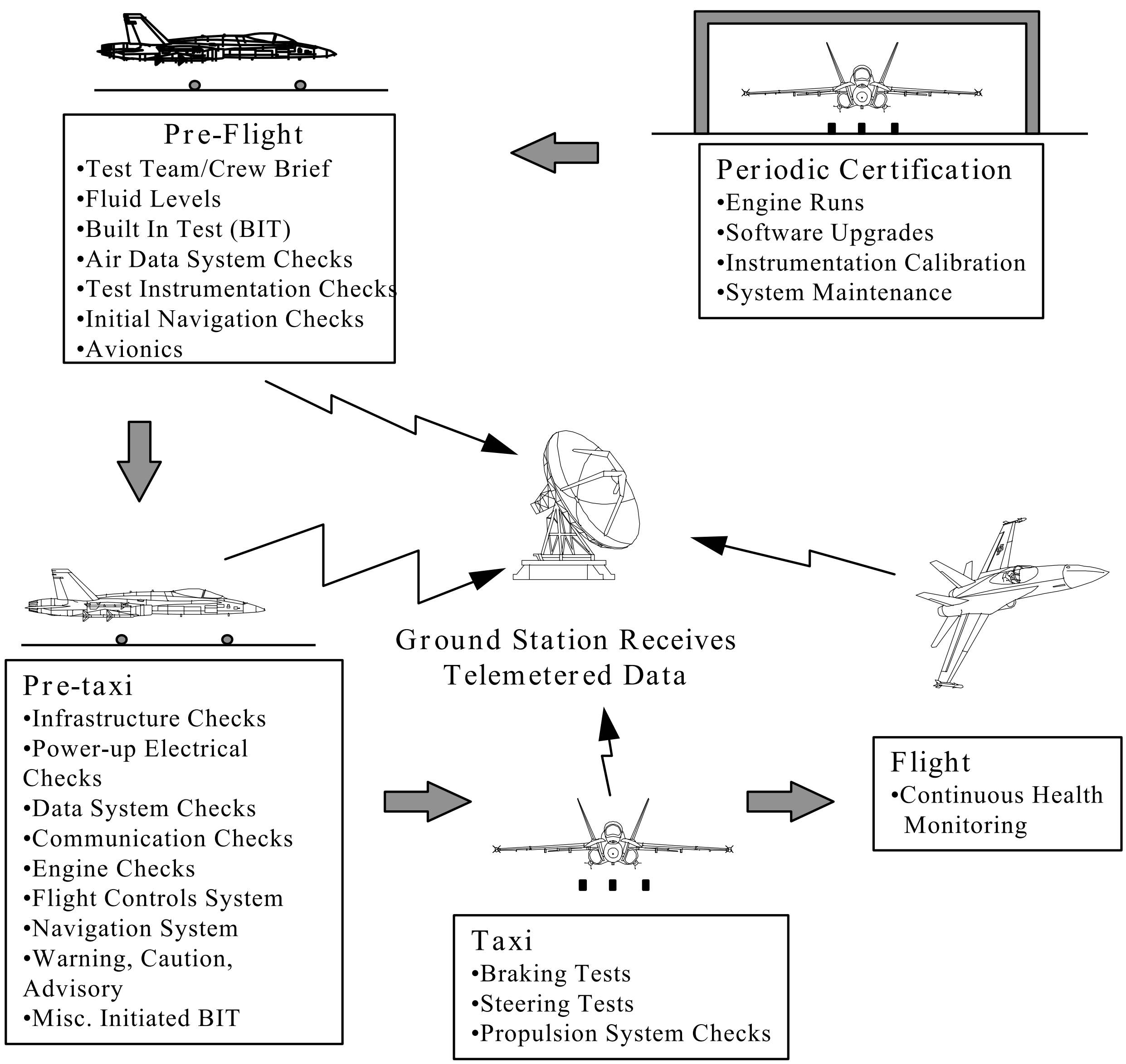


Figure 3-7. Air Vehicle Flight Test Check-In Process

3.1.2.2 Automotive Technology Assessment

Discussions were held with elements of five automobile manufacturers to gain an understanding of current automotive design and future trends. The companies contacted were Chrysler Corp., Ford Motor Corp., General Motors Corp., Honda Corp., and Toyota Corp. The primary elements contacted were R&D centers to gain general knowledge on where automotive system design is headed and dealer service facilities. Through the latter, access was gained to detailed service manuals which give good insight into current automotive system design.

These discussions highlighted the fact that the automotive companies are proceeding down the developmental path the aerospace industry followed, especially in the direction of digital serial line communication systems. The vehicle systems clearly show the trend within the automotive industry to increase on-board system monitoring for purposes of maintenance, safety, and engine monitoring associated with emissions. It also confirms that the number and sophistication of system test and monitoring capability is growing and will continue to grow.

Given this trend, much of the system check capability required for entry onto the AHS will exist on the vehicle, or be a straightforward extension of existing capability. For example, the Lincoln Mark VIII has a system scanner that reports information to the driver on the following: fuel level, travel direction (compass), distance to empty fuel, voltage, air ride (suspension and loading), oil level, oil temperature, oil life (viscosity), coolant level, brake fluid level, open doors or trunk, non-operating headlights, and windshield fluid. This data could be evaluated on-board the vehicle and the results transmitted to the AHS control system or the outputs themselves can be sent as a message for evaluation by the AHS. The former is the obviously preferred approach since the on-board processing required is trivial and it reduces the demand on the AHS control system.

Some of the systems which support the automotive system design trends are due to their public acceptance based on improved safety. This includes systems such as anti-lock brakes and airbags. Both have embedded within them system health monitors which alert the driver to any malfunction. These safety items are picked up by the insurance companies, resulting in premium discounts if they are installed. This is often followed by government regulations that provide a strong incentive for their installation, or they become mandatory to improve vehicle safety. By the year 2013, it is expected that 100% of vehicles will be equipped with anti-lock brakes [2]. This process strongly supports the development of on-board systems for vehicle monitoring. Identifying and supporting the acceptance and requirements for on-board health and safety monitoring systems that are beneficial both to the AHS and independent of it could reduce the "chicken and egg" problem of having AHS capabilities on existing vehicles before there is an AHS to use or vice versa. Near-term systems that fall in this category include blind spot detectors, which are under development by any number of vendors, and intelligent cruise control systems.

The introduction of systems associated with operation on the AHS will require an increase in the sophistication of the BIT capability presently existing or being developed for vehicles. The introduction of a sophisticated automatic control system will require multiple system components to operate in concert. This will require the BIT check to ensure not only that the individual components are operating properly but also that they are communicating and responding appropriately to each other so that the system as a whole will operate in the manner intended.

An issue that may need to be addressed is the potential variation in the level of system monitoring included as standard on the different vehicles in a manufacturer's product line. Will the systems available on the low end cars mature to the point of providing the minimum checks required to ensure the vehicle is safe for operation on the highway, or will back-up methods within the infrastructure be required? The potential greater cost of upgrading a low-end car to AHS standards, which may be in direct contradiction to the financial situation of the probable owner, would force more capability into the infrastructure.   If the selected approach to the development of the AHS is to put much of the health check and monitoring on the vehicle, national standards would need to be set for the level of this capability required for an AHS compliant vehicle.

Another force which will result in much of the monitoring capability being on the automobile is the need for continuous monitoring of the vehicle's health and safety once on the highway. It is unlikely that continuous monitoring of safety critical systems would not be an AHS requirement for both safety and to prevent slowdowns due to breakdowns.

Advanced aircraft sophistication notwithstanding, current generation automobile technology matches current military aircraft technology virtually feature for feature, varying only in scale, maintainability, reliability, and obviously cost. Multiple dedicated digital processors communicating on serial digital buses, built-in test, fault sensing, indication and recording, automated controls, and augmented steering are either baseline elements or optional features in today's automobiles. As a result, there is significant fall-out from aircraft technology and flight test instrumentation design practices which can benefit the planning and design of vehicles for automated highways:

1. Industry standards are vital to the integration of on-board vehicle systems with external supporting systems. These include:
    a. Serial bus communication protocol and software governing data word lengths, frame structure, engineering units algorithms, and synchronization strategy.
    b. RF communication standards.
    c. Standards for pressure, position, temperature sensors.
    d. Standards for vehicle design, which affect system safety and vehicle certification.

2. Utilization of existing vehicle diagnostics and status reporting features can provide rich resources for external monitoring and control of onboard systems, with minimum impact on vehicle design.

3. Test-unique sensors are employed when the required data cannot be obtained from the vehicle subsystems.

4. Programmability of on-board systems to support evolution and modification of vehicle and external support systems.

5. Modularity of system components enhances troubleshooting and maintenance.

3.1.2.3 Aircraft Data Acquisition Technology and The AVCS Smart Car

The flight test instrumentation data acquisition systems used in present day aerospace vehicle test programs, from the standpoint of function and technology, are credible models for the equipment to be added to the AVCS vehicle to support check-in. Unmanned aerospace vehicle instrumentation systems are perhaps even more representative of what may be in the smart car because the test instrumentation is integrated with the air vehicle's command and control system in an operational sense. Data required for real-time monitoring of vehicle health and status are acquired by the test instrumentation system and formatted for interface with the vehicle command and control transponder system, which time shares vehicle status and health reporting functions with vehicle guidance and control functions on the vehicle-to-infrastructure communication link. Figure 3-8 depicts an instrumentation system configuration common to both manned and unmanned test vehicles at Northrop Grumman.

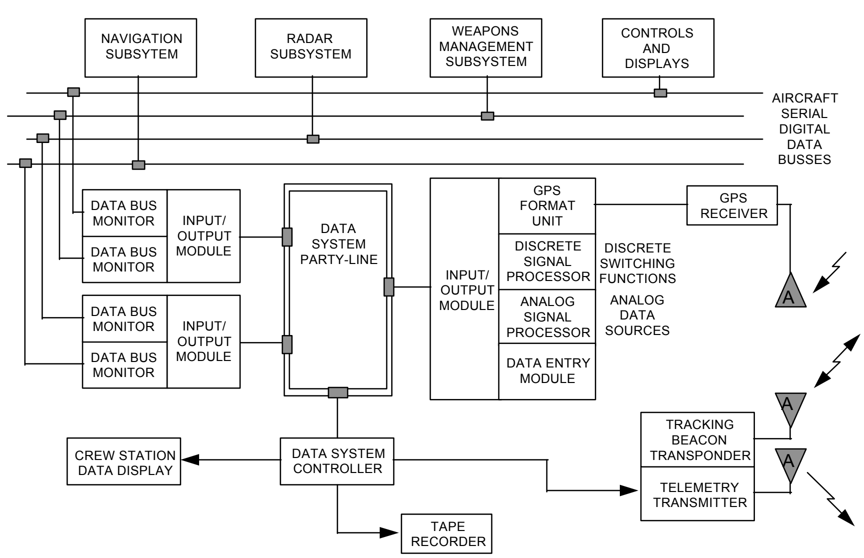


Figure 3-8. Generic Flight Test Instrumentation System

The depicted data acquisition system utilizes a party-line or serial digital communication bus which connects various data acquisition units to a system controller. The party-line concept makes it possible to deploy data collectors throughout a large test vehicle to reduce wiring and minimize electrical noise. In smaller vehicles the data modules are integrated into a single, centralized unit. The data acquisition units place data on the party-line in response to system controller commands. The system controller integrates all of the data responses and formats them into a single, serial, pulse code modulated (PCM) data stream which is recorded on board the air vehicle and/or telemetered to a ground monitoring facility. As indicated in the diagram, the raw data may be generated in various forms; the data modules perform the normalizing function which translates and organizes the various signals into a common format.

A data acquisition approach for the AVCS automobile is shown in figure 3-9, which is analogous to the configuration used by some unmanned aerospace vehicles in which the transponder RF link is time-shared by command/control and diagnostic functions. The system is conceived as a centralized set of modules configurable to match the personality of the particular vehicle type and manufacture. Programmable gain analog modules would accept signals in raw voltage form from sensors and perform analog to digital conversion and scale factor normalization. Binary or "go/no-go" discrete indication functions are assimilated into standard format "mother words" for easier handling. The individual serial data buses are expected to provide the preponderance of data for monitoring and control.

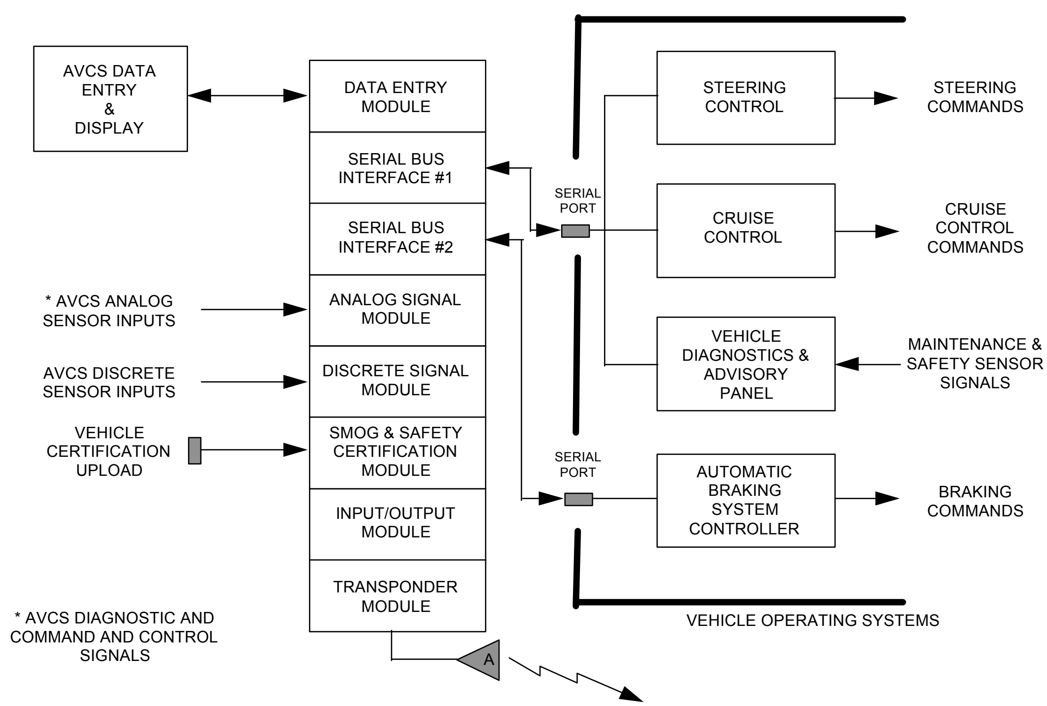


Figure 3-9. Data Acquisition Approach For AVCS Vehicle

Given the likelihood that serial bus communication systems in early generation AVCS vehicles will have been designed to different operating protocols, the serial bus interface units, much like their counterparts in the flight test environment, will be required to reformat serial bus data in various forms from different vehicle types into a common format compatible with the roadway infrastructure.

The data acquisition system provides a natural point of interface for the AVCS data entry, data display, and route planning utility. Again, the aircraft example data system incorporates features for operator interface, information logging, and crew station data display which has direct application to the AVCS requirement.

In summary, the study has shown that there is a high degree of commonality in the functional requirements and hardware/software design requirements for AVCS vehicle check-in and flight test data acquisition systems for aerospace vehicles. The integration of test systems and operational systems is facilitated by the presence of industry standards, especially in regard to serial bus communication protocol. However, in the absence of standardized systems, or during the evolution leading to standardization, intelligent data acquisition interfaces will be required to normalize data flowing between the AVCS vehicle and the IVHS infrastructure.

3.1.2.4 Data Issues For Aircraft Flight Test and Automotive Systems

Data and Data Acquisition Characteristics. Ground vehicle data characteristics could emulate the data characteristics found on current aircraft flight test vehicles if military standards, protocol, and instrumentation standards are adhered to.

Following MIL-STD 1553B protocol for data word ("measurand") and message transmission, data transmission rates, both periodic and aperiodic, will have to be specified. Periodic data rates will also have to be specified for test unique ("hard-wired") instrumentation. Data ranges must be specified for non-encoded data words as well as bit assignments for encoded words. Accuracy requirements (i.e., based on percent of full scale or number of significant bits) must be addressed and specified for all non-encoded data. Units for non-encoded words as well as calibration information must be specified.

Data sampling rates must be specified for all data words extracted. Bandwidth (number of words per second) requirements for extracted measurands must be addressed due to probable limitations in software and hardware design in the acquisition system.

Data Quality. The quality of flight test data is of major concern for aircraft flight test programs. Poor quality data will result in inaccurate and erroneous results when the data is reduced post flight. Real time monitoring of erroneous flight test data may lead to test aborts or calls for a Return to Base (RTB) if system warnings or system degradations are perceived or lead to the perception that systems are functioning properly when the opposite case exists. Poor data quality inevitably leads to re-tests of test points or test blocks resulting in slipped flight test schedules and flight test cost increases.

Data anomalies are exhibited in many forms, from simple telemetry data drop outs, misapplied bit masking, calibration errors, etc., to instrumentation failures, data acquisition errors, and mux-bus failures. From recent Northrop Grumman flight test experience, data anomalies are widely varied, difficult to detect, and difficult to diagnose. Detection and prevention of data anomalies also take on many forms. Pre-flight checks of ground tare data may be examined real-time for inconsistencies. Out of tolerance reports may be generated for flight test instrumentation by a ground support unit. Instrumentation may be examined using continuity checks during aircraft lay-up. Data system software checks may be employed for detection of calibration inconsistencies, mux-bus protocol errors, periodic data sampling rate anomalies, etc.

Data anomaly detection and prevention will be major factors during vehicle check-in to the AHS. Erroneous data may lead to vehicles being rejected, or worse, vehicles accessing the AHS when something was wrong but not detected. Similar to air vehicle flight test articles, ground vehicles could experience the same forms of data anomalies. Data tolerances will have to be defined as well as means for data anomaly detection.

3.2 Assessments/Analysis

Section 3.2.1 assesses the alternative approaches for obtaining and evaluating the information necessary to complete the check-in process. Also included in this section are the results of the queuing analysis and the user survey (see sections 3.2.2 and 3.2.3).

3.2.1 Check-in Information Acquisition/Evaluation Approaches Assessments.

Each of the potential approaches for obtaining information was assessed on its individual merits in terms of availability, advantages, disadvantages, and issues relative to its use. This assessment included consideration of human factors and cost issues. These assessments are summarized in the following sections.

3.2.1.1 Built in Test (BIT)

Built-In-Test, a standard feature in advanced technology aircraft, is a "smart vehicle" approach which would perform self test functions. "Built-in" implies test capabilities designed into systems or system elements that exercise, to the maximum extent possible, every signal path and working element of the system to verify system integrity. The BIT capability incorporated in current state-of-the-art aircraft flight control systems, for instance, provides a high degree of confidence that this critical vehicle subsystem is operating properly, in both a pre-flight ground test mode as well as an operational in-flight mode.

A primary objective of AVCS vehicle BIT should be to compare vehicle responses (braking, cruise control, steering) to known signal values introduced in a programmed sequence at the servo loop summing junction of each primary control channel. Although this test method effectively verifies performance of the control actuators, position sensors, vehicle motion sensors, and servo control loops, it is less than a full "end-to-end" test in that it fails to exercise the infrastructure interfaces through which operational control signals pass. Its advantages, however, are that the test can be accomplished autonomously in a relatively short period. A modified BIT approach which would use infrastructure steering cues such as the undulation magnetic strip depicted in figure 1-4 in lieu of a stored digital simulation to exercise the steering channel.

To the extent that communications to or from the infrastructure are required to support verification testing at vehicle check-in, a proportionately heavier workload is imposed on the control center, with attendant complications in time sharing control center functions with all other vehicles in the system. The ultimate test methodology will most likely consign test intelligence and responsibility to either the vehicle or to the infrastructure based on the criticality of the function to be verified and the safety, reliability, and maturity that can be achieved in AVCS hardware and software.

At the check-in point the BIT sequence can be initiated by driver action with a button push or switch throw, or by a signal from the control center (Initiated BIT). A stored program in a vehicle processor(s) issues instructions, performs emulation of functions such as control system inputs, verifies that system responses are in accordance with predicted values, and produces either a discrete "system OK" or "system not OK" output to the infrastructure. A failure type or system degradation report could be generated to permit a potential "degraded mode accepted" response from the central control system if safe operation is still deemed possible. An indication can also be given to the driver as to the nature of the problem which results in check-in rejection and to permit a decision not to enter the AHS in the degraded mode even if the system is willing to allow access.

A comprehensive BIT sequence for a complex system can consume significant time (20 minutes of test time for a complex quad--redundant flight control system). However, the BIT systems designed for vehicles to operate on an AHS can be less complex in terms of the number of elements to be tested. This lower complexity should result in times acceptable for check-in to the highway. In addition, a less comprehensive, non-intrusive, test sequence can and will most likely occur in the background at all times the vehicle is active to provide an indication of system health (Periodic BIT). Since this data will already be available when the check-station is reached, the Initiated BIT sequence can be reduced.

Public safety and liability concerns will require standards for performance, accuracy, and reliability equivalent to those applied to aerospace equipment. It should also be noted that experience has shown that BIT capability is not a feature to be added to an existing system. To be effective and efficient it should be included in the system's baseline design. This impacts the assumption that retrofit of AHS capability is required. In the early years and until the number of vehicles wanting to operate on the AHS without BIT capability becomes small, alternate capability to check the systems normally checked by BIT will be required. Fortunately, the trend in the automotive industry is to increase the use of BIT on vehicles, minimizing an alternate capability requirement.

Technology Maturity. The technology for developing sophisticated BIT systems already exists in the aerospace industry and is starting to be exploited by the auto industry. In fact, the basis for extensive on-vehicle checks already exists on modern vehicles in the form of health monitoring systems and system failure indicators. The trend within the auto industry is to increase the use of BIT especially with the pending introduction of sophisticated capabilities such as intelligent cruise control systems and their supporting sensors.

Strengths. Verification of the automobile control system's health and integrity is an essential element of vehicle check-in. A legitimate check-in health test would perform a dynamic end-to-end validation of the vehicle control systems and assess the status of safety-related vehicle functions. A full-up system test would involve a sequence of commands issued from the control center via the communication link to exercise the vehicle longitudinal and lateral controls and compare vehicle response to the commanded inputs. This dynamic end-to-end test concept would provide virtually 100% validation of the vehicle control systems in conjunction with the external infrastructure, but would also place a heavier workload on the control center processor. BIT provides the means to perform these tests on the vehicle which significantly reduces control center workload and complexities associated with the integrated check-in system within the infrastructure; BIT also supports on-the-fly check-in and continuous health monitoring.

Weaknesses. The use of BIT on the vehicle will require additional design effort in order to integrate this capability and require additional processing capability on the vehicle. This will cause resistance due to cost from both the manufacturing community and the user community. In the case of the manufacturer this can also add to the time-to-market for a new vehicle due to the additional complexity of the design. This will also require the manufacturers to increase the sophistication of their low end vehicles, again increasing development cost, time-to-market, and the cost to the consumer.

Cost. Basic BIT resident in the vehicle will be performed through the use of firmware contained in a RF transponder. Full up BIT sequences will also be performed using the RF transponder in conjunction with a roadside receiver. RF transponders and roadside receivers were estimated by quotes provided by Mark IV Industries Ltd, IVHS Division of Ontario, Canada. MARK IV currently manufactures vehicle-to-roadside RF communications equipment for automatic vehicle identification called Roadcheck. Roadcheck's system consists of a roadside reader that establishes high speed, 2-way communications between vehicle mounted transponders and a central computer system. This system has been selected by the Orlando/Orange County Expressway Authority for computerized toll collection and traffic management, by the Pittsburgh International Airport for revenue control, and by the Arizona Department of Transportation for truck weight and safety compliance monitoring. Discussions with the marketing manager of MARK IV confirmed that their current models of transponders and roadside readers could be customized to accommodate Northrop Grumman's concepts with nominal electronic modifications.

Price quotes from the marketing representative of $50 for the transponder and $10,000 for the roadside processor were used to calibrate the PRICE H model (see appendix E for description of the model) to generate product complexity factors. These resultant factors were compared to the model's industry technology factors and placed the transponder in an analog RF technology category using medium scale integrated circuits, and placed the roadside reader in an analog RF technology category using discrete electronic components. The calibrated factor for the transponder fell into a reasonable technology while the roadside reader calibrated factor was slightly below the expected technology. These factors were deemed plausible and used to estimate development and production costs using the groundrules and assumptions listed in section 2.2.4. Results are shown in appendix E.

Costs for firmware were assumed to be included in the RF transponder cost since extensive on-vehicle checks already exists on modern vehicles. Full-up BIT sequence software requirements resident in the infrastructure check-in site were estimated to be 250,000 lines of code (LOC) that will test the AHS vehicle condition. Costs to develop this software was estimated using the REVIC model (see appendix E for description of the model). The BIT software was broken into modules of no more than 100,000 LOC each to simulate a more realistic programming process. The software was characterized as a real-time application with advanced math to handle the vehicle's control laws, with some new algorithms, moderate interfaces, and some timing constraints. The staff developing this software was assumed to have normal experience in developing similar software and will utilize modern programming practices with tools in a fully integrated environment. BIT software reliability was characterized as very critical since high financial loss would occur upon failure. REVIC produced results of 2,611 man-months. REVIC's default labor rate of $73/hour and 152 hours/man-month was used to calculate development costs of $28.9M. Maintenance of this software for two years was calculated using the model's default change traffic factor of 15 percent per year. Maintenance costs totaled $9.4M for two years.

3.2.1.2 Data Entry Transfer

3.2.1.2.1 Driver Interaction

Driver interaction refers to a check-in approach in which the AHS central computer system prompts the driver for information by presenting menus to select. Graphic displays could also be used for the selection of destinations and routes. This interaction could occur by use of an on-board system which can communicate with the AHS control system or could be mounted off-board in the check-in station. In every case there would be a display, and responses would be through buttons located along the sides of the display or by use of touch screens. Note that audio input provides another option for driver responses. However, audio input represents a more advanced technological capability and as such was treated independently (See section 3.2.1.2.3).

The system will provide feedback to the operator in the form of repeating the inputs on the screen or by audio responses to each key stroke, and by presenting the results of an action such as a destination and asking for a confirmation. In addition, an option can exist to bypass many instructions to reduce the time required to enter the data for experienced drivers.

As is discussed in the operator keys section (section 3.2.1.2.2), an option that permits data entry before starting out on a trip is desirable to minimize the times the driver is distracted from driving. The problem in this case is the need for the menus to be generated. One way to do this is through an on-board modem and cellular phone technology to dial into an AHS service. This service would provide the prompts necessary for the driver to run through the menu selections while still parked. The responses would be stored on the vehicle and transmitted to the AHS control system at check-in. Alternatively, the connection could be directly to the AHS control center and the information stored as a "flight plan." This "flight plan" is opened when the AHS control center identifies the vehicle at a check-in point.

A second alternative would be to have the necessary software and database on-board the vehicle to provide the prompts necessary to generate the desired inputs and store them. Depending on the size of the software and database necessary, this may or may not be a better option. The potential for this option is higher for vehicles with existing navigation systems since the largest part of the required data, geographic, is already on-board. A problem with an on-board system would be if the AHS system periodically updated its menus and databases. The on-board system would be unusable or need to be updated.

Technology Maturity. Interactive systems of this nature are in wide spread use ranging from automatic teller machines to the electronic displays on modern military and commercial aircraft.

Strengths Like the operator keys discussed in the next section, a key strength is that most users are familiar with this type of human/machine interface from the use of Automatic Tellers to personal computers. A strength of this approach over the operator keys is the limited number of key strokes required. This can make entry faster and less error prone.

Weaknesses. On the down side, the use of menus can increase the time required to enter the data if several menus or graphical displays are required to enter the desired information. For instance, destination may be as simple as one graphical display if only traveling in the local area. However, if the destination is farther away a series of selections may be required to bring up the desired graphical display or list of destinations. In addition, this approach requires thought, time, and effort on the part of the driver to understand each menu and make the desired selection. This will slow the entry process down at a station, or result in a greater distraction for the driver while driving if done while in motion. This will pose some level of safety risk.

Cost. A portion of driver interaction is trip planning. Trip planning/navigation systems are now on-board Oldsmobile Eighty Eight LSS automobiles for rent by Avis in California, Detroit and Chicago. The system is equipped with a navigation system that plans routes, displays maps, and gives drivers audible instructions. The Oldsmobile Navigation/Information System is a modified version of NAVMATE from Zexel USA Corporation. It includes an on-board computer, roadway database, and Global Positioning System (GPS) receiver. The official number of Oldsmobiles equipped with the navigation system was not available so an initial quantity of 400 was assumed to cover the locations mentioned. This translated to approximately 55 cars over 7 metropolitan areas; Sacramento, San Francisco, San Jose, Los Angeles, and San Diego were selected as the California cities. Literature cited the price to be $2,000 each. This price was used to calibrate the PRICE H model to generate product complexity factors. The resultant factor was compared to the model's industry technology factors and placed the data entry pad in a transmitter technology category using very large scale integrated circuits. This was deemed reasonable due to the GPS interface and roadside processing requirements. This factor was used in the model estimate development and production costs using the groundrules and assumptions shown in section 2.2.4. Results are presented in appendix E. Other electronic travel aids such as TravTek are also available but cost information could not be located in time to use in this analysis. There is a high potential that this unit can be modified to retrieve and relay other AHS status conditions through driver interaction.

3.2.1.2.2 Operator Keys (Keyboard)

The use of a key board either within the vehicle or in the check-in station provides a means to "inform" the AHS system of information such as trip plan, vehicle characteristics, and certification numbers. Additionally, it can be utilized to assess the impairment/alertness of a driver. For example, the driver would repeat sequences in a specified time period using the keyboard.

Although the use of a keyboard is a form of driver interaction, it is differentiated from the prior "driver interaction" section in that instead of menus of alternate selections being generated by the AHS control system from which the driver selects, the driver inputs data directly, i.e., 'Ford Mustang', or an off ramp number. Destinations could also be input much as zip codes are for mail. The driver would select destination codes from a trip book (possibly available at a local Automobile Association), and enter the number into the system at time of entry. If an on-board approach is taken, the driver would be able to enter data after start-up and have it stored for transmittal to the AHS control system at entry. Data could be maintained in on-board memory as long as the battery maintains a charge.

Technology Maturity. The technology is very mature and in use on both ground and air vehicles.

Strengths. Key strengths are that most users are familiar with this type of human/machine interface from the use of Automatic Tellers to personal computers. This type of approach is also very flexible. It can be adapted as the means to enter a wide range of information.

Weaknesses. The key weakness is the need for the driver to pull his attention away from driving the vehicle while entering data. Though the system could be designed to permit all data entry before driving away from a location or while under full control of an AHS, it has to be assumed that people will use it while in motion. This raises a safety concern like that associated with drivers dialing a cellular phone. The keyboard could be made inoperable while the vehicle is in motion unless under full control by the highway. However, this is undesirable since it would result in the need for a full stop at check-in if the driver has not previously entered the required information or needs to change it. It also does not permit a change in destination while on the automated highway for any AHS system which does not have complete control of the vehicle.

Another potential problem area is that errors in typing may cause delays or incorrect information to be entered. Use of a standard keyboard/numeric keypad configuration will alleviate much of the need for training or familiarization and help to limit errors. Other design considerations to minimize errors will be key size, spacing and readability. Placement will also be critical to permit easy use. Placing the keypad as close as possible to the driver's normal line-of-sight would be desirable.

To provide an easy means to identify when an error occurs, feedback to operator responses is necessary. Though this could take the form of displaying the entered data and the results of an entry such as a destination on a screen, audio feedback is the desired method for an on-vehicle system. This permits the driver to know the results of an entry without having to look at a screen. Such audio response systems have been in use on aircraft and automobiles for some time and pose no technological challenge.

Cost. Costs for this technology are addressed as part of Driver Interaction, section 3.2.1.2.1

3.2.1.2.3 Off/On-Board Audio Input

The audio input system refers to a check-in approach in which the AHS central computer system and driver interact by voice/audio communication. This check-in approach could be used either on an on- or off-board configuration. The central computer would be linked with the driver through an auditory feedback loop. Route and destination information, driver and vehicle identification, and vehicle characteristics may all be transmitted through the audio link.

Technology Maturity. Audio input systems are in current use in the voice activated personal computer and voice activated telephone card systems. However, most current systems utilize discrete dictation, meaning that the user is required to pause briefly between each word. Continuous dictation allows a person to use natural language input, which does not require pauses between words, and would be more effective in audio input AHS applications because of its familiarity and accommodation for variances in audio delivery. One of the biggest problems in audio input and speech recognition is people; they are the weak link in speech recognition interactions. A few vendors currently offer continuous dictation for the desktop, including IBM, but the technology is not perfect. Full speech recognition requires real-time processing and the corresponding hardware for this is still relatively new. Fortunately, this technology development is expected to accelerate during the next few years and should be quite mature by the year 2000.

Strengths. The hardware requirements are not demanding with many off-the-shelf components (i.e. microphones, low bandwidth communication links, etc.). Audio input obviates the need for key pad entries and reduces driver interaction time at check-in. Driver distraction is reduced as well as the intrusiveness of the AHS check-in procedure.

Weaknesses. Environmental and vehicle noise could jeopardize the audio input approach. Limitations of vocabulary and word recognition must be overcome. Drivers with voice or auditory handicaps might be excluded from this system as well as languages or dialects different from English. Speaker training may be required so that the system can recognize sentence structures.

Cost. Discussions with Northrop Grumman personnel familiar with audio input technology were the basis for the cost estimates in this analysis. An existing Texas Instruments board which inserts into a personal computer and purchased for approximately $4,000 was calibrated using the PRICE H model to generate a product complexity factor. The resultant factor was compared to the model's industry technology factors and placed the board in a military airborne analog/digital technology category using large scale integrated circuits. This complexity factor was higher than expected but was deemed plausible due to the required level of electronic sophistication and was used to generate development and production costs based on the groundrules and assumptions listed in section 2.2.4. Results are presented in appendix E. Other audio input applications are also in use but their costs have not been researched in this analysis. For example, some cellular phones have voice activation and command options and costs for these options are most likely lower than the one shown in this analysis.

3.2.1.3 Certification Station

The certification inspection will include a complete safety inspection of the vehicle including items like tires, alignment, suspension, drive train/u-joints, onboard computer functions, wipers, lights, shocks, brakes, steering hardware, and engine functions. The station would also include the test equipment required to dynamically check the braking and steering systems and the control hardware and software associated with AHS longitudinal and lateral control systems, and AHS-related sensors.

If the vehicle passes inspection, the certification validation could be stored within the vehicle or by use of a smart card and passed to the AHS control system at entry. Information storage on the vehicle can take the form of an Electrically Programmable Read Only Memory (E-PROM) device that can be programmed by the certification station after inspection or a PROM can be "burned" and inserted in the vehicle's processor. The use of the E-PROM permits re-use, however, the PROM has the security benefit of not being re-programmable (See section 3.2.1.4.2).

Alternatively, the certification information could be added to a national database accessible by the AHS central computer system for verification at check-in. The database would be entered via modem. A tag giving an inspection number would be attached to the vehicle, such as a bar code sticker on the windshield to be read by a laser based scanner at the check-in point. This inspection number would be used as an address within the central database to find the inspection results and verify that the certificate is still valid.

The station operation should be a paperless operation with the exception of a receipt for the person having their vehicle checked. The computer program for the certification station should be a paperless system with error detection, operator prompting, and storage of results in a register that can be transferred to the AHS main database in an off-hour mode so as not to burden "real time data requests."

Such a system will eliminate recurring supply costs and especially reduce cost by eliminating hard copy manuals which will need to be replaced regularly as new vehicle types go on the market. On-line reference systems can be updated from a central point making the issuance of new "manuals" almost a trivial task. The ease with which manuals can be updated will also support more frequent updates, keeping all stations up to date with all new vehicles on the road. Both advanced military and commercial aircraft programs have demonstrated the viability of paperless systems. Many airlines are shifting to paperless maintenance facilities from which they will receive the benefits noted relative to system manuals and parts catalogues.

Some of the items that will be required in an AHS certification station are:

- A dynamic dynamometer (the state of Florida has talked to dynamometer manufacturers about these systems for inclusion in their safety check program)
- An engine test unit
- A PROM burn tool or an interface permitting E-PROM programming
- Computer with modem to AHS Central Computer
- Vehicle interface capability
- RF test set
- Special IR and radar test sets
- Software supplied by the AHS system management

The certification station also provides the means to verify the BIT system is functioning properly. The probable heavy dependence on BIT to monitor the health and safety of the vehicle will make this a critical safety check. In addition, many of the sensors that can be used as part of a "smart vehicle" will require special test hardware for certification testing, which will lean toward the need for a certification station. Another operation which can be performed at check-in station is re-calibration of sensors, such as pressure transducers, if necessary.

The certification will be valid for a limited time and number of miles. The PROM, if used, would be mileage and time degradable. The odometer reading would need to be determined at check-in to the roadway and compared to the value loaded in the PROM or on a smart card. An electronic odometer, available on many of the digital dashboard displays available today, would be able to provide this information and also would be able to inform the driver when vehicle certification inspection is due.

Technology Maturity The certification system could be developed in each state based on existing periodic inspection programs that address emissions and safety. However, Present Federal Regulations (A9 - CFR 393 and 396) for vehicle qualification, as modified by each state, do not cover the safety requirements for certifying a vehicle in a manner that would be required for an AHS. This would require most states to develop or expand their safety check system since only five states presently concentrate on vehicle safety checks, with the majority concentrating on emissions checks. The issue of national standards for testing for AHS certification will also have to be addressed.

As part of this study activity, fourteen states were contacted to discuss vehicle check programs in their states including safety and emissions. The states contacted were: Arizona, California, Florida, Georgia, Maryland, Michigan, New Jersey, Ohio, Pennsylvania, Texas, Utah, Virginia, Washington, and West Virginia. Each of these states is pursuing tighter vehicle safety control which would provide a good existing foundation for an AHS certification system. In fact, several of these states, including Maryland and Virginia, already require a safety inspection.

Current testing methods used by the five states that require safety checks do not address dynamic testing. Florida is the first state to start looking into dynamic testing which would bring them even closer to the AHS desired system. They are looking into a braking system that checks the brakes at low speed (4.8 to 6.4 kilometers per hour) by a roller type dynamometer method. To properly validate the advanced AHS vehicle systems and to validate the BIT program, a dynamic test will be required for both the longitudinal and lateral control systems. Also, additional test systems will be required for the tracking and blind spot detectors.

A standard for all test functions and the test hardware needs to be generated. Without such standards there will be a proliferation of test approaches and associated hardware creating a great administrative burden upon the "AHS system" and will impact the total cost of the system. In order to ensure standards are established and maintained, consideration may need to be given to an "AHS Administration" not unlike the Federal Aviation Administration (FAA).

Inspection and testing equipment technology is rapidly advancing, especially for brakes. Innovative brake testing devices, such as a roller dynamometer that is currently being tested in Nevada, Ohio, and West Virginia, can reduce the time of inspection by as much as two-thirds. [3]

Strengths This "technological" approach takes advantage of the fact that not all systems need to be checked as frequently as every entry to an AHS. The introduction of a few certification sites, or licensing vehicle repair businesses to perform the checks, will reduce the complexity of the highway infrastructure and/or on-vehicle check-in systems. It also provides the means to more extensively test the critical AHS longitudinal and lateral control hardware and software than would occur at check-in using BIT alone. The certification station provides a way to perform dynamic testing on both the vehicle control systems and the braking system.

Weaknesses A certification station approach would suffer from problems similar to many of the smog check programs throughout the country. The primary problem is the need to police the certification system to ensure that equipment is being maintained in such a manner to perform the checks accurately and to prevent the issuance of fraudulent certificates. Unlike emission checks which are not safety critical, these checks will play a highly critical role in the level of safety on the AHS which will require very high standards to be maintained. This will in turn require very frequent checks of the stations themselves. The cost of these checks will have to be weighed against the additional development, installation, operational and maintenance costs of a more complex entry check-in approach. Though issuing licenses to existing garages, which may already have much of the test equipment needed, holds the promise of quickly and easily establishing the certification system, consideration may have to be given to government-run stations to ensure proper and accurate checks.

A training program for AHS vehicle inspectors will also need to be established and administered. This adds to the administrative burden associated with the AHS system and potentially the operating cost if the full cost of training can not realistically be recovered from the "students" or fees paid by licensed check stations.

Since most states have at a minimum an active smog check program, vehicle users are accustomed to the idea of periodic inspections. However, they may be resistant to the required frequency and associated costs. Most smog check programs require recertification every two years. An AHS certification may be required as frequently as every six months and 25.000 to 50,000 kilometers (15,000 to 30,000 miles) to ensure continued safe operation. The frequent inspections are needed not only to meet safety goals, but also to ensure that goals related to achievable traffic volumes, arrival time confidence, and emissions are not compromised by frequent vehicle breakdowns. Not every inspection, however, needs to be comprehensive as is the case with normal maintenance schedules. The high frequency and/or low mileage requirement for certification will be driven by items such as tires, belts, and engine performance. Older cars may need more frequent inspections due to the higher probability of components failing or may be required to have components whose failure is hard to estimate, such as timing chains and water pumps replaced at a certain number of miles independent of failure.

A design issue for the next phase, or perhaps more of a challenge, is how to achieve the necessary reliability of on-board systems and component life to permit yearly or bi-yearly checks.

Cost. Technology common in the aerospace industry has already been introduced to the vehicle service departments. Major automobile manufactures, such as Ford and Chrysler, have expanded large sums in the development of vehicle analyzers. These analyzers represent an expenditure for each unit up to $50,000, not counting the development of the system itself. The auto industry distributes three to four thousand units to dealerships. These analyzers provide one of the tools required to certify the vehicles and as such will smooth the introduction to a system for AHS certification. Often, however, this test equipment is not compatible with all vehicles. This is an area where national standards will be required to reduce cost by not requiring multiple systems to check all types of vehicles. It will potentially put a requirement on the manufacturers to develop and install a "vehicle personality module" which will translate the signals from their specific on-board monitoring systems to a common output standard.

Discussions with other automobile service departments revealed test and diagnostic equipment price ranges from $20,000 for engine analyzers to $200,000 for tire alignment platforms. The $50,000 mentioned above was used to calibrate the PRICE H model to generate a product complexity factor. The resultant factor was compared to the model's industry technology factors and placed the certification station test set in a military airborne analog technology category using medium scale integrated circuits. This complexity factor substantiated the use of aerospace technology within the test set and was used to generate development and production costs to equip 1,435 certification stations with one test set each.

Costs to users were assumed to be more involved than the smog checks with certificates of approval that cost an average of $30 per inspection. Additional diagnostics to check vehicle compliance was paralleled to an intermediate tune-up, i. e., not minor not major, which currently costs on the order of $60. To account for at least these types of inspections, an average certification cost of $100 per occurrence was used in this analysis. Costs to repair, recalibrate, etc., were included in the user's operations and maintenance estimate.

3.2.1.4 Encoded Data/Scanners

3.2.1.4.1 Smart Cards

This small plastic card embedded with microprocessors and memory chips can be used to carry a range of information including driver's license data, AHS training certification, and AHS vehicle certification. As an example, when a car is purchased it would come with a smart card containing vehicle characteristics. This card would be used as a means to transfer this information to the AHS central control computer system at check-in and can also be used to store AHS safety certification and general maintenance information.

At check-in, the card can be read by a dash mounted reader which sends the information to the infrastructure via a radio transponder. Alternatively the card reader could be mounted in a check-in station. The driver in this case would stop at the station and insert or "swipe" the card through a reader to enter the data into the AHS control system. To prevent unauthorized access, a means to verify driver identity would be needed, i.e., personal identification number (PIN) entered via operator keys or a unique physical signature sensor. The driver will receive feedback as to whether the data was accepted or not.

Depending on the check-in system approach selected there is the potential for the driver to need multiple cards. These could possible include a personal Department of Motor Vehicle card, a vehicle characteristic/certification card, and, in the case of a commercial vehicle, a card containing vehicle weight as recorded at a weigh station and cargo type. The inconvenience of having multiple cards can be minimized if the card reader is on board the vehicle and volatile memory is present that the card data is read into as soon as the vehicle is turned on. At check-in the data would be passed to the AHS control system as part of a broadcast data packet directly from the volatile memory. This information would not be maintained whenever the car was turned off for privacy reasons.

As a preemptive note, though a smart card could be used for the purposes of storing and transferring vehicle specific information, it makes more sense to store this data within the vehicle on a Programmable Read Only Memory (PROM) so that it is permanently available and accessible to the AHS control system. PROMs are discussed in 3.2.1.4.2.

A quick rejection mode based on whether a personal smart card is available could be considered. The first check performed queries for a personal smart card; if not present, immediately reject the vehicle prior to initiating further checks. This will prevent time delays resulting from the check of vehicles that will be ultimately rejected due to the inability to verify driver qualifications.

The desirability of the alternate case should also be considered. If the driver has lost any of the smart cards, should data entry through operator keys be permitted? The data entered such as driver license number or AHS certification number would be used to check vehicle and driver qualifications in a national database. Again, driver license data would need to be verified through a driver identification process. One drawback with this approach, as in all approaches which require a central database, is the maintenance costs, accuracy, currency, and privacy issues.

Technology Maturity. Smart card technology is in use. As an example, Smart cards are being used as a means for toll collection on some roads. In some ways the technology is still unproven due to the newness of its application. Because of this, "real world" reliability and useful life are still being studied but will most likely be fully mature by the time the AHS is fully deployed.

Strengths. The smart card is highly portable and very flexible. It can be used to store a wide variety of information. Cards can be easily programmed when desired to add information such as date of AHS certification and valid time period and miles. Alternatively, for data that needs to be protected from alteration, a ROM can be "burned" and embedded in the card with the desired information. This type of memory device can not be altered.

Weaknesses. A primary weakness of the smart card is a function of one of its strengths, namely highly portability. This raises the potential for it to be forgotten, stolen, misplaced, or lost causing check-in delays either while the card is being searched for at the check-in point or an alternate, slower, means of data entry is used. A safety issue also arises if the card needs to be found and put in the reader while in motion since the driver will be distracted and not fully attentive to his vehicle or the vehicles around him. Another weakness concerns the device's short battery life. The AT&T smart card has recently been used in tolling operations in California, however officials have complained about the device's bulkiness, short battery life, and tendency to overheat on hot days. In addition, other uses for the smart card have not yet materialized at this particular tolling operation, whereby subscribers to the system are paying for a technology that need not be so expensive; they have now switched to a windshield-mounted plastic tag.

Cost. Discussions with the Harris County Toll Road Technology revealed that electronic toll collection cards currently cost users $15 per year. Cards contain user and toll account balance information; a type of smart card. California drivers' licenses are now magnetically striped, containing driver information, and can also be considered a type of smart card. The addition of the magnetic strip allows the highway patrol to swipe the license through their on-board computers to access driver information. Drivers pay $10 per year for their licenses. This analysis used $15 per year per user as the price for smart cards. This value was also used to calibrate the PRICE H model to generate a product complexity factor to estimate development costs.

The cost of a Smart Card reader was estimated and included in this analysis. Manufacturers of magnetic card readers were not contacted to obtain price quotes, so the PRICE H model was used to estimate development and production costs. Relatively low technology components, i.e., medium scale integrated circuits, were assumed as the product technology complexity and used in this analysis. Results are presented in appendix E.

3.2.1.4.2 Read Only Memory (ROM)/Programmable Read Only Memory (PROM)/Electrical - Programmable Read Only Memory (E-PROM)

An E-PROM can be used to store regulatory information such as the AHS system certification. The certification station can put the information into the ROM through a computer connection to the vehicle and the check-in station can access it. This approach again mitigates the need for the user to carry another form of the certificate such as a smart card. This approach also eliminates a requirement for a large national AHS certification database. If this latter approach was taken the certification status would need to be verified by reading a "certification check number" in some manner such as a laser scanner of a bar code on the windshield and checking the database.

For commercial vehicles, an E-PROM can be used to store data such as gross weight and cargo type. Again the information would be stored via a computer connection by a weigh station and freight forward, respectively.

Technology Maturity. This technology is a mature existing technology. PROMs are in use in data acquisition during flight tests of current Northrop Grumman advanced aircraft. PROMs are 'burned' and are used by data acquisition systems to extract data from serial digital data buses. PROM technology is also used in many electronic applications, from cellular phones and telecommunications equipment to medical equipment.

Strengths. Rugged and highly reliable PROMs are available from multiple suppliers. They can store significant amounts of information and only require power when operating. The use of PROMs is transparent to the user and one can be installed at time of manufacturing containing all the vehicle characteristic data. This information can be queried by the infrastructure at check-in. This method for storing data does not require the driver to carry an additional smart card with this type of information.

Weaknesses. Nothing of note.

Cost. E-PROMs typically are priced at less than $100 each based on electronic product literature searches. This price was used to calibrate the PRICE H model to generate a product complexity factor. The resultant factor was compared to the model's industry technology factors and placed the E-PROM in a military airborne memory technology category using very large integrated circuits. This complexity factor is probably higher than required for ground applications but deemed conservative and used to estimate development and production costs. Lower costs per EPROM will most likely be attained when actual performance specifications are defined. Results are presented in appendix E.

3.2.1.4.3 On/Off-Board Bar Code Scanner (Laser)

Laser bar code scanners may be used during AHS check-in to obtain details concerning driver certification/licensing, safety certification, maintenance certification, and vehicle identification. Information would be encoded into a bar code, read by a laser scanner, and interpreted by the central processor.

Technology Maturity. There are many examples of current applications of bar code scanners in industry and the private sector. The most familiar applications of bar code scanning technology is visible during grocery store checkout. Price and product information is encoded by bar code and is processed by a laser bar code scanner. Scanners are also widely seen in industry. They are used for tracking items on assembly lines, tracking inventory, reordering stock, and tracking materials, documents, and tools. Bar codes are also used to track and identify employees/visitors of/to industrial facilities using bar code security badges. Current bar code scanners have high reading rates, data throughput, and decoding rates, They are also functional at large scanning ranges, from contact to 36 inches, are sensitive to poor quality bar codes, and are functional in bright ambient light conditions.

Strengths. Off-board scanners maintain check-in transparency and eliminate additional operator tasks, which reduces the possibility of input error. Further, encoded information eliminates driver sensitivity to privacy concerns.

Weaknesses. The amount of information stored on a bar code is much less than on other storage devices (i.e. smart cards, PROMs, etc.). Also, a dirty environment may affect the resolution.

Cost. Discussions with managers of retail stores using laser scanning systems for merchandise check-out did not disclose prices. Therefore, the PRICE H Model was used to estimate development and production costs for this system. The model's industry technology factor for laser modules was the governing complexity factor used in this analysis. Electronics associated with this module were assumed to be a mix of digital large scale integrated circuits and analog medium scale circuits. A roadside processor would most likely accompany the module. Resultant production unit cost per laser module was projected to be $17,440. The processing for the laser module conceivably could be included as part of the transponder's roadside processor and was included as part of the roadside processor cost in this analysis when applicable.

3.2.1.5 Imaging Sensors

3.2.1.5.1 Optical Sensor (Image Processor)

Optical imaging systems could be used during AHS check-in to obtain information on vehicle dimensions, check for functionality of lights and wipers, and to a lesser extent, make determinations concerning steering and braking functionality.

Technology Maturity. Video camera and optical imaging systems are currently in use for traffic surveillance in several high traffic areas in the country. Most of the systems in use are black and white imagers with poor resolution and detail. Higher resolution, color imaging systems are currently in development. Video scanning systems are currently in use to capture license plate information. The system digitizes license plate information from a passing vehicle for image enhancement and plate identification. Image processing sensors are also in use in industry to measure dimensions and tolerances of molds, metal and plastic parts, extruded sections, and machining tools. Dimensions can be measured in the sub micrometer range. Grey-scale image processing is implemented by a high precision imaging lens and special image processing software.

Strengths. Imaging systems in the visual range are in current use throughout the country. Recognition and identification of visual images require less training or software when compared to recognition and identification of IR images.

Weaknesses. Image resolution and identification may be adversely affected by inclement weather and darkness. Range perception limitations will have to be addressed.

Cost. Video scanner systems are currently in use. The Harris County Toll Road Authority in Hampton, Texas has installed a Video Enforcement System (VES) that continually captures toll violation data on a 24-hour basis. Cubic Toll Equipment of New York manufactures these cameras that have adequate resolution from its mounted site to identify license plate numbers. Actual costs could not be obtained from Cubic for this equipment due to competition sensitivity so the PRICE H Model was used to estimate development and production costs. A technology factor characterizing highest quality optics was selected as the governing assumption used in this analysis. A total weight of 9.1 kilograms (20 pounds) was assumed based on its volume similarity with the IR scanner (6.8 kg or 15 lbs) with an additional 2.3 kg (5 lbs) to account for the optical components. The projected production estimate was $6,940 per system as shown in appendix E.

3.2.1.5.2 Infrared Sensor

Infrared sensors may be used in similar fashions as the optical imaging systems. IR imaging systems have the capability of vehicle identification. IR imaging might also be useful in determining the condition of the braking system through changes in thermal signature, as well as monitoring vehicle exhaust emissions.

Technology Maturity. A Northrop Grumman IR traffic sensor prototype is currently being tested on the Long Island Expressway. The traffic sensor is a passive infrared imaging sensor with high resolution allowing continuous roadway monitoring. It can see equally well at night and see farther in adverse weather than conventional optical systems. Within the sensor is a built-in processor to reduce the large volume of raw imagery data to the required useful vehicle information. The sensor is linked to a roadside processing unit that transmits information to a traffic center for further monitoring and feedback. The prototype is currently able to distinctly identify cars, trucks, and motorcycles based on their IR signatures. Future capabilities include monitoring exhaust emissions and automated brake inspections. IR sensors are also being used in California to detect and record vehicle exhaust emissions. A narrow beam of infrared light is sent across a vehicles emissions and is sensed by an infrared photoelectric detector. The infrared energy is converted to an electrical signal. The higher the electrical signal converted from the IR energy that is detected, the lower the exhaust emissions. Future capabilities include automated brake inspections.

Strengths. IR imaging systems are desirable during night time and adverse weather operations, where image resolution is not degraded as significantly as in optical sensors. IR sensors have been used significantly on advanced fighter aircraft for air-to-surface target identification.

Weaknesses. Recognition and identification of IR images will require more training or software than images in the visual range. Capabilities for AHS check-in require more development.

Cost. Costs for the IR sensor were based on a Northrop Grumman IR traffic sensor prototype. Discussions with the Northrop Grumman engineer involved with the construction of the IR traffic sensor system prototype revealed the cost to be $50K. This cost includes the IR sensor unit and the associated roadside processor. Cost drivers in this system include the focal plane optics and germanium window in the IR sensor unit, and the electronics required to perform parallel processing in the roadside unit. The prototype unit cost was used to calibrate the PRICE H model to generate technology complexity factors. The resultant complexity factors placed the IR sensor in a good quality optics category and the processor in an analog small scale integrated circuit technology category. These factors were lower than expected and therefore adjusted upward based on known costs of IR components used in aircraft. The factors were adjusted to reflect the highest quality optics for the IR scanner and large scale integrated circuits for the processor. These complexity factors were used to estimate development and production costs based on groundrules and assumptions listed in section 2.2.4. Production costs for the IR scanner and processor were estimated to be $17,530 and $5,380 respectively.

3.2.1.5.3 Radar

Synthetic aperture imaging radars may be used during AHS check-in for identification of ground vehicles and determination of vehicle size. Transponder equipped vehicles may also be interrogated by the radar to obtain vehicle identification numbers. Pulse Doppler radars may be used to measure vehicle motion. Braking capability may be determined through radar measured deceleration.

Jet Engine Modulation (JEM) is a technology where the radar return signal that has been modulated by the target's rotating engine turbines is decoded by Fourier analysis. Since each jet engine type has its own unique characteristics, this technology may be used to "fingerprint" aircraft by the frequency of the rotating turbines and any wobble they may have. Rotating wheels modulate a radar signal in a like manner. Wheels that are out of alignment will vary the rotational frequency. When a Fourier spectrum of these frequencies is generated and compared to one with aligned wheels, any difference can indicate a need for wheel alignment.

Technology Maturity. Pulse Doppler radars are used extensively on advanced aircraft platforms. Aircraft radars are designed for long ranges. The short range requirements for AHS would significantly reduce the cost primarily because of much lower power requirements. AHS also requires less accuracy and fewer functions to be performed, which reduces software and hardware requirements and thus reduces cost as well. Many low cost civilian radars, such as small ship radars and police radars, are currently in use.

Strengths. Pulse Doppler radars are used widely throughout the aircraft industry as well as in the civilian environment, such as in law enforcement, providing a good technology and a manufacturing base.

Weaknesses. Radar signals at high power levels pose a health hazard. The safety at low levels will have to be investigated. A laser radar (LADAR) may solve this problem.

Cost. Radar has historically been a major cost driver on aircraft systems due to its imaging capabilities. If imaging is not required, radars being used in law enforcement for tracking speed may be adequate and would substantially lower costs of an AHS system. Since the QFD ranking for this technology was very low, a design concept was not created to provide inputs to the PRICE H model to generate cost estimates. No costs estimates for radar are included in this analysis.

3.2.1.6 Standard Vehicle Instrumentation

Standard instrumentation is referred to as instrumentation that is currently on most ground vehicles for checks of system health. This includes engine sensors which monitor engine health, performance, and emissions. Fluid level sensors are also standard on most ground vehicles which includes checks of fuel level, transmission fluid level, oil level, and engine coolant level. Standard temperature sensors are also common on current ground vehicles for measurements of coolant temperature, and engine temperature.

Technology Maturity. Standard instrumentation and sensors are found in most ground vehicles. Sensor installation, calibration, and repair can be done by current ground vehicle maintenance personnel. No special training will be required.

Strengths. Since this instrumentation is standard and a mature technology, no new development costs will be incurred. No special training is required for maintenance personnel. Outputs can be assessed by BIT system or data transmitted to the infrastructure for assessment.

Weaknesses. Nothing of note.

Cost. No additional costs were included in this analysis for standard instrumentation since it is currently installed in the majority of vehicles.

3.2.1.7 Add-On Instrumentation

Special add-on instrumentation might be required for testing of specific ground vehicle components where data is not available from other sensors, BIT indications, or standard instrumentation. This instrumentation includes strain gauges/load cells, pressure transducers, accelerometers, electrical current meters, contact sensors, and thermocouples. This instrumentation can measure, directly or indirectly, loads, pressure, acceleration, electrical signals, electrical continuity, and temperature.

Technology Maturity. The add-on instrumentation discussed above is in use on current Northrop Grumman flight and ground test vehicles. Strain gauges are applied in several configurations (bridges) to indirectly measure tension, compression, and bending loads on structural members on test airframes and components. They are used widely in the aircraft industry to test airframe fatigue, static and dynamic loads, and structural integrity. Pressure transducers and their associated plumbing are used to measure fluid pressures in many aircraft systems. Current test vehicles use pressure transducers to measure air data parameters, wing pressures, hydraulic fluid pressures, engine inlet pressures, engine performance, and environmental control system parameters. Thermocouples are installed on current test vehicles to measure temperature and thermal properties of aircraft systems. Thermocouples are used extensively to measure temperatures in the propulsion, environmental control, hydraulic, and electrical systems. Accelerometers, contact sensors, and electrical current meters are used less extensively but are still an important part of air vehicle test instrumentation.

Strengths. This is a proven low cost approach to special data acquisition which can be considered for present and future applications. Instrumentation has proven to be reliable and robust in harsh aircraft operating environments.

Weaknesses. Well trained technicians will be required for installation and calibration of test instrumentation. Signal conditioning equipment and special data acquisition hardware may be required.

Cost. Prices for the add-on instrumentation package consisting of the sensors and gauges mentioned above were obtained from various sources. They primarily included the B-2 flight test labs and electronic component catalogs. The price per package was estimated to be $440 each. Development costs were not estimated for the add-on instrumentation since most of the components can be purchased off-the-shelf.

3.2.1.8 Driver Physiological Sensors

3.2.1.8.1 Physical Condition Sensor

Physical sensors include both the measurement of the physical condition of the driver (alertness, impairment, etc.) and driver identification by examining unique physical characteristics. Physical condition of the driver while in the AHS lane(s) is a critical safety factor. Prior to implementation of a fully automated AHS (all vehicle functions are controlled by the roadway) the driver must be alert to control some portion of the vehicle operation (such as steering). Even in a fully automated AHS the driver must be prepared to take full control of the vehicle if the AHS fails. Further, if graceful degradation is implemented, the driver must be alert and ready to take over at least partial control functions. There are current research programs focused on technologies which would enable monitoring driver performance during check-in and while in the AHS lane(s). The two driver conditions of particular concern are drowsiness and the influence of intoxicants/depressants (alcohol and/or drugs). Three current research focus areas could provide the solution to this problem: 1) operator performance; 2) physiological status; and 3) intoxicant/depressant monitoring.

Physical sensors are designed to identify individuals based on unique physical characteristics. Devices based on finger prints are presently in use for non-vehicle purposes. As in the case of physical assessment sensors, considerable research is underway to improve these systems. This research includes vehicle applications for security purposes.

Technology Maturity. Dr. Walter Wierwille of the Virginia Polytechnic Institute and State University's Vehicle Analysis and Simulation Laboratory is conducting extensive operator performance research on drowsiness and the use of direct, unobtrusive driver psycho physiological monitoring (e.g. eye closure). Results of this research to date were presented in a paper at the IVHS

America Fourth Annual Meeting. This research will provide the foundation for technology to monitor driver alertness.

Physiological status research on monitoring items such as amino acids, eye gaze, and eye blink plus non-intrusive brain wave monitoring is being conducted under several programs. This research can be applied to detecting the use of intoxicants/depressants. A University of Tokyo project sponsored by Toyota is concentrating on monitoring amino acids to determine driver condition. The Northrop Grumman 3-In-One System IVHS IDEA project is focused on tracking head and eyelid movement to determine driver alertness status. Northrop Grumman and others have also conducted research on brain wave monitoring and brain wave sensors. These projects could yield unobtrusive means to detect the use of intoxicants/depressants by drivers to enable the AHS check-in system to deny access.

By the time AHS deployment begins in the early 21st century, the technologies necessary to monitor physical condition of drivers should be available. Non-obtrusive physiological monitoring should provide sufficient data to determine driver psycho physiological status during AHS check-in and to monitor driver psycho physiological status while in the AHS lane(s). The AHS check-in system can deny access to a driver whose physiological condition indicates an unsafe condition. Procedures will have to be developed for dealing with drivers whose physiological condition becomes unsafe once in the AHS lane(s).

Strengths. Most current research on physiological testing is non-intrusive, while physiological states are monitored on a continual basis. Physiological data processing is not considered to be computational intensive, which would have a positive effect on time to check-in. System development is on schedule for implementation by the year 2000 for possible AHS support.

Weaknesses. The major weakness is the cost of system development and test. Other weaknesses include some physiological tests requiring obtrusive hardware/driver interfaces; the amino acid monitoring project will require a driver wrist band. There are also privacy concerns associated with the use of these technologies for check-in.

Cost. The system cost provided in this analysis envisions the use of an on-board laser-type physiological sensor. This technology is in a conceptual stage and no costs have been estimated. Therefore, the PRICE H model was used to estimate development and production costs. The model's industry technology factor for laser modules was the governing complexity factor used in this analysis. Electronics associated with this module were assumed to be mainly analog large scale integrated circuits. An average production unit estimate of $733 was projected by the model and presented in appendix E.

3.2.1.9 Off-Board Laser

Laser applications vary widely throughout industry and include a multitude of applications for AHS vehicle and infrastructure systems. An off-board laser system could be used to determine vehicle dimensions, tire tread conditions, wheel alignment, and suspension system anomalies.

Technology Maturity. Some of the many laser applications include bar code scanning, object detection and tracking, solid model rendering from CAD drawings (stereo lithography), wind velocity measurements, and 3-D object sensing in real time. Laser technology applications range from very simplistic and inexpensive to highly complex and very expensive. Stereo lithography is an example of a very complex laser technology system. Solid models are produced from a vat liquid epoxy where a laser, driven by a CAD drawing, heats and therefore solidifies the epoxy. A less complex example of laser technology application is systems used sense 3-D objects in real time. Lasers are used with video systems and high speed image processors to locate and calculate 3-D coordinates of objects using triangulation methods. Once the image is processed, size determinations can be made. Laser triangulation technology also exists for range and size measurement in the range of 0.5 inches to three inches with high resolution. A laser is directed to the surface of an object, where the beam is reflected and scattered. The laser is then moved across the object. Sensors, which consist of lenses and photo detectors, detect the reflected laser image. Image processing electronics determine changes in distance from the sensing equipment to the object by changes in the reflected light position on the detector. This scanning process is currently used for seam tracking, high speed surface profiling, and height, depth, and thickness measurements. Technology for these and other systems are very mature and applications for them are numerous and growing.

Strengths. Maturity strengthens laser technology application for AHS. Laser applications are diverse with many commercial products currently on the market that may be developed or adapted directly to AHS. Also, the highly accurate nature of measurements of object dimensions, alignment, speed, and location using lasers adds to the strength of applying this technology to AHS.

Weaknesses. While bar code scanning is a relatively simple and inexpensive application of laser technology, stereo lithography is highly complex and very expensive. Laser technology applications for AHS may not be as complex as those for stereo lithography but using the technology may increase overall costs of off-board AHS systems significantly. There are also environmental concerns for using lasers related to operational efficiency. Highways are dirty environments filled with dust and other airborne contaminants. Laser energy may be scattered by these particles degrading images or other information collected by lasers.

Cost. For this analysis, this system's general componentry is assumed to be identical to the laser scanning system described in a previous section but packaged differently. The PRICE H Model was also used to estimate development and production costs for this system. The model's industry technology factor for laser modules was the governing complexity factor used in this analysis. Electronics associated with this module were assumed to be a mix of digital large scale integrated circuits and analog medium scale circuits. Similar to the laser bar code scanner described above, a roadside processor would most likely accompany the module. Again, the processing for the laser module conceivably could be included as part of the transponder's roadside processor and was included as part of the roadside processor cost in this analysis when applicable. Since the model input parameters were identical to the laser scanning system, an identical production unit cost of $17,440 resulted. Estimates for the off-board laser and laser scanning system can be further refined when more design details are available.

3.2.1.10 Off-Board Load Cells/Slip Plates/Tactile Patch

An off-board weigh-in system may be implemented using scales/load cells to measure vehicle weight and load distribution. Instrumented slip plates may also be utilized for checks of the braking system, wheel alignment, and steering. A tactile patch can determine the tire tread depth, measure the contact area, and measure the total force on the patch to determine tire pressure.

Technology Maturity. Off-board weigh-in scales are used extensively by the California Highway Patrol (CHP) for truck weight determination. The test community in the auto industry uses slip plates to measure side loads and instantaneous forces on test vehicles. This technology area has been expanded to have on-board sensors integrated with the infrastructure in the form of weigh-in-motion technology.

Strengths. Proven and existing technology can easily be integrated into check-in system.

Weaknesses. Weigh-in systems and slip plate testing would require vehicles to stop at check-in stations. This will increase check-in time.

Cost. Scales used by the CHP for weigh-in are owned by Caltrans. Discussions with Caltrans engineering disclosed costs of $175K per system. This is a weigh-in motion system consisting of a series of sensors transmitting load data to a control station. The control station processes the data to determine load violations. The system is capable of identifying loads by axle that exceed a predetermined threshold. The cost mentioned above is used in this analysis when applicable.

3.2.2 Queuing Analysis

A simulation was constructed to analyze queuing effects in the vicinity of an AHS check-in station. The primary factors that can lead to queue build-ups at check-in stations are the arrival rate of vehicles at a station and the length of time required to check if a vehicle and its driver are safe to enter the AHS. Queue build-ups near freeway on-ramp type AHS check-in stations could cause traffic congestion (i.e. spill back) on arterials leading up to an AHS entry point. Therefore, time required for check-in is a potential issue for the AHS check-in function. The measures of effectiveness for this analysis are: 1) vehicle time in the system (i.e. time in queue plus time for check-in), 2) queue length, and 3) check-in station utilization.

For the purposes of this analysis, the check-in stations are configured similar to freeway on-ramps with ramp meters. Many of today's ramp meters permit more than one vehicle to enter a freeway at a time. This could similarly apply to AHS check-in stations. The queuing analysis will therefore consider cases where between one and four vehicles can be checked in simultaneously. A possible configuration for four vehicle check-in stations is presented in figure 3-10. Positive benefits could still be realized even though a vehicle checking in at Station #2 may be delayed by a vehicle with a longer check-in time at Station #1.

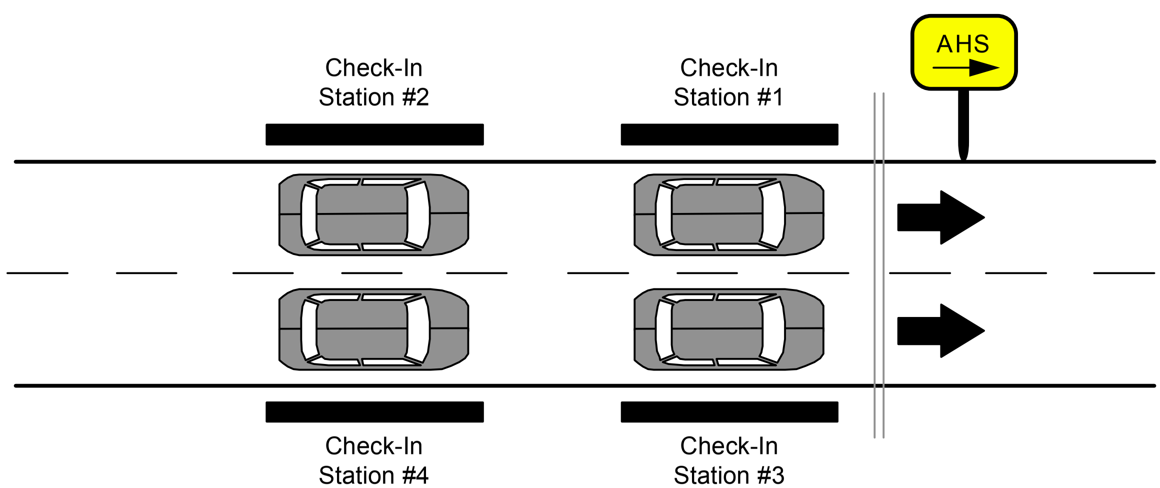


Figure 3-10. Two-By-Two Check-in Station Scenario

The mean vehicle arrival rates at a check-in station for this analysis are 3, 5, and 7 seconds. Arrival rates are assumed to be distributed exponentially. An arrival rate of one vehicle every three seconds (1210 vehicles/hour) represents ramp traffic during a peak travel period[1] (i.e. between 7:00am and 8:00am). For the analysis, check-in time is varied from 0 to 40 seconds and the simulation keeps track of the average time a vehicle is in the system and the average number of vehicles in the check-in queue. The simulation for this analysis was written in SIMAN, a discrete event simulation language.

Results from the simulation for a mean arrival rate of three seconds are presented in figures 3-11 through 3-13. These graphs display the average vehicle time in system, number of vehicles in queue, and check-in station utilization, respectively, as a function of check-in time. It is important to remember that "check-in time" is the time required for the AHS check-in system to verify that a vehicle and its driver can safely operate on the AHS and that "time in system" is check-in time plus the time spent in any queue that has formed at the check-in site. These graphs and those for vehicle arrival rates of five and seven seconds can be found in appendix C.

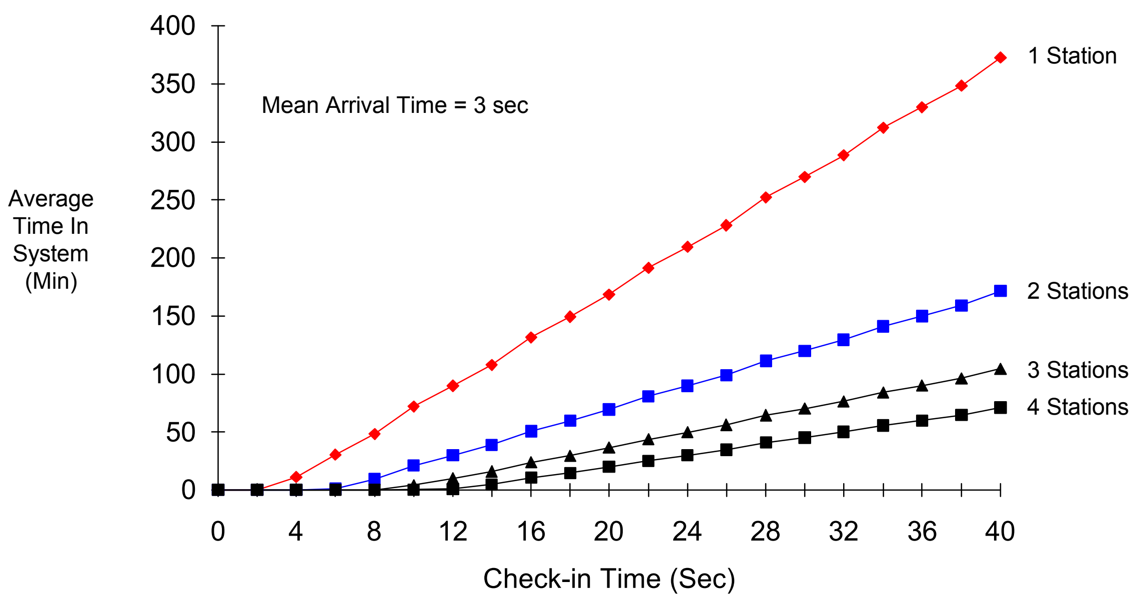


Figure 3-11. Average Time In System vs Check-in Time

Examining figure 3-11 shows that average time in system varies greatly with the number of check-in stations available. Notice that a check-in time of five seconds for the 2, 3, and 4 check-in station cases produces an average time in system of less than one minute while the single check-in station case results in excess of twenty minutes average time in system. Proceeding on out to check-in times of forty seconds, even the four check-in station case results in average time in system of over an hour. Similarly, figure 3-12 demonstrates that average vehicle queue length is also highly

[1] Source: Daganzo, C. F. (Editor), Transportation and Traffic Theory, Effects of Merging Lane Length on the Merging Behavior at Expressway On-Ramps", Elsevier Science Publishers B. V. Amsterdam, 1993, pg. 39

sensitive to check-in time. Even though all four cases are sensitive to check-in time, there is a substantial payoff in going from one check-in station to just two check-in stations. This is evident in that as we increase our check-in time to six seconds the one check-in station case results in just over thirty minutes time in system while the two station case produces only approximately one minute for time in system. One minute time in system is roughly equivalent to typical times waiting at a busy signalized intersection.

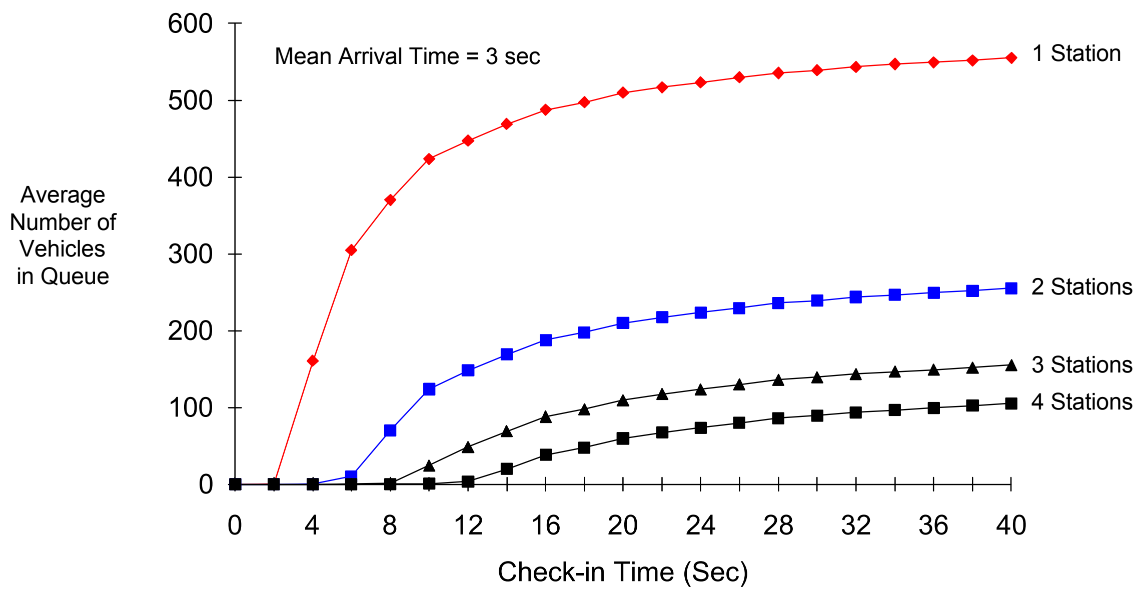


Figure 3-12. Average Number Vehicles in Queue vs Check-in Time

Average check-in station utilization is depicted in figure 3-13. The one check-in station case utilization curve demonstrates that as the check-in time reaches the arrival rate the single check-in station utilization goes to 100 percent. This is an obvious result since vehicles are arriving at the station faster than the average time to process each vehicle. The coarseness of the data in this graph makes it appear that 100 percent utilization occurs at a check-in time around four seconds. Running the simulation for smaller intervals of check-in time would result in 100 percent utilization as check-in time approaches the mean arrival rate, 3 seconds. Therefore, for each of the three mean arrival rate cases (3, 5, and 7 seconds), 100 percent utilization should be achieved at approximately the number of check-in stations multiplied by the mean arrival rate. Simulation results concur with this observation. As an example, from the simulation, the two check-in station case, using a three second mean arrival rate, 100 percent utilization is reached at approximately six seconds. Utilization reaches 100 percent for the four check-in station case at a check-in time of approximately twelve seconds.

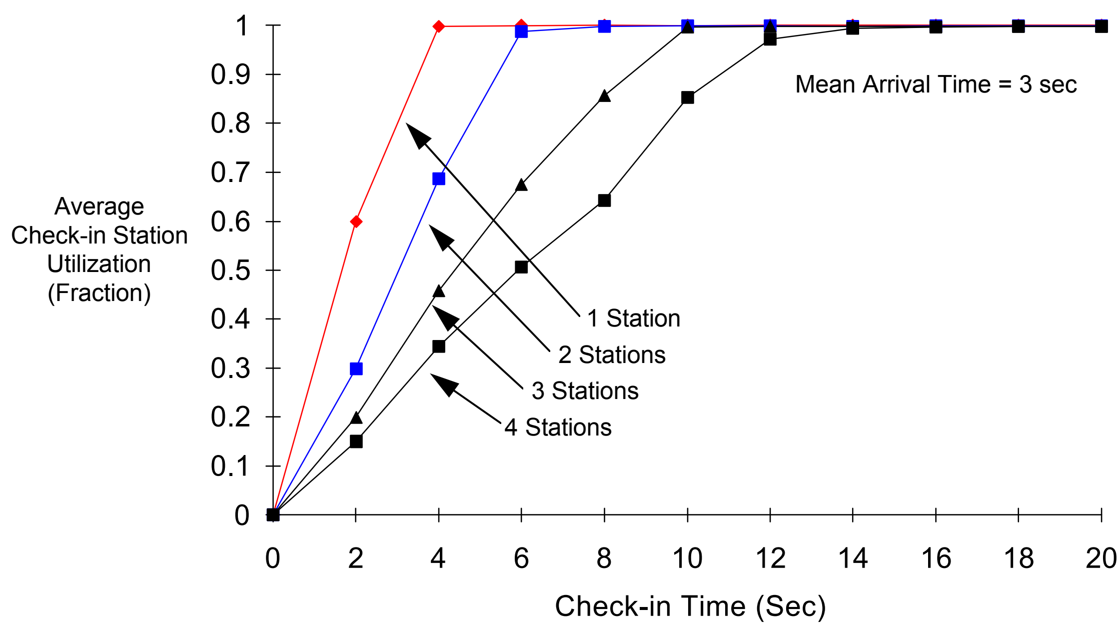


Figure 3-13. Check-in Station Utilization vs Check-in Time

The maximum efficiency of checking vehicles will obviously occur when the arrival rate is low (i.e. more time between vehicle arrivals), the check-in time is minimal, and the number of stations is high. The question is what values can be tolerated without introducing long delays especially if the infrastructure will not permit multiple stations and a long entry ramp. In general, a check-in requirement of anything greater than two seconds using only one check-in station would result in an unreasonable amount of time that the vehicle, on average, would spend in the system. However, the addition of a second station can significantly change this requirement. In fact, the added value of the second station is better, in terms of vehicle time in system, by a factor of ten and thirty for check-in times of four and six seconds, respectively. Adding additional stations further decreases the average time in system but not as drastically as going from one to two check-in stations.

This difference between check-in stations is primarily due to the number of vehicles in the queue, as shown by figure 3-12. In the one check-in station case, the increase in queue size occurs rapidly as soon as the check-in time exceeds the vehicle arrival rate. However, additional check-in stations decrease the magnitude of the queue build-up and also delay its occurrence over similar arrival times. Therefore, in looking at the number of vehicles in queue and the time in system, at least two check-in stations are required for efficient traffic flow in a full-stop, check-in station AHS scenario.

3.2.3 User Acceptance (Survey)

As described in section 2.2.2 a series of focus groups were held to gain insight into user-related issues relative to proposed check-in systems. Regarding the participants in the user survey, there were two large focus groups consisting of six and eight individuals, respectively, and one small focus group consisting of two participants. All the participants in these three groups can be categorized as "commuters," that is, driving is not part of their job description, it is merely a mode of transportation.

Additionally, we surveyed a few individuals whose jobs require the use of a vehicle, such as a truck driver and real estate appraiser. These individuals were chosen for the survey in order to include a more representative sample of potential AHS users. The most noticeable difference in opinion between the commuters and non-commuters was the emphasis placed on increased safety by the non-commuters due to their increased time "on the road." There were 19 participants in our survey. Although this number would be considered too small for a formal, scientific survey (which was not the purpose), it was a sufficient number to elicit the types of responses we were looking for, specifically issues and risks that had not been previously identified.

The demographics of the groups surveyed are shown in figure 3-14 as well as the commuters' driving characteristics in figure 3-15. As figure 3-14 shows, most of our participants drive alone, usually on freeways, about ten to fifteen hours per week. Looking at figure 3-15, over 50% of the commuters travel 16-32 kilometers (10-20 miles) each way to work, and approximately 35% of the commuters drive 20-30 minutes each way. As would be expected, commuters generally leave for work and return home during peak traffic periods. This demographic data is intended to provide additional information on participants in relation to the types of responses we received.

The key results from these surveys are summarized in figures 3-16a through 3-16c and are grouped into three categories of opinions: unanimous, majority, and other. appendix B includes the actual questions asked during the focus groups and individual surveys and various responses by the participants. The responses are also grouped by opinions (unanimous, majority, and other).

In general, participants seemed willing to accept either a transition lane approach to check-in or the check-in station similar to today's on-ramp metering. However, they would prefer not to stop but to have a smooth transition into and out of manual lanes. For these reasons, the transition lane was favored among the majority of participants who also emphasized that stopping should not occur in a transition lane due to the potential safety hazard resulting from the unnatural queuing on a high-speed road. There was a special concern for the possibility of non-AHS-compatible or non-"checked" vehicles to enter the automated lanes thus introducing a volatile element into an otherwise controlled environment. How would you stop this from happening? This was the main reason why participants would accept the check-in station scenario since it would have better control on the vehicles entering the AHS. Some participants wondered how many check-in stations there might be at an entry point, so as to reduce the necessary waiting time for the vehicle to be checked. An obstacle course was viewed by all as an impediment to the system, a waste of time, and, in general, a driver irritant.

A majority of participants feel that a driver's license and AHS training should be required in order to access an AHS since the system will probably be more complex than current manual lane procedures. It is also interesting to note that checking the criminal record at check-in was viewed favorably as a means to locate and capture lawbreakers, especially in the context of a stolen vehicle. AHS training would best be offered to users through the DMV and certification of the training should be shown on your driver's license. Some felt that training should not be necessary because the system should be operationally obvious. Others noted that driving is a privilege, not your right, thus you should be trained like any other classification of drivers, such as truck drivers. On an administrative note, some believe that AHS training (and the AHS in general) should be run by a private consortium with a profit basis in order to ensure efficient operation.

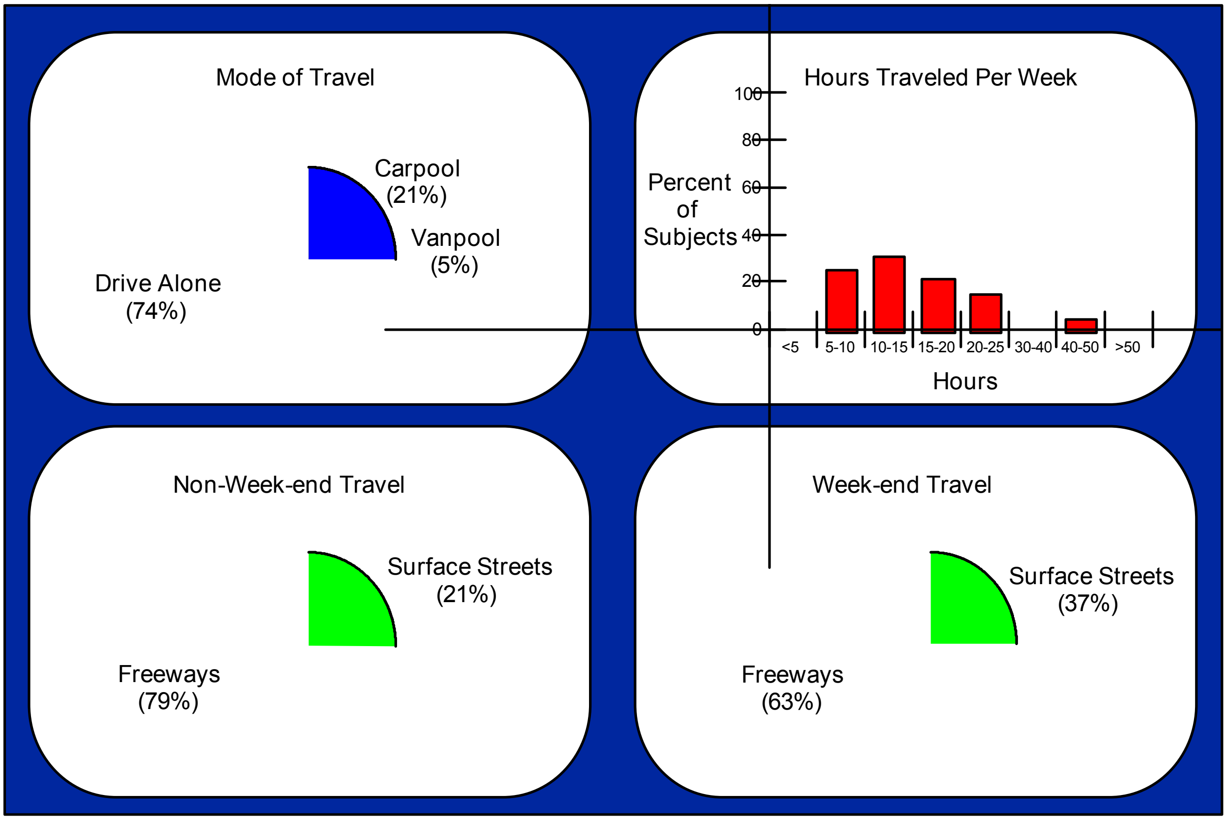


Figure 3-14. User Survey Demographics (All

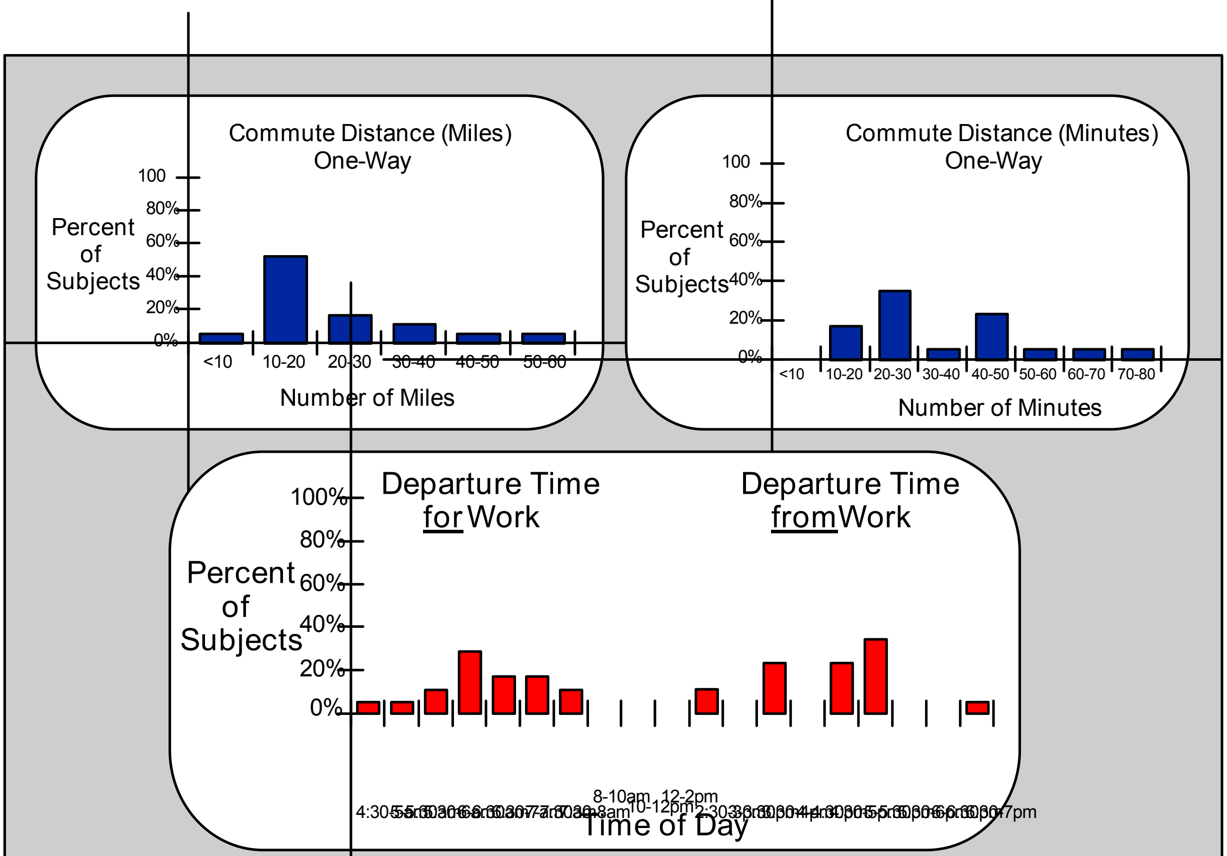


Figure 3-15. Commuter Driving Characteristics

CHECK-IN SYSTEM AREA	UNANIMOUS OPINIONS	MAJORITY OPINIONS	OTHER OPINIONS*
Scenarios			
Check-In Station		• Check-In station is acceptable since it's similar to ramp metering, but people would prefer not to stop • Stopping could help to screen out non-AHS vehicles	• Would there be several check-in stations? • How would you stop someone from entering the AHS?
Transition Lane		• Prefer the transition lane since it's easier to get on the AHS • No stopping in the transition lane	• If congestion increases, this is not acceptable • Optimum would be a combination of both the check-in station and transition lane
Obstacle Course	• Absolutely not		
Preference		• Transition Lane, but concerned about non-AHS entering the AHS	
Check-In Criteria			
Minimum Driver Requirements		• Driver's license should be required • AHS certification should be required	• No additional requirements than already needed for driving today • Registration, no parking tickets, insurance, warrants
AHS Training		• Some minimal training is acceptable • Offer training via Dept. of Motor Vehicles (DMV) • Training certification should be shown on your driver's license	• System should be obvious, no training necessary • Offer through private consortium
Safety Inspections	• Safety inspections should be mandatory for operation on the AHS	• Would be willing to have vehicle inspected every two years	• Should have vehicle inspected at least once a year - some states already mandate this • Inspections based on miles, not time

* Opinions that are interesting and insightful, but were not majority opinions

Figure 3-16a. User Survey Responses

CHECK-IN SYSTEM AREA	UNANIMOUS OPINIONS	MAJORITY OPINIONS	OTHER OPINIONS*
Check-In Criteria (Cont.) Maintenance		• Willing to spend $100-$200 per year on AHS related maint. • Cost and preventative maint. are biggest factors in deciding to have vehicle maintained	
Check-In Information Personal and Vehicle Information		• Any information relating to driving is okay to check (license, registration, cert., insurance, destination, drunk driver,etc.) plus criminal record	• Any personal information should remain private
Information Release	• No junk mail as a result of information released	• Acceptable to release criminal information to authorities • Statistical information may be released on a collective basis only	• AHS may be safest place for intoxicated drivers
Driver Interaction Destination Input		• Do not always have a specific route in mind, but usually have a destination • Destination input should be provided as an option, not a req'mt.	• Destination input should be required for traffic flow planning • Make the destination input changeable
System Control		• Less driver interaction the better since this would cause less delay	
Check-In Equipment and Costs User Cost Factors in AHS		• Accessibility of AHS, convenience, and proven "advertised benefits" would yield a higher acceptable price for the system	• Depends on other sources of available transportation
On-board Equipment Costs		• Would be willing to pay between $500-$1,000	

* Opinions that are interesting and insightful, but were not majority opinions

Figure 3-16b. User Survey Responses

CHECK-IN SYSTEM AREA	UNANIMOUS OPINIONS	MAJORITY OPINIONS	OTHER OPINIONS*
Check-In Equipment and Costs (Cont.) Off-board Equipment Costs (Infrastructure)		• Users of AHS should pay for maintaining the system	• All drivers should pay since they benefit from the reduced traffic in manual lanes
Sources of Revenue for Maintaining the System		• Tolls	• Pay through registration • Gas tax (1-2 cents per gallon) • Concerns about administrative fees with tolls, registration • Run the AHS through a private consortium
Summary	• People would definitely use a AHS considering the benefits and costs	• Initial cost (on-board) has greatest impact on choice to use the AHS	

* Opinions that are interesting and insightful, but were not majority opinions

Figure 3-16c. User Survey Responses

Most participants felt that safety inspections should be mandated due to the higher speeds and performance requirements (especially braking) for an AHS and also their lack of trust in the auto care practices of other drivers. Participants would be willing to have their vehicles inspected every two years, similar to California's smog check requirement for vehicle registration that occurs every two years, although some felt that inspections should be more frequent (i.e. every 6 months) and based on mileage more than time. A majority of participants would be willing to spend between $100 and $200 per year on AHS-related maintenance.

The information that the check-in system would access was a very interesting subject in these focus groups. Most survey participants said that any information relating to driving is okay to access, such as the driver's license number, vehicle registration, AHS training certification, safety inspection certification, driver's insurance, destination of vehicle, and driver's condition (i.e. intoxicated or not). One person mentioned the fact that the AHS may actually be the safest place for drunk drivers to be since their driving would be much less erratic and dangerous. Although they wanted the driver's license to be a requirement for AHS access, some felt that accessing the address and other personal information from the license was unacceptable. However, accessing one's criminal record and the ownership status of the vehicle (i.e. whether it's stolen, etc.) and the relay of this data to authorities was acceptable to the participants in the survey. It was pointed out during the survey that the statistical information, such as driver origin and destination, that could be extracted during check-in would be extremely valuable for some agencies, especially those involved in marketing. The sale of this data to agencies, if and only if it was on a collective basis and not individual, was acceptable to participants since they viewed this as a possible revenue source for decreasing their overall cost to utilize the AHS. Obviously, a concern over receiving "junk" mail as a result of information obtained during the check-in process by agencies was voiced, which is why only collective data could be released.

Driver interaction should be kept to a minimum according to a majority of the survey participants. The main reason for this response was to minimize any check-in delay. For example, if a Smart Card was required, what if the driver could not find the card easily or lost it? It was realized that some information would have to be manually input into the system, such as destination. However, most participants felt that this input should be an option since one does not always have a route and/or destination in mind. For individuals who drive as part of their living, a specific off-ramp may not be known at check-in (i.e. they may be looking at a map along the highway). There were several participants who felt that a destination input was mandatory in order to provide better traffic flow planning and management, but it should be changeable after you enter the AHS. If a destination input was required, participants were asked if they should be able to override some requirements, such as the fuel needed to arrive at the destination. The most common response to this was "no," however, it was pointed out that if you input your destination as San Francisco when you're in Los Angeles, your vehicle will not have enough fuel, so what would the system convey to you? Could you fool the system by entering a short-trip destination just so you could enter the AHS, change your destination en-route, and pass by the fuel requirement for the new destination?

Interestingly, participants seem to prefer that AHS-compatible equipment be off-board as much as possible to decrease the initial cost of equipment on the vehicle and to reduce driver responsibility. However, we realize that many potential check-in functions are already available on many vehicles in the form of Built-In-Test. The most that survey participants were willing to spend for AHS on-board equipment would be between $500 and $1,000. This cost is acceptable only if the AHS delivers as advertised, that is, all benefits must be attainable.

A majority of the participants indicated that the actual users of the AHS should pay for the off-board equipment maintenance and operation. This question was asked since all drivers would benefit from such a system whether or not they are in the automated lanes or manual lanes. However, although some felt the burden should fall in part on the non-AHS users via a gas/energy tax, most felt that some kind of toll system or payment through vehicle registration should be utilized to target AHS users only. Unfortunately, these two forms of payment suggest increased administrative costs. A comment was made during the survey that the cost of utilizing the AHS may differ by area, for example urban vs. rural, which also may affect the amount users are willing to pay for both on-board and off-board AHS equipment. If the cost became unreasonable, participants stated that they would revert to another form of transportation, either utilizing the manual highway lanes or seeking mass transit options.

In summary, when considering the AHS as a whole, the two main benefits of AHS as perceived by the survey participants are their increased efficiency in time use and safety. Their decision to utilize the AHS will be significantly impacted by the initial cost of purchasing the on-board AHS-compatible equipment for their vehicle, whether the vehicle is new or already purchased. Considering all the benefits of the AHS and costs mentioned during the survey, participants unanimously agreed that they would use the AHS we described.

3.3 AHS Check-in Options

The key questions to answer in developing an integrated check-in system are: what are the tests that need to be performed, when would the test be performed, where would the test be performed, how long will it take, how good are the results, and what is the cost. The primary requirement is that all safety-critical functions and the condition of the components involved with safety critical functions must be inspected, and the inspection results must be highly accurate. In addition, information that will support AHS efficiency is highly desirable. Based on this, all check-in integrated system approaches proposed at a minimum must address the "critical" and "desirable" information from the QFD analysis (section 3.1.1). This then answers the first question. The rest of this section addresses the other five questions.

Alternate integrated systems approaches were developed for a mature (circa 2010) AHS based on the QFD analysis and the assessment and analysis discussed in section 3.2. A brief discussion of the possible evolution of the check-in system as the AHS matures is included in section 3.6. In order to perform an analysis of the merits of each approach, an operational context is needed. The operational context in this case is the manner in which the highway entry point will be implemented. The entry implementation options assumed for this work are discussed in the next section.

A consideration in developing the alternatives is how and in what form is the check-in data supplied to the Control Center. Trades include using roadside sensors either directly tied into the center or which transmit to the center, and measuring the data on-board the vehicle and either transmitting "raw" data to the control center for evaluation or the results of an on-board evaluation. Figure 3-17 shows the data acquisition and

Option 1	Option 2	Option 3	Option 4
Information Generation O.B.	Information Generation O.B.	Information Generation R.S.	Information Generation R.S.
	Transmission to R.S.	Transmission to R.S.	
Checking O.B.	Checking R.S.	Checking R.S.	Checking R.S.
Transmission to R.S.			

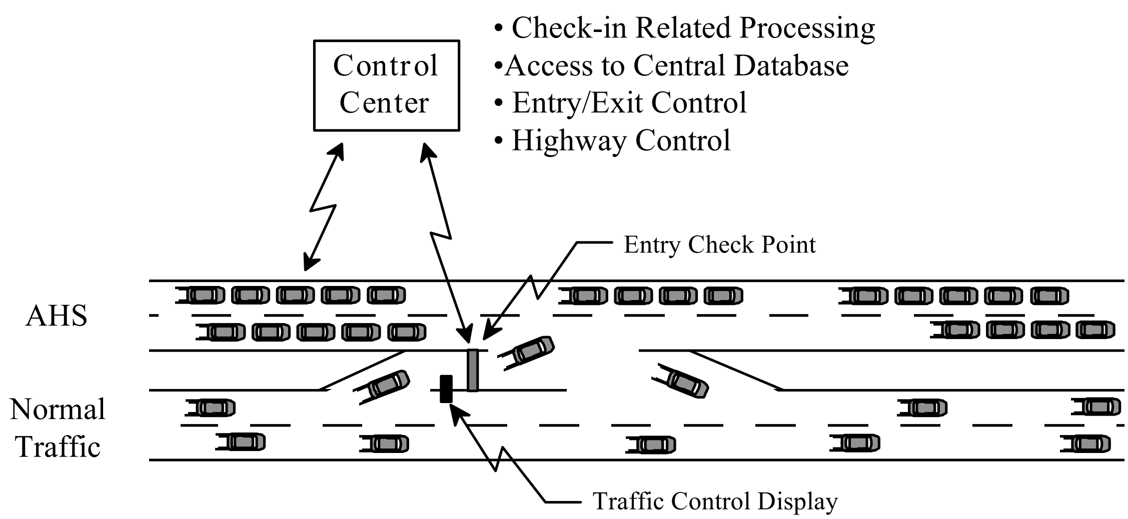
R.S. = Roadside Equipment
O.B. = On Board Equipment

Figure 3-17. Data Acquisition and Evaluation Options

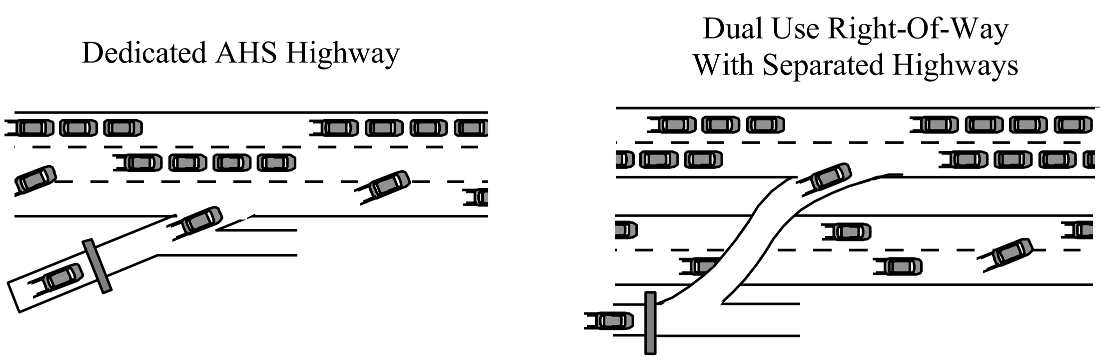
evaluation options. Though all the options were used, emphasis was placed on option '1'. Most vehicle health monitoring and BIT systems are implemented in this manner. In general, this emphasis is preferred when the required on-board processing will not result in a large increase in vehicle cost, the data traffic to and from the control center is minimized, and the load on the central processing capability is minimized. The other reason for favoring this assumption is to avoid the need to develop and maintain large national databases on vehicle characteristics including the normal operating bands of a wide range of systems. Given the number of vehicles introduced each year multiplied by the number of option levels for each vehicle, the maintenance of this databank will become a major effort.

3.3.1 Entry Implementation Approaches

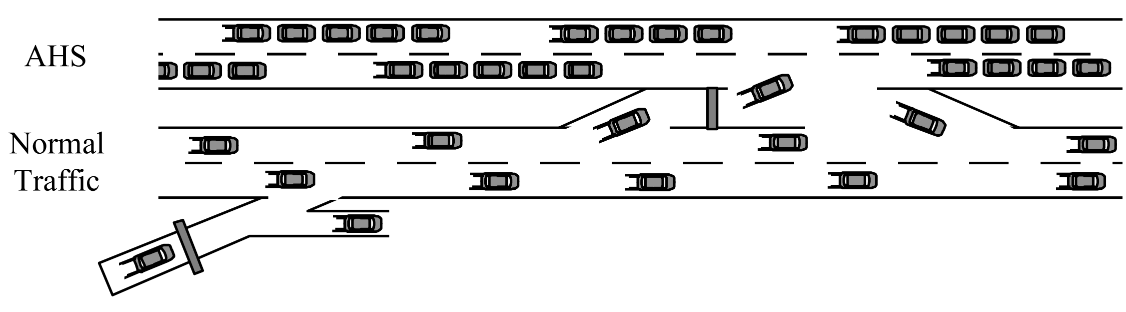
Three entry approaches were used for this analysis. They are: A) entry via a transition lane, B) direct entry to the AHS, and C) entry to a normal traffic lane followed by a transition lane. The last concept assumes all vehicles go through some level of safety check before entering the normal highway, with the vehicles desiring entry to the AHS entering a transition lane where additional AHS specific checks are performed. The possibility of using safety check stations for all highways is being considered by some states, with only Florida, of the states we contacted, giving it a serious look at this time. These three approaches are portrayed in figures 3-18a through 3-18c.



3-18a. Entry Implementation Approach A - Transition Lane



3-18b Entry Implementation Approach B - Direct To AHS



3-18c Entry Implementation Approach C - Pre-Check/Transition

Transition Lane Entry. Vehicle check-in in this case is accomplished in transition lanes which will permit entry to the AHS from the normal highway at periodic entry points. The driver receives instructions on how to proceed through roadway signs or via on-board displays including the possibility of a head-up display. Two-way RF communications will be established between the vehicle and control center at the check-in point or upon entry to the transition lane if instructions are displayed on-board. If communication cannot be immediately established, no checks will occur and the driver will be instructed to return to the normal highway via a road sign. The vehicle will be equipped with a transponder to provide the data link for these communications.

Direct Entry. Vehicle check-in is accomplished on the on-ramp to the AHS either at a check-in station or as the vehicle transits a particular section of the ramp. Indications will be given to the driver of a need to stop, slow down, or proceed at speed, as well as, whether the station or check-in ramp section is operational through roadway signs or via on-board displays. RF communications will be established at the check-in point or at the ramp entry if instructions are displayed on-board.

Pre-Check/Transition Lane. This approach is a variation on the Transition Lane Entry that would grow out of the development of entry safety checks for all vehicles entering a highway. In this case, some level of vehicle check-out would occur on the entry lane to the normal highway. At the entry point no communication is established between the vehicle and the AHS. All instructions would be via roadsigns. If a vehicle fails the entry safety test it will not be allowed entry to the non-AHS which would prevent entry to an AHS transition lane. Once on the normal highway, a vehicle would use a transition lane to enter the AHS. Communications would be established upon entry to the transition lane and vehicle checks not performed at the on-ramp would be completed as well as the transfer of operational information.

The entry ramp checks would have to potentially accommodate "smart and dumb" vehicles. For "smart" vehicles with transponders much of the information required for entry would be via on-board checks and stored data for transmission to the safety check system. For vehicles not so equipped, other means to check the vehicle would be required such as bar code readers and optical sensors. For the purposes of this study, the information checked at the on-ramp was assumed to be: Annual Safety Check current, lights, wipers, hitch & chains, brakes, and tires. Since this study is focused on an AHS system, it was assumed that the general on-ramp safety check point was able to use the same approaches for checking AHS compatible vehicles as a direct entry ramp would. Alternate systems to check non-AHS compatible systems were not looked at since they are not considered part of the AHS system.

3.3.2 Alternative Integrated Check-in Systems

The baseline and six alternate systems are shown in figure 3-19. These are discussed in sections 3.3.3 through 3.3.9. The baseline is as defined in section 3.1.2 and is based on the most highly rated approaches identified in the QFD analysis. For the baseline, it was assumed that all functions that could be performed on-board the vehicle were. This is representative of a smart car and is in line with vehicle technology trends and the approach assessments (section 3.2.1). The first alternate reverses this assumption to some extent and moves the driver/system interface to the infrastructure. The vehicle was not rendered truly "dumb" since this did not make sense in light of the trend toward vehicle based health monitoring systems independent of AHS and the assumptions that indicate the vehicle will contain on-board control systems (general assumptions 2 and 6). This alternative only moved those systems that would be add-on for the purposes of check-in to the infrastructure. The next four alternatives add different approaches for supplying, acquiring, and/or evaluating a specific information item(s). These were identified as potentially better approaches in the earlier assessment work (section 3.2.1). The last alternative investigates the impact of eliminating the certification station and putting additional test capability into the infrastructure, including an obstacle course.

Option	BIT	Certif. Station	Oper. Keys	Add-On Instru- ment.	Smart Card	Driver Interact.	ROM	Phys. Cond. Sensor	Unique Phys. Sig.	Audio Input	IR Sensor s
Baseline	X	X	X	X(w,t,h)	X	X					
Alt 1	X	X	X(i)	X(w,t,h)	X(i)	X(i)					
Alt 2	X	X	X	X(w,t,h)	X	X	X				
Alt 3	X	X	X	X(w,t,h)	X	X	X	X			
Alt 4	X	X	X	X(w,t,h)	X	X	X	X	X		
Alt 5	X	X	X	X(w,t,h)	X	X	X	X	X	X	
Alt 6*	X		X	X(w,t,h,p)	X	X	X				X

(i) = Infrastructure
(w) = Vehicle Weight Measurement
(t) = Tire Pressure
(h) = Hitch and Chain
(p) = Pressure Transducer, Strain Gauge, and Accelerometer to Obtain Component Data
* Obstacle course required

Figure 3-19. Baseline and Six Check-in Alternatives

Timelines. The times associated with performing the checks for the baseline and alternative systems are shown in figure 3-20 and will be described individually in the following sections. Numbers in the "Before" column refer to those pieces of information that can be "checked" prior to arriving at a check-in point. In general, such information includes travel input (destination, route selection) and Smart card-related information (driver's license, training, vehicle information). The "During" column in this figure represents the entire check-in process occurring at the check-in point, whether through a check-in station or transition lane (if applicable). In the "After" column, those items that can possibly be input after check-in is granted are shown. For this case, information relating to travel, specifically destination and route, is assumed to be input as the driver is on the AHS. The actual timelines by approach option for each alternative are shown in appendix D.

AHS OPTION	TRANSITION LANE	CHECK-IN STATION	TIME REQUIRED TO CHECK-IN*		
			Before	During	After
Baseline	Yes	Yes	2.02 sec.	15.02 sec.	8.02 sec.
Alternative #1	No	Yes	15.02	15.02	15.02
Alternative #2	Yes	Yes	2.02	12.02	5.02
Alternative #3	Yes	Yes	1.0	10.22	3.22
Alternative #4	Yes	Yes	1.0	10.42	3.42
Alternative #5	Yes	Yes	1.0	7.42	3.42
Alternative #6	No	Yes	5.0	15.0	8.0

* The time required to check in will differ depending on whether data can be checked and/or input prior to arriving at the check-in point, during the actual check-in, or after the vehicle has been granted access to the AHS.

Figure 3-20. AHS Alternatives and Required Check-in Times

Cost. Each of the entry options brings with it its associated cost. Within each design alternative described below are a listing of components required for implementation based on discussions with Northrop Grumman engineering. For each alternative design a figure is provided showing the total price of the alternative along with a distribution of the price by life cycle phase and sector. These prices were first order calculations based on the assumptions previously mentioned. Cost drivers and any perceived risks/issues are also discussed for each alternative. They are best available to date and may be updated to reflect improved data.

Costs were accounted for by the sector and phase depending on where the final costs would be paid. Costs to the user includes the purchase price of the AHS hardware, associated hardware maintenance, and semi-annual certification when applicable. Costs to business includes the development costs to develop the AHS hardware being installed by the user (see listing under User), the check-in roadside hardware (see listing under Government), the hardware required by the command center, and the certification test analyzer along with its associated inspection and maintenance. Businesses show low costs because their manufacturing expenses are recovered through sales to users. Costs to government include the development of software for the full-up BIT sequence described in section 3.2.1.1 and the data processing in the command center, the purchase price of the check-in site and command center hardware, and associated hardware and software maintenance. Costs to the public were not examined in depth in this study due to limited time and budget.

3.3.3 Baseline

Since there is duplication in terms of the ways a particular information item can be handled within the baseline integrated check-in system approach, the first step was to define what would be the primary method and what alternate methods would be available. These selections were made based on the approach assessments, human factors, convenience to the driver, safety considerations, and the trends in automotive system design and infrastructure development. The results are shown in figure 3-21.

If the vehicle is at the check-in point, it is assumed that RF communications have been established or the vehicle would have already been directed to the "escape" lane. At the entry point there is assumed to be an order of precedence for the checks to minimize the time-to-reject for a vehicle or driver that is not qualified for entry. The first check would validate that the driver is licensed and trained for AHS operations and is not impaired. If either check is failed the vehicle is immediately given a no-go and directed to the escape lane without further checks occurring. (What action should be taken for a driver who is found to be impaired is an issue which needs to be addressed.) For the baseline case, the driver information is supplied via a perennial smart card. The required information can be "burned" into a PROM on the card at a state motor vehicle department. Since the smart card reader is on-board the vehicle, the card can be read at vehicle start-up and the information stored in volatile memory for transmittal to the Control Center at check-in. The ability to pre-store data supports safety for on-the-fly entry by not requiring driver action at the check-in point. When the vehicle is turned off, the data is erased to maintain its security and the driver's privacy. If the vehicle volatile memory contains no smart card information, the vehicle would be rejected. A personal identification number is entered via the operator keys to verify the license belongs to the driver.

Impairment/Alertness is assessed by means of the driver repeating sequences in a specified time period using the operator keys. Though this method provides some measure of assessment, and has been successfully tested, it is not judged to be a fully adequate means to measure impairment. For instance, drivers who have a blood alcohol level that makes them legally drunk might not be sufficiently affected at the entry point to fail the test, but soon after entry, fall asleep as a result of the alcohol. Also, since this test would occur at entry, safety concerns due to driver distraction would tend to favor a full stop check-in. On-the-fly is potentially possible at a reduced speed if the display and entry keys are positioned so the driver can continue to monitor the road (glare shield mounted entry keys and head-up display for instance) and the test is short enough to minimize the time the driver is distracted.

The next check is to verify that the vehicle's AHS certification is current. This data is also entered via a smart card given to the driver when the check was completed. This data would most likely not be contained on the driver's personal card since multiple drivers may use the vehicle. The card contains the time duration and number of miles for which the certification is valid. The miles are checked against an electrical odometer reading. Again, if the certification has expired, the vehicle is immediately rejected without further checks occurring. In order to verify that the smart card does in fact belong to the vehicle at the check-in point, a vehicle serial number would have to appear on the smart card that corresponds to the vehicle's identification number. As discussed in the acquisition approach assessment section all the required information is assumed to be present on the smart card vs. residing in a national database. This is assessed to be the most efficient way to implement the AHS system.

Baseline Critical Information	BIT	Certif. Stat.	Operator Keys	Add-On Instrument-ation	Smart Card	Driver Interaction	Standard Vehicle Instrumentation	Driver Awareness
Driver Qualifications								
Driver's License/Training			C		P			
Impairment/Alertness						P		
Vehicle Characteristics								
Vehicle Type			A		P			
Entry Weight				P				
Dimensions			A		P			
Vehicle Regulatory								
AHS System Certification					P			
Safety Systems								
Hitch & Safety Chain	P			C				
Warnings/Advisories	P							A
BIT System		P						
Steering/Braking								
Braking System	V	P					C	
Steering System	V	P						
Automated Control Systems								
Actuators	V	P						
Sensors	P	CR						
Communication Equipment	P	CR						
Operator Interface	P	CR				A		
Computer Systems	P	CR						
System Integration	P	CR						
Propulsion & Drive Train								
Tire Pressure/Condition	P (Press.)	P (Cond.)		C				A
Driver Information Systems								
Enunciator Panel	P							A
Desirable Information								
Trip Plan								
Destination			P		A	A		
Preferred Route			P		A	A		
Time Arrival			P		A	A		
Selected Route			A		A	P		
Vehicle Regulatory								
Scheduled Maintenance Certificate					P			
Safety Systems								
Lights	P							A
Wipers	P							A
Useful Information	**BIT**	**Certif. Stat.**	**Operator Keys**	**Add-On Instrument-ation**	**Smart Card**	**Driver Interaction**	**Standard Vehicle Instrumentation**	**Driver Awareness**
Trip Plan								
Estimated Fuel Required			P					
Vehicle Characteristics								
Cargo Type					P			
Weight Distribution				P (Opt.)				
Vehicle Regulatory								
Annual Safety Check					P			
Propulsion & Drive Train								
Engine Performance	P	CR					C	A
Fuel Level	P						C	A
Ambivalent Information								
Vehicle Characteristics								
Fuel Type			A		P	A		
Propulsion & Drive Train								
Wheel Alignment/Balance		P						A
Suspension	V (Act.)	P						A
Coolant Temperature	P						C	A
Alternator & Electrical System	P	CR						A
Oil Pressure	P						C	A
Driver Information Systems								
Gauges	P							A
Speedometer	P	CR						A

P - Primary Method
A - Alternate Method Available
C - In Conjunction with Pimary Method
V - Verify to Extent Possible at Check-in that Certified Components are Still Good
CR - Certify System Operating within Design Ranges
D - Dual Check, Use Two Sources at Chech-in
NC - Not Checked

Figure 3-21. Baseline Check-in Systems

If both the previous checks are passed, the control system sends a signal to the vehicle to initiate the BIT system. This would perform all the noted checks including "nudging" the brakes, automated lateral control system, and engine to ensure that actuators are responding to system inputs. No large system deflections, such as would be performed using a obstacle course, are made due to the extensive checks completed as part of the periodic certification. The items listed under BIT as a 'V' imply that the test system will check those components of the system that are electrical in nature to provide some validation or back-up check to the certification. This includes the "nudging" of the actuators as noted earlier and can go as far as the suspension if it is an active system. The items noted as 'CR' under certification station imply that the BIT system checks the operation of the systems at check-in, but cannot perform tests on all operating parameters. For instance, systems like RF sensors may require special test equipment to fully calibrate. These tests will be performed at the certification station. If BIT system has failed in total or in a critical part, the Control Center will receive a signal to this effect (or not receive an initiation confirmation) and immediately reject the vehicle.

It was also assumed that the outputs of both the standard vehicle instrumentation and add-on instrumentation are evaluated on-board the vehicle to ensure they are within safe operating ranges as part of the BIT. This is indicated in the charts by a 'P' for the BIT system with a 'C' in the standard vehicle instrumentation or add-on column (Data Flow Path Option 1). The output of these sensors is an electrical signal and can be easily tied into the BIT system. The add-on instrumentation determines vehicle weight, verifies hitch and chain connection if required, and checks tire pressure. Adding weight sensing capability to the vehicle is seen as the preferred approach. The required components are inexpensive and the implementation simple and in use on many load carrying vehicles. The alternative, to build weighing capability into every entry point, would unnecessarily add to the complexity of the infrastructure and add substantial cost in terms of development, installation, and maintenance. In addition, if the weighing system on-board the vehicle fails, one car is rejected; if a roadside system fails and no alternative is available, part or all of an entry point is closed. Tire life is assumed to be one of the bases for setting the mileage limit on the certification. The issue, as always, with on-board installation is the design, development and manufacturing cost and time for the additional system, and the cost to the user to purchase the vehicle.

Tire pressure is assumed to be checked by means of an on-board pressure transducer with the output evaluated by the BIT. The addition of this capability was felt necessary to ensure safe operation. Although tire condition is one of the bases for setting the mileage limit on the certification, under inflation is also critical since it can eventually result in tire failure. Given the high speeds planned for an AHS, a failure may occur in a shorter time span than under normal driving conditions. A recent issue of Automotive Engineering states that by the year 2013, "...10% (of vehicles) will have tire failure sensing devices, 15% will use puncture-resistant tires, and 10% will be equipped with run-flat tires."[2] These capabilities will help to decrease the overall cost of additional AHS components since the technology will already be resident on some vehicles.

No prediction is offered as to what will constitute "Standard Vehicle Instrumentation" in 2010. It is expected that this will go well beyond present sensors. For instance, some automobile manufacturers are developing imbedded sensors for brake pads which would permit monitoring of this aspect of the brake system. The existence of such systems will smooth the transition to an AHS by reducing the scope of the modifications required for AHS operations and consequently the percent of purchase cost directly attributable to AHS specific equipment.

Note that the only information item from all four categories not checked or obtained by the baseline integrated check-in system is weight distribution. This information can be obtained by the proper design of the weighing system. However, since this information was not rated as "critical" or "desirable" it was assumed to be an optional capability available to the purchaser.

Once a "System Okay" is received by the Control System, the driver will be prompted to enter trip and vehicle related data or prompt its transmission from on-board volatile memory if pre-stored. This data will permit the Control System to plan the entry timing and route of the vehicle as well as matching its performance to a platoon if this type of operation is in place. This information will be entered via operator keys. Some driver interaction may occur if the Control Center offers options based on road conditions. The driver would then select from a menu. Once the data is entered the vehicle is released for entry onto the AHS by whatever manner the AHS is designed to take control of the vehicle.

For this baseline system, the time required to check-in is heavily dependent on when information can be obtained. For example, if all data must be entered at the check-in point, then the time required for check-in would be approximately 15.02 seconds. According to the queuing analysis, if check-in is occurring via a check-in station, the resultant queue length and vehicle waiting time associated with 15 seconds is extremely large if two or less check-in stations are available (see figures 3-11 and 3-12). The main contributors to this time value are the travel-related inputs via operator keys and driver interaction (destination, selected route) and Smart card insertion. However, if the information is input either before or after the check-in point, the time required to check-in is drastically reduced by approximately 87% and 47%, respectively. The primary issues with this integrated system approach are:

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[2] Holt, Daniel J., "Model Year 2013", Automotive Engineering, June 1994, pg. 6

1. How well alertness/impairment can be checked using driver interaction with the Central System. From a safety standpoint this probably makes any option other then full-stop unattractive. The driver's attention would be distracted from driving for too long.

2. Safety issues associated with requiring any driver action if entry is on-the-fly even at reduced speeds.

3. Smart card security using only PIN numbers, which can be stolen. What level of positive identification of the driver required?

4. The inconvenience of potentially having to use multiple smart cards (personal and vehicle) and having to key in data.

5. It is felt, based on aircraft experience, that the use of a periodic certification approach and BIT would provide the needed confidence that the vehicle would be safe to enter and operate on the AHS. The use of BIT will provide a re-check to some extent of many of the certified items. However, if the means to "double-check" more of the key parameters is desired, what would be the impact?

The Baseline design used the groundrules and assumptions listed in section 2.2.4 along with the following systems to estimate costs shown in figure 3-22:

User	Business	Government
RF Transponder	Certification Test Set	Roadside Receiver
Smart Card		Traffic Control Display
Data Entry Panel		Command Control Center
Add-On Instrumentation		Smart Card Reader
		Software

Cost drivers for the users in this design included the add-on instrumentation, data entry panel, and the semi-annual certification requirement. The main cost drivers for the government were software development and maintenance, the traffic control display, and check-in site maintenance. Primary areas of uncertainty and risk reside in the software requirements and in the estimation of development costs.

Concept: Baseline

COST $1.298B (1994$) Los Angeles County

	DEVELOPMENT	PURCHASE/ PRODUCE	O & M (2 YRS)	TOTAL
USER	0%	34%	20%	54%
BUSINESS	1%	7%	0%	8%
GOV'T	24%	5%	9%	38%
PUBLIC	Provide Funds for Gov't			
TOTAL	25%	46%	29%	100%

Cost Drivers

- Add-on Instrumentation, Data Entry Panel Purchase Price
- User Certification Costs
- Traffic Control Display Purchase Price
- Software Development & Maintenance Costs
- Check-In Site Maintenance Costs

Risks/Issues

- Software Development Requirements
- Groundrule and Scenario Alignment With Official AHS Plans
- Development Costs Require Further Analysis

Figure 3-22. Baseline Cost Analysis

3.3.4 Alternate 1

This alternative is the same as the baseline in terms of the information acquisition approaches used with the exception of picking the off-board options (see figure 3-23). This option would require a full stop check since all operator keys, smart card readers, and driver interaction functions are moved into a check station. The driver would enter the station and the check sequence would proceed in exactly the same manner as before, beginning with the driver inserting his personal smart card into the off-board card reader.

The time to perform the check increases significantly compared to other alternatives since there is no option of entering data either before or after the check-in request. In fact, this alternative requires the most time at 15.02 seconds. Additionally, this alternative is only available with a check-in station; a transition lane would not be an option here since most of the equipment required for this alternative resides in the infrastructure and would be located at specific entry points along the AHS. Requiring a full-stop on a transition lane would result in a safety hazard if traffic backed up onto the normal road, not to mention the associated traffic delays. The lane lengths required to handle heavy arrival traffic at the transition lane as calculated in the queuing analysis are most likely prohibitively expensive in both dollars and real-estate terms. Therefore, when comparing the queuing effects in section 3.2.4 in association with a check-in time of 15.02 seconds, this alternative is highly inefficient.

The baseline issues still exist. Additional problems arise in terms of dropped smart cards and weather conditions since the driver would have to perform the entry operations through an open window. The entry station would need to accommodate different height vehicles, or multiple stations designed to handle the different vehicle types would be required.

Alternate 1 Critical Information	BIT	Certification Station	Operator Keys	Add-On Instrument-ation	Smart Card	Driver Interaction	Standard Vehicle Instrumentation	Driver Awareness
Driver Qualifications								
Driver's License/Training			C		P			
Impairment/Alertness						P		
Vehicle Characteristics								
Vehicle Type			A		P			
Entry Weight				P				
Dimensions			A		P			
Vehicle Regulatory								
AHS System Certification					P			
Safety Systems								
Hitch & Safety Chain	P			C				
Warnings/Advisories	P							A
BIT System		P						
Steering/Braking								
Braking System	V	P					C	
Steering System	V	P						
Automated Control Systems								
Actuators	V	P						
Sensors	P	CR						
Communication Equipment	P	CR						
Operator Interface	P	CR				A		
Computer Systems	P	CR						
System Integration	P	CR						
Propulsion & Drive Train								
Tire Pressure/Condition	P (Press.)	P (Cond.)		C				A
Driver Information Systems								
Enunciator Panel	P							A
Desirable Information								
Trip Plan								
Destination			P		A	A		
Preferred Route			P		A	A		
Time Arrival			P		A	A		
Selected Route			A		A	P		
Vehicle Regulatory								
Scheduled Maintenance Certificate					P			
Safety Systems								
Lights	P							A
Wipers	P							A
Useful Information	BIT	Certification Station	Operator Keys	Add-On Instrument-ation	Smart Card	Driver Interaction	Standard Vehicle Instrumentation	Driver Awareness
Trip Plan								
Estimated Fuel Required			P					
Vehicle Characteristics								
Cargo Type					P			
Weight Distribution				P (Opt.)				
Vehicle Regulatory								
Annual Safety Check					P			
Propulsion & Drive Train								
Engine Performance	P	CR					C	A
Fuel Level	P						C	A
Ambivalent Information								
Vehicle Characteristics								
Fuel Type			A		P	A		
Propulsion & Drive Train								
Wheel Alignment/Balance		P						A
Suspension	V (Act.)	P						A
Coolant Temperature	P						C	A
Alternator & Electrical System	P	CR						A
Oil Pressure	P						C	A
Driver Information Systems								
Gauges	P							A
Speedometer	P	CR						A

P - Primary Method
A - Alternate Method Available
C - In Conjunction with Pimary Method
V - Verify to Extent Possible at Check-in that Certified Components are Still Good
CR - Certify System Operating within Design Ranges
D - Dual Check, Use Two Sources at Chech-in
NC - Not Checked

Figure 3-23. Alternate 1 Check-in Systems

Making investments to put the system interfaces in the infrastructure may not make sense since various systems already found on many vehicles have many of the desired functional capabilities. This includes on-board navigation systems, trip computers, and on-board smart card readers for toll collection. The IVHS initiatives in these areas will only serve to accelerate this trend. On the other hand, this alternative may have to be implemented in conjunction with a system like the baseline to ensure universal access. The cost of upgrading the low end vehicles may make it prohibitive, and if full retrofit to all vehicles on the road is not available, then some entry points would have to offer an alternate means of entry.

The Alternate 1 design used the groundrules and assumptions listed in section 2.2.4 along with the following systems to estimate costs shown in figure 3-24:

User	Business	Government
RF Transponder	Certification Test Set	Roadside Receiver
Smart Card		Traffic Control Display
ROM		Command Control Center
Add-On Instrumentation		Data Entry Panel
		Smart Card Reader
		Software

Concept: Alternative 1

COST	$1.166B (1994$) Los Angeles County			
	DEVELOPMENT	PURCHASE/ PRODUCE	O & M (2 YRS)	TOTAL
USER	0%	28%	22%	50%
BUSINESS	1%	8%	0%	9%
GOV'T	26%	6%	9%	41%
PUBLIC	Provide Funds for Gov't			
TOTAL	27%	42%	31%	100%

Cost Drivers

- Add-on Instrumentation Purchase Price
- User Certification Costs
- Software Development & Maintenance Costs
- Check-In Site Maintenance Costs
- Traffic Control Display Purchase Price

Risks/Issues

- Software Development Requirements
- Groundrules and Scenario Alignment With Official AHS Plans
- Development Costs Need Further Analysis

Figure 3-24. Alternate 1 Cost Analysis

In this alternative, the majority of the check-in functions reside in the infrastructure, so costs to purchase AHS equipment were decreased for the user. However, semi-annual certification was a cost driver to users in the O & M phase. Main cost drivers for the government were software development and maintenance, the traffic control display price, and check-in site maintenance. Primary areas of uncertainty and risk reside in the software requirements and in the estimation of development costs.

3.3.5 Alternate 2

This alternative is in essence a trivial change, but with a payback in terms of safety and convenience, and with a small cost impact to the manufacturer. ROMs are common processor components and do not truly add anything new to the vehicle in terms of hardware. The only reason this technology was not included in the baseline is that in following the QFD process, the baseline is defined by starting with the highest scoring approach and working down the approach list in descending order until all information items can be checked; ROMs did not make this initial cut.

The use of a ROM device "burned" permanently with static data will eliminate the need for any smart cards other than the driver's personal card. It also adds a level of security since the data on the resident ROM cannot be changed, and in order to create a new ROM, special equipment would be required. This equipment exists, but is not widely available. Protections could also be built into the software to detect unauthorized replacement of a ROM. The information to be stored on a ROM device is shown in figure 3-25. This component will be a factory installed item whose primary role will be to store the vehicle characteristic data. Certification stations can also use these devices to record test results by using a PROM (Programmable ROM).

The time impact of this change is directly correlated to the amount of time that it takes to read vehicle information with a smart card or with the ROM device. Specifically, the time required in using a ROM device to read particular vehicle information, such as vehicle type, dimensions, and safety check validity, is virtually instantaneous as opposed to the use of the smart card, which requires human interaction and therefore more time.

The addition of the ROM eliminates baseline concern number 4 (inconvenience of multiple smart cards) and addresses baseline concern number 3 (smart card security) for some forms of information as listed under the baseline.

Alternate 2 Critical Information	BIT	Certification Station	Operator Keys	Add-On Instrument-ation	Smart Card	Driver Interaction	ROM	Standard Vehicle Instrumentation	Driver Awareness
Driver Qualifications									
Driver's License/Training			C		P				
Impairment/Alertness						P			
Vehicle Characteristics									
Vehicle Type							P		
Entry Weight				P					
Dimensions							P		
Vehicle Regulatory									
AHS System Certification							P		
Safety Systems									
Hitch & Safety Chain	P			C					
Warnings/Advisories	P								A
BIT System		P							
Steering/Braking									
Braking System	V	P							
Steering System	V	P							
Automated Control Systems									
Actuators	V	P							
Sensors	P	CR							
Communication Equipment	P	CR							
Operator Interface	P	CR				A			
Computer Systems	P	CR							
System Integration	P	CR							
Propulsion & Drive Train									
Tire Pressure/Condition	P (Press.)	P (Cond.)		C					A
Driver Information Systems									
Enunciator Panel	P								A
Desirable Information									
Trip Plan									
Destination			P		A	A			
Preferred Route			P		A	A			
Time Arrival			P		A	A			
Selected Route			A		A	P			
Vehicle Regulatory									
Scheduled Maintenance Certificate							P		
Safety Systems									
Lights	P								A
Wipers	P								A
Useful Information	BIT	Certification Station	Operator Keys	Add-On Instrument-ation	Smart Card	Driver Interaction	ROM	Standard Vehicle Instrumentation	Driver Awareness
Trip Plan									
Estimated Fuel Required			P						
Vehicle Characteristics									
Cargo Type					P		A		
Weight Distribution				P (Opt.)					
Vehicle Regulatory									
Annual Safety Check					P				
Propulsion & Drive Train									
Engine Performance	P	CR						C	A
Fuel Level	P							C	A
Ambivalent Information									
Vehicle Characteristics									
Fuel Type			A		A	A	P		
Propulsion & Drive Train									
Wheel Alignment/Balance		P							A
Suspension	V (Act.)	P							A
Coolant Temperature	P							C	A
Alternator & Electrical System	P	CR							A
Oil Pressure	P							C	A
Driver Information Systems									
Gauges	P								A
Speedometer	P	CR							A

P - Primary Method
A - Alternate Method Available
C - In Conjunction with Pimary Method
V - Verify to Extent Possible at Check-in that Certified Components are Still Good
CR - Certify System Operating within Design Ranges
D - Dual Check, Use Two Sources at Chech-in
NC - Not Checked

Figure 3-25. Alternate 2 Check-in Systems

The Alternate 2 design used the groundrules and assumptions listed in section 2.2.4 along with the following systems to estimate costs shown in figure 3-26:

User	Business	Government
RF Transponder	Certification Test Set	Roadside Receiver
Smart Card		Traffic Control Display
Smart Card Reader		Command Control Center
Data Entry Panel		Software
ROM		
Add-On Instrumentation		

Alternate 2 cost drivers for the users included the add-on instrumentation, data entry panel, and the cost of semi-annual certification. The main cost drivers for the government were software development and maintenance, the traffic control display, and check-in site maintenance. Primary areas of uncertainty and risk reside in the software requirements and in the estimation of development costs.

Concept: Alternative 2

COST $1.390B (1994$) Los Angeles County

	DEVELOPMENT	PURCHASE/ PRODUCE	O & M (2 YRS)	TOTAL
USER	0%	40%	20%	60%
BUSINESS	1%	7%	0%	8%
GOV'T	22%	3%	7%	32%
PUBLIC	Provide Funds for Gov't			
TOTAL	23%	50%	27%	100%

Cost Drivers

- Add-on Instrumentation, Data Entry Panel Purchase Price
- User Certification Costs
- Software Development & Maintenance Costs
- Check-In Site Maintenance Costs
- Traffic Control Display Purchase Price

Risks/Issues

- Software Development Requirements
- Groundrule and Scenario Alignment With Official AHS Plans
- Development Costs Need Further Analysis

Figure 3-26. Alternate 2 Cost Analysis

3.3.6 Alternate 3

Alternate 3 proposes a means to eliminate baseline issue number 1, the effective determination of driver impairment/alertness, through the addition of a Physical Condition Sensor. This sensor would only support this one function (figure 3-27) which is the reason its QFD score was low. However, it may be the only way to determine physical condition with the desired level of confidence. For this reason, a special purpose sensor should be a consideration. Considerable research is underway to explore ways to monitor the physical condition of pilots and drivers, as was stated in section 3.2.1.8. To the extent literature is available on this often proprietary research, there is little doubt that systems will be developed by 2010 which can achieve the desired goals. The concern is more with cost, size, and acceptance of the system if the driver, for instance, is forced to wear some sort of device. There is also a large invasion of privacy concern. However, according to the survey results, users are more concerned with unsafe drivers entering the AHS and would prefer that these drivers are identified and prevented from doing so.

With the addition of the physical condition sensor in this alternative, the time required to check for impairment or alertness of a driver is reduced significantly. In the previous alternatives and baseline, this function was performed through driver interaction. Again, with a system utilizing less human interaction, the time decreases. In this case, there is also the potential to obtain information before or after check-in, which further reduces the time requirement.

The use of sensors specifically designed to determine driver impairment and alertness will provide a highly reliable means to determine this critical piece of information. If produced in the volumes associated with automobiles, trucks, and buses the cost will most likely come down into a reasonable range. The primary obstacle will be user acceptance.

Alternate 3 Critical Information	BIT	Certification Station	Operator Keys	Add-On Instrument-ation	Smart Card	Driver Interaction	ROM	Physical Condition Sensor	Standard Vehicle Instrumentation	Driver Awareness
Driver Qualifications										
Driver's License/Training			C		P					
Impairment/Alertness								P		
Vehicle Characteristics										
Vehicle Type							P			
Entry Weight				P						
Dimensions							P			
Vehicle Regulatory										
AHS System Certification							P			
Safety Systems										
Hitch & Safety Chain	P			C						
Warnings/Advisories	P									A
BIT System		P								
Steering/Braking										
Braking System	V	P								
Steering System	V	P								
Automated Control Systems										
Actuators	V	P								
Sensors	P	CR								
Communication Equipment	P	CR								
Operator Interface	P	CR				A				
Computer Systems	P	CR								
System Integration	P	CR								
Propulsion & Drive Train										
Tire Pressure/Condition	P (Press.)	P (Cond.)		C						A
Driver Information Systems										
Enunciator Panel	P									A
Desirable Information										
Trip Plan										
Destination			P		A	A				
Preferred Route			P		A	A				
Time Arrival			P		A	A				
Selected Route			A		A	P				
Vehicle Regulatory										
Scheduled Maintenance Certificate							P			
Safety Systems										
Lights	P									A
Wipers	P									A
Useful Information	BIT	Certification Station	Operator Keys	Add-On Instrument-ation	Smart Card	Driver Interaction	ROM	Physical Condition Sensor	Standard Vehicle Instrumentation	Driver Awareness
Trip Plan										
Estimated Fuel Required			P							
Vehicle Characteristics										
Cargo Type					P		A			
Weight Distribution				P (Opt.)						
Vehicle Regulatory										
Annual Safety Check					P					
Propulsion & Drive Train										
Engine Performance	P	CR							C	A
Fuel Level	P								C	A
Ambivalent Information										
Vehicle Characteristics										
Fuel Type			A		A	A	P			
Propulsion & Drive Train										
Wheel Alignment/Balance		P								A
Suspension	V (ACT.)	P								A
Coolant Temperature	P								C	A
Alternator & Electrical System	P	CR								A
Oil Pressure	P								C	A
Driver Information Systems										
Gauges	P									A
Speedometer	P	CR								A

P - Primary Method
A - Alternate Method Available
C - In Conjunction with Pimary Method
V - Verify to Extent Possible at Check-in that Certified Components are Still Good
CR - Certify System Operating within Design Ranges
D - Dual Check, Use Two Sources at Chech-in
NC - Not Checked

Figure 3-27. Alternate 3 Check-in Systems

The Alternate 3 design used the groundrules and assumptions listed in section 2.2.4 along with the following systems to estimate costs shown in figure 3-28:

User	Business	Government
RF Transponder	Certification Test Set	Roadside Receiver
Smart Card		Traffic Control Display
Data Entry Panel		Smart Card Reader
ROM		Command Control Center
Add-On Instrumentation		Software
Physical Condition Sensor		

Alternate 3 cost drivers for the users included the physical condition sensor, add-on instrumentation and AHS equipment maintenance. The main cost drivers for the government were software development and maintenance, the traffic control display, and check-in site maintenance. Primary areas of uncertainty and risk reside in the software requirements, in technology development for the physical condition sensor, and in the estimation of development costs.

Concept: Alternative 3

COST $1.800B (1994$) Los Angeles County

	DEVELOPMENT	PURCHASE/ PRODUCE	O & M (2 YRS)	TOTAL
USER	0%	51%	17%	68%
BUSINESS	1%	5%	0%	6%
GOV'T	17%	3%	6%	26%
PUBLIC	Provide Funds for Gov't			
TOTAL	18%	59%	23%	100%

Cost Drivers

- Physical Condition Sensor, Add-on Instrumentation Purchase Price
- User Certification Costs
- Software Development & Maintenance Costs
- Check-In Site Maintenance Costs
- Traffic Control Display Purchase Price

Risks/Issues

- Physical Condition Sensor Technology Development
- Software Development Requirements
- Groundrule and Scenario Alignment With Official AHS Plans
- Development Costs Need Further Analysis

Figure 3-28. Alternate 3 Cost Analysis

3.3.7 Alternate 4

Similar to Alternate 3, this alternate adds a sensor capability to address one of the baseline issues. In this case, an approach to gain a high confidence driver identification. As shown in figure 3-29 this sensor would work in concert with the smart card. Driver identification was one of the more controversial issues in both the QFD analysis and the user survey work due to privacy issues. Interestingly, the opinions as to whether AHS should provide policing information tended to be strong one way or the other. The key questions are: 1) is it important to determine that the driver is currently licensed? 2) is it critical to obtain this information if no AHS specialized training is necessary? 3) does verification warrant employing highly secure approaches? and 4) how is the verification handled? The answer to the first question is yes. Since some driver interaction will be necessary to enter and exit the highway, and most likely to respond to emergency situations, it is important to verify that the driver is currently "AHS" licensed. The answer to the second question is not as easy. Though it is felt that it is important to verify the driver is licensed, it is not critical barring the need for extensive training in driver involved emergency actions to ensure safety. Based on material available on alternative proposals for implementing an AHS, it appears that extensive training will not be necessary. If verification is not critical, then the answer to the third question is probably that no "extreme" measures need to be taken to ensure a positive identification. This would eliminate the need and desirability of this alternative.

One last note on this subject is how the verification of the driver's license would occur. It could be implemented such that the data on the smart card is read and verified against a national database on license status and a "thumbs up" given to the control center. At this point the specific information is deleted and no record of the entry is maintained. This provides the maximum level of privacy given that a check is required. Similarly, a system that uses unique physical characteristics could verify that the person driving the car is the person on the license after which the data is again purged.

Alternate 4 Critical Information	BIT	Certification Station	Operator Keys	Add-On Instrument-ation	Smart Card	Driver Interaction	ROM	Physical Condition Sensor	Unique Physical Signature	Standard Vehicle Instrumentation	Driver Awareness
Driver Qualifications											
Driver's License/Training			C		P				C		
Impairment/Alertness								P			
Vehicle Characteristics											
Vehicle Type							P				
Entry Weight				P							
Dimensions							P				
Vehicle Regulatory											
AHS System Certification							P				
Safety Systems											
Hitch & Safety Chain	P			C							
Warnings/Advisories	P										A
BIT System		P									
Steering/Braking											
Braking System	V	P									
Steering System	V	P									
Automated Control Systems											
Actuators	V	P									
Sensors	P	CR									
Communication Equipment	P	CR									
Operator Interface	P	CR				A					
Computer Systems	P	CR									
System Integration	P	CR									
Propulsion & Drive Train											
Tire Pressure/Condition	P (Press.)	P (Cond.)		C							A
Driver Information Systems											
Enunciator Panel	P										A
Desirable Information											
Trip Plan											
Destination			P		A	A					
Preferred Route			P		A	A					
Time Arrival			P		A	A					
Selected Route			A		A	P					
Vehicle Regulatory											
Scheduled Maintenance Certificate							P				
Safety Systems											
Lights	P										A
Wipers	P										A
Useful Information	BIT	Certification Station	Operator Keys	Add-On Instrument-ation	Smart Card	Driver Interaction	ROM	Physical Condition Sensor	Unique Physical Signature	Standard Vehicle Instrumentation	Driver Awareness
Trip Plan											
Estimated Fuel Required			P								
Vehicle Characteristics											
Cargo Type					P		A				
Weight Distribution				P (Opt.)							
Vehicle Regulatory											
Annual Safety Check					P						
Propulsion & Drive Train											
Engine Performance	P	CR								C	A
Fuel Level	P									C	A
Ambivalent Information											
Vehicle Characteristics											
Fuel Type			A		A	A	P				
Propulsion & Drive Train											
Wheel Alignment/Balance		P				C					A
Suspension	V (Act.)	P									A
Coolant Temperature	P									C	A
Alternator & Electrical System	P	CR									A
Oil Pressure	P									C	A
Driver Information Systems											
Gauges	P										A
Speedometer	P	CR									A

P - Primary Method
A - Alternate Method Available
C - In Conjunction with Pimary Method
V - Verify to Extent Possible at Check-in that Certified Components are Still Good
CR - Certify System Operating within Design Ranges
D - Dual Check, Use Two Sources at Chech-in
NC - Not Checked

Figure 3-29. Alternate 4 Check-in Systems

Unique physical signature identification approaches are currently in use (fingerprints) for some purposes, and research is underway to develop new methods and alternate applications for existing approaches. These devices will provide a more secure, positive identification of the driver. It is a reasonable assumption then, that this technology can be adapted for use with the check-in process either by placing an identification system in a check-in station or directly in the vehicle. Specifically for this alternative, we have assumed installation within the car to support on-the-fly check-in. As discussed in alternative one, any approach which requires the driver to stop at a station is much less desirable due to the impact on flow onto the highway. The availability of an on-vehicle system was also assumed to be a reasonable assumption since much of the impetus for the development of these systems will come from vehicle security issues regardless of the existence of an AHS.

There is virtually no impact on time to check-in with the addition of this sensor compared with the previous description of Alternate 3. The identification check is quick and happens concurrently with other checks. The use of sensors specifically designed to positively identify the driver will provide a highly reliable means to determine this information item. If produced in the volumes associated with automobiles, trucks, and buses, the cost will most likely come down into a reasonable range. The primary obstacle will be user acceptance due to privacy issues. The need for this level of positive identification is an issue which needs to be addressed.

The Alternate 4 design used groundrules and assumptions listed in section 2.2.4 along with the following systems to estimate costs shown in figure 3-30:

User	Business	Government
RF Transponder	Certification Test Set	Roadside Receiver
Smart Card		Traffic Control Display
Smart Card Reader		Command Control Center
Data Entry Panel		Software
ROM		
Add-On Instrumentation		
Physical Condition Sensor		
Unique Physical Signature		

Concept: Alternative 4

COST $1.914B (1994$) Los Angeles County

	DEVELOPMENT	PURCHASE/ PRODUCE	O & M (2 YRS)	TOTAL
USER	0%	52%	17%	69%
BUSINESS	1%	5%	0%	6%
GOV'T	16%	3%	6%	25%
PUBLIC	Provide Funds for Gov't			
TOTAL	17%	60%	23%	100%

Cost Drivers
- Physical Condition /Unique Physical Signature Sensor, Add-on Instrumentation Purchase Price
- User Certification Costs
- Software Development & Maintenance Costs
- Check-In Site Maintenance Costs
- Traffic Control Display Purchase Price

Risks/Issues
- Physical Condition/Unique Physical Signature Sensor Development
- Software Development Requirements
- Groundrule and Scenario Alignment With Official AHS Plans

Figure 3-30. Alternate 4 Cost Analysis

Cost drivers in this alternative for the users included the physical condition sensor, the unique physical signature sensor, add-on instrumentation, and AHS equipment maintenance. The main cost drivers for the government were software development and maintenance, the traffic control display, and check-in site maintenance. Primary areas of uncertainty and risk reside in the software requirements, in technology development for the physical condition and unique physical signature sensors, and in the estimation of development costs.

3.3.8 Alternate 5

This alternative directly addresses issues 2 and 4 related to safety and convenience by adding audio input as the means for much of the data entry. Again, the system is assumed to be on-board the vehicle to support on-the-fly check-in. Empirical evidence suggests a separation of spatial and auditory human information processing channels. Therefore, where additional tasks must be performed, they should be designed so as not to overload the spatial channel, which is already taxed by driving. If data entry can occur via voice inputs, coupled with audio prompts, then driver distraction will be minimized.

Information input tasks such as destination are good candidates for interactive speech. Also, since audio input is eliminating the need for the driver to enter data via keys and buttons, the overall intrusiveness of the AHS system is reduced which will increase driver acceptance. However, the other entry methods need to be maintained as alternatives to support drivers with impaired hearing. Non-English speaking drivers also raise an additional consideration. Figure 3-31 shows where the use of audio input is proposed.

On-going research of audio input technology is expected to accelerate in the next few years, which will continue to eliminate the limitations associated with audio input; hence, a fully capable system could be installed in AHS compliant vehicles. Two concerns are limited vocabulary and word recognition in a noise "cluttered" environment. Significant progress has been made in both areas in recent years as evidenced by the marketing of voice activated personal computers and voice activated telephone card systems.

Since the use of audio input is primarily for trip input, including destination and routing, operator keys are no longer necessary to perform this function. Therefore, the time associated with this alternative decreases. In fact, if all data is entered at the check-in point, Alternate 4 (along with Alternate 5) yield the smallest required check-in time. When considering the queuing analysis, these two alternatives are basically the only acceptable scenarios if a check-in station is utilized and vehicles must stop in order to check-in during a peak period traffic flow.

Alternate 5 Critical Information	BIT	Certif. Station	Operator Keys	Add-On Instru-mentation	Smart Card	Driver Interact.	ROM	Physical Condition Sensor	Unique Physical Signature	Audio Input	Standard Vehicle Instru.	Driver Aware.
Driver Qualifications												
Driver's License/Training					P				C	A/C		
Impairment/Alertness								P				
Vehicle Characteristics												
Vehicle Type							P					
Entry Weight				P						A		
Dimensions							P					
Vehicle Regulatory												
AHS System Certification							P					
Safety Systems												
Hitch & Safety Chain	P			C								A
Warnings/Advisories	P											A
BIT System		P										
Steering/Braking												
Braking System	V	P										
Steering System	V	P										
Automated Control Systems												
Actuators	V	P										
Sensors	P	CR										
Communication Equipment	P	CR										
Operator Interface	P	CR				A						
Computer Systems	P	CR										
System Integration	P	CR										
Propulsion & Drive Train												
Tire Pressure/Condition	P (Press	P (Cond.)		C								A
Driver Information Systems												
Enunciator Panel	P											A
Desirable Information												
Trip Plan												
Destination			A		A	A				P		
Preferred Route			A		A	A				P		
Time Arrival			A		A	A				P		
Selected Route			A		A	A				P		
Vehicle Regulatory												
Scheduled Maintenance Certificate							P					
Safety Systems												
Lights	P											A
Wipers	P											A
Useful Information	BIT	Certif. Station	Operator Keys	Add-On Instru-mentation	Smart Card	Driver Interaction	ROM	Physical Condition Sensor	Unique Physical Signature	Audio Input	Standard Vehicle Instru.	Driver Aware.
Trip Plan												
Estimated Fuel Required			P									
Vehicle Characteristics												
Cargo Type					P		A					
Weight Distribution				P (Opt.)								
Vehicle Regulatory												
Annual Safety Check					P							
Propulsion & Drive Train												
Engine Performance	P	CR									C	A
Fuel Level	P										C	A
Ambivalent Information												
Vehicle Characteristics												
Fuel Type			A		A	A	P					
Propulsion & Drive Train												
Wheel Alignment/Balance		P				C						A
Suspension	V (Act.)	P										A
Coolant Temperature	P										C	A
Alternator & Electrical System	P	CR										A
Oil Pressure	P										C	A
Driver Information Systems												
Gauges	P											A
Speedometer	P	CR										A

P - Primary Method
A - Alternate Method Available
C - In Conjunction with Pimary Method
V - Verify to Extent Possible at Check-in that Certified Components are Still Good
CR - Certify System Operating within Design Ranges
D - Dual Check, Use Two Sources at Chech-in
NC - Not Checked

Figure 3-31. Alternate 5 Check-in Systems

The addition of audio input is seen as highly desirable to increase safety and acceptance due to increased convenience. The use of audio also increases entry design flexibility since the check-in time is minimized which in turn minimizes the length of the transition lane required. In addition, if the direct entry option is used, the length of the check-in "section" of the entry ramp is minimized or alternatively, a short entry ramp with a full-stop check-in point could be supported without causing unacceptable entry delays.

The Alternate 5 design used groundrules and assumptions listed in section 2.2.4 along with the following systems to estimate costs shown in figure 3-32:

User	Business	Government
RF Transponder	Certification Test Set	Roadside Receiver
Smart Card		Traffic Control Display
Smart Card Reader		Command Control Center
Data Entry Panel		Software
ROM		
Add-On Instrumentation		
Physical Condition Sensor		
Unique Physical Signature		
Audio Input		

Cost drivers in this alternative for the users included audio input, physical condition and unique physical signature sensors, and AHS equipment maintenance. The main cost drivers for the government were software development and maintenance, traffic control display, and check-in site maintenance. Technology development and costs for audio input and the physical condition and unique physical signature sensors require further research. Other areas of uncertainty and risk reside in the software requirements and in the estimation of development costs.

Concept: Alternative 5

COST $2.757B (1994$) Los Angeles County

	DEVELOPMENT	PURCHASE/ PRODUCE	O & M (2 YRS)	TOTAL
USER	0%	64%	14%	78%
BUSINESS	1%	3%	0%	4%
GOV'T	11%	3%	4%	18%
PUBLIC	Provide Funds for Gov't			
TOTAL	12%	70%	18%	100%

Cost Drivers

- Audio Input, Physical Condition/Unique Physical Signature Sensor Purchase Price
- User Certification Costs
- Software Development & Maintenance Costs
- Traffic Control Display Purcahse Price
- Check-In Site Maintenance

Risks/Issues

- Physical Condition/Unique Physical Signature Senor Development
- Audio Input Costs Require Further Analysis
- Software Development Requirements
- Groundrule and Scenario Alignment With Official AHS Plans
- Development Costs Require Further Analysis

Figure 3-32. Alternate 5 Cost Analysis

3.3.9 Alternate 6

This last alternative was designed to look at a check-in scenario which does not take advantage of a regulatory approach and performs all checks at the AHS entry point. This approach is seen as an alternate baseline so the additional systems, such as audio input, were not included. Their addition would provide the same benefits to this approach as noted for the original baseline.

The BIT system is still assumed to be present on the vehicle, but the periodic check and certification of the system is gone, as are the sensor checks. Check of both would become a normal maintenance item at the dealer or garage of choice. Since not all dealers and garages would have the proper equipment or required training, confidence in the system capabilities would be lessened. To address this, it is assumed that an obstacle course would be necessary to more fully exercise the control systems (steering, brakes, and throttle). Data generated from these tests would be transmitted to the control center for evaluation and comparison with data measured by sensors in the infrastructure (Data Flow Option 1 in figure 3-17). In order to collect the necessary on-board data, "add-on instrumentation" would need to be included in the vehicle design." This will complicate the design of the vehicle and consequently the various related costs.

Based on the earlier analysis, the addition of an infrastructure based IR or EO sensors was found to be able to supply the desired data from the obstacle course to the Control Center. IR sensors were selected for their night/day versatility. The effectiveness of both sensor types will suffer in inclement weather. The add-on instrumentation will be used to gain information on mechanical components to assess failures and indications that a failure could be imminent. For instance, actuators could be instrumented with strain gauges and pressure transducers to provide the means to detect abnormal structural loads and hydraulic pressures. Both can be used as indicators of system problems. The evaluations of this additional information will be part of the BIT and the results will be sent to the Control Center to combine with off-board data for an assessment of vehicle health. Figure 3-33 shows how the information items will be obtained for this alternative.

Alternate 6 Critical Information	BIT	Operator Keys	Add-On Instru-mentation	Smart Card	Driver Interact.	ROM	IR Sensor	Standard Vehicle Instru.	Driver Aware.
Driver Qualifications									
Driver's License/Training		C		P					
Impairment/Alertness					P				
Vehicle Characteristics									
Vehicle Type						P			
Entry Weight			P						
Dimensions						P			
Vehicle Regulatory									
AHS System Certification						P			
Safety Systems									
Hitch & Safety Chain	D		C				D		A
Warnings/Advisories	P								A
BIT System (N.C)									
Steering/Braking									
Braking System	D		C				D		
Steering System	D		C				D		
Automated Control Systems									
Actuators	P		C						
Sensors	P								
Communication Equipment	P								
Operator Interface	P				A				
Computer Systems	P								
System Integration	P								
Propulsion & Drive Train									
Tire Pressure/Condition	P (Press.)		C				P (Cond.)		A
Driver Information Systems									
Enunciator Panel	P								A
Desirable Information									
Trip Plan									
Destination		P		A	A				
Preferred Route		P		A	A				
Time Arrival		P		A	A				
Selected Route		A		A	P				
Vehicle Regulatory									
Scheduled Maintenance Certificate						P			
Safety Systems									
Lights	D						D		A/C
Wipers	D						D		A/C
Alternate 8 Useful Information	**BIT**	**Operator Keys**	**Add-On Instru-mentation**	**Smart Card**	**Driver Interact.**	**ROM**	**IR Sensor**	**Standard Vehicle Instru.**	**Driver Aware.**
Trip Plan									
Estimated Fuel Required		P							
Vehicle Characteristics									
Cargo Type				P		A			
Weight Distribution			P (Opt.)						
Vehicle Regulatory									
Annual Safety Check				P		A			
Propulsion & Drive Train									
Engine Performance	P							C	A
Fuel Level	P							C	A
Ambivalent Information									
Vehicle Characteristics									
Fuel Type		A		A	A	P			
Propulsion & Drive Train									
Wheel Alignment/Balance			P		C				A
Suspension			P						A
Coolant Temperature	D						D	C	A
Alternator & Electrical System	P								A
Oil Pressure	P							C	A
Driver Information Systems									
Gauges	P								A
Speedometer	P								A

P - Primary Method
A - Alternate Method Available
C - In Conjunction with Pimary Method
V - Verify to Extent Possible at Check-in that Certified Components are Still Good
CR - Certify System Operating within Design Ranges
D - Dual Check, Use Two Sources at Chech-in
NC - Not Checked

Figure 3-33. Alternate 6 Check-in Systems

Lateral displacement during the obstacle course commanded maneuvers will be measured by IR sensors. These can be mounted above the lane to monitor the vehicle's motion and to determine its lateral displacement. This data will be compared to the expected motion for the commanded maneuver by the control center and, in turn, to the data received by the on-board sensors to verify the lateral control system is operating properly. BIT will perform its normal checks including evaluating the outputs of the standard vehicle instrumentation and transmit its assessment of component status to the control center as additional information on which to base a go/no-go decision. This approach uses data flow path options 1, 2, and 3 (see figure 3-17).

This alternative's time to check-in is high due to the abundance of human interaction intensive approaches to check information, specifically operator keys, smart cards, and driver interaction. Further, because the vehicle does not utilize a certification station to check critical components, an obstacle course is required, which adds approximately three seconds to the time requirement. A check-in station is the only possible scenario for this alternative given the obstacle course and off-board equipment. Therefore, the queues and vehicle waiting time to be checked in for Alternate 6 are very large.

This is not seen as a desirable approach. Given the wide use of regulatory checks for safety and especially emissions checking, the addition of an AHS certification requirement is not seen as a major acceptance problem given that vehicle reliability is such that the checks are not too frequent and the cost is kept low. Consideration should also be given to different levels of checks at different check times. For instance, a minor inspection could be required frequently which only looked at items such as tires and the engine, which would be a fairly quick and inexpensive check. Major inspections would pull sensors to test and dynamically test the control systems. An approach of this nature, similar to normal maintenance schedules, would make the certification process more palatable. Given the payoff in using certification, both in terms of confidence in system status and reduction in the complexity of the integrated check-in system at the entry point, the use of regulatory is desirable and should be utilized as part of the AHS check-in process.

The Alternate 6 design used groundrules and assumptions listed in section 2.2.4 along with the following systems to estimate costs shown in figure 3-34:

User	Business	Government
RF Transponder		Roadside Receiver
Smart Card		Traffic Control Display
Smart Card Reader		IR Scanner

Data Entry Panel	IR Scanner Processor
ROM	Command Control Center
Add-On Instrumentation	Software

Cost drivers for the users in this design included the data entry panel. The main cost drivers for the government were software development and maintenance, the traffic control display, IR scanner, and check-in site maintenance. Primary areas of uncertainty and risk reside in software requirements, and in the estimation of development costs. Another important issue to consider and quantify is the cost of safety due to the absence of vehicle certification.

Concept: Alternative 6

COST $1.100B (1994$) Los Angeles County

	DEVELOPMENT	PURCHASE/ PRODUCE	O & M (2 YRS)	TOTAL
USER	0%	50%	5%	55%
BUSINESS	1%	0%	0%	1%
GOV'T	28%	6%	10%	44%
PUBLIC	Provide Funds for Gov't			
TOTAL	29%	56%	15%	100%

Cost Drivers
- Add-on Instrumentation Purchase Price
- Software Development & Maintenance Costs
- Check-In Site Maintenance Costs
- Traffic Control Display, IR Scanner Purchase Price

Risks/Issues
- Software Development Requirements
- Groundrule and Scenario Alignment With Official AHS Plans
- Development Costs Need Further Analysis
- Cost of Safety Due To Lack of User Certification

Figure 3-34. Alternate 6 Cost Analysis

3.3.10 Check-In Alternatives Comparison

In general, each alternate system has increased capability from the baseline up to alternate 6. With these advances come cost, time, safety, and technological maturity tradeoffs. These tradeoffs, applied to each alternate system, are shown in figure 3-35. In order to select which check-in concept is the most appropriate for AHS needs, these four aspects (cost, time to check-in, safety, and technology assessment) must be carefully considered along with the preferred AHS infrastructure concept.

Option	Cost*	Time to Check-In (sec) Min./Max.	Safety	Technology Assessment	Comments
Base-line	1.3B	2.02/15.02	• Too much driver interaction • Deficiency in checking driver alertness	• Only technology not mature is smart cards • Certification station can be developed off existing systems	
Alt. 1	1.2B	15.02/15.02	• Full stop transition lane may back up onto freeway	• Same as the baseline, but technology is placed in the infrastructure	• Only feasible with a check-in station • Check-in time penalty (all checks occur at a check-in station)
Alt. 2	1.4B	2.02/12.06	• Use of ROM decreases required driver interaction	• ROM is a fully mature tech-nology	• ROM adds level of security by being a tamper resistant form of data storage
Alt. 3	1.8B	1.0/10.22	• Reliable check of driver cond-ition by physical condition sensor	• A physical condition sensor should be avail-able by 2010.	• Some concern with cost, size, and acceptance
Alt. 4	1.9B	1.0/10.42	• High confid-ence of driver identification	• Unique physical signature systems are in develop-ment.	• Privacy issues are a major concern with positively identifying the driver
Alt. 5	2.8B	1.0/7.41	• Audio input decreases driver distraction	• Audio input and voice recognition is in development for continuous dictation.	• Audio input supports check-in on-the-fly • Cost concern
Alt. 6	1.1B	5.0/15.0	• Full obstacle course checks AHS systems	• IR sensors are in development today for vehicle identification	• Only available with a check-in station

* Relative Life Cycle Cost (LCC) to the user, business, government, and public. LCC includes development, production, operations and maintenance phases of a system.

Figure 3-35. Alternate Check-In System Comparison

3.4 Alternative Integrated Check-in Approaches Cost Analysis

This section contains summaries of results presented in previous sections. Assumptions, basis of estimates, and analysis of individual concepts reside in their respective sections. Basis of estimates for items not discussed previously, such as the Command Control Center, can be found in section 3.4.3 Other Costs. Discussions of cost estimates among the concepts are also in the following sections.

3.4.1 Cost Summaries

The basic scenario reflected in the following costs summaries is Los Angeles County with approximately 551,000 AHS users operating and maintaining their vehicles for 2 years. Vehicles can have any one concept installed as described in section 3.3. Results for each AHS design concept in this scenario are summarized in the figures below. Relative magnitudes, rather than absolute values, are shown with the intent to provide an indication to where costs would be expended. However, an absolute total value is included for each concept to enable an overall cost ranking among the concepts. Detailed costs that comprise the following distributions can be found in appendix E.

Figure 3-36 summarizes the cost distribution of the AHS check-in concepts by life-cycle phase.

Concept	Development	Purchase/ Produce	Operations & Maintenance	Total Cost ($1994)
Baseline	25%	46%	29%	$1.298 B
Alternative 1	27%	42%	31%	$1.166 B
Alternative 2	23%	50%	27%	$1.390 B
Alternative 3	18%	59%	23%	$1.800 B
Alternative 4	17%	60%	23%	$1.914 B
Alternative 5	12%	70%	18%	$2.757 B
Alternative 6	29%	56%	15%	$1.100 B

Figure 3-36. Cost Distribution of AHS Check-In Concepts

The least expensive life cycle cost (LCC) concept was Alternate 6 due to minimum hardware requirements on-board the AHS vehicle. The absence of regular certification also contributed to the lowest total cost. The most expensive LCC concept was Alternate 5. The high costs were attributed to a full complement of on-board system options as well as multiple vehicle diagnostic systems at each check-in site. Figure 3-36 is a summary that shows the majority of costs in the Purchase/Produce phase due to the 2-year operations and maintenance assumption made at this time. If an O & M time frame, along with a profile of anticipated users over the same time frame can be identified, costs would most likely shift towards the O & M phase. Purchase/Production costs would also decrease over an extended time frame as a result of the market volume increasing and technologies maturing.

Figure 3-37 summarizes the cost distribution of the AHS check-in concepts by sector. This figure also summarizes the estimated costs to AHS users specifically to allow comparison to survey results shown in sections following. User costs shown are the estimated cost of an installed AHS system along with the associated annual operations and maintenance cost.

Concept	User	Business	Government	Total Cost ($1994)	User Unit Cost	User Annual O&M Cost
Baseline	54%	8%	38%	$1.298 B	$ 799	$240
Alternative 1	50%	9%	41%	$1.166 B	$ 588	$230
Alternative 2	60%	8%	32%	$1.390 B	$ 998	$250
Alternative 3	68%	6%	26%	$1.800 B	$1,674	$284
Alternative 4	69%	6%	25%	$1.914 B	$1,813	$290
Alternative 5	78%	4%	18%	$2.757 B	$3,202	$360
Alternative 6	55%	1%	44%	$1.100 B	$ 998	$ 50

Figure 3-37. Cost Distribution of AHS Check-In Concepts by Sector

The cost distribution summary above shows the users bearing most of the burden from a sector standpoint. This is due to the large volume of AHS equipment initially purchased by the user. As stated in the previous summary, if an O & M time frame, along with a profile of anticipated users over the same time frame can be identified, costs would most likely shift away from the user and towards the government. Purchase/Production costs would also decrease over an extended time frame as a result of the market volume increasing and technologies maturing. Business shows a very low total cost relative to the total due to the costs accounting for development only. Costs to produce hardware are captured in the purchase price to the users.

The least expensive per unit concept to the user overall was Alternate 1. This was due to minimum hardware requirements on-board the AHS vehicle. The absence of regular certification also contributed to the low total cost. The most expensive concept to the user was Alternate 5. The high costs were attributed to a full complement of on-board system options. Survey responses showed users were willing to pay between $500 and $1,000 per installed AHS system. Based on the unit cost estimates shown above, the Baseline, Alternates 1, 2, and 6 were acceptable to AHS users. These concepts were basic AHS vehicle systems that do not contain any advanced driver identification options. Survey responses also showed users were willing to spend between $100 to $200 on AHS related maintenance annually. Based on O & M cost estimates shown above, only Alternative 6 was affordable to users from an ownership standpoint. This was due to the absence of AHS vehicle certification. Semi-annual certification was the cost driver for user O & M costs in the remaining alternatives.

Alternative 6 was the only affordable concept to users from both purchase and ownership perspectives based on the cost estimates and user survey results discussed above. The Baseline, Alternative 1, 2, and 3 unit costs for AHS equipment was also affordable to users but the associated O & M costs were higher than acceptable to users from an absolute viewpoint. From a relative viewpoint, the annual O & M may be considered marginally affordable for these concepts and deemed feasible to users.

Common cost concerns throughout all concepts involved software development and maintenance as well as overall development cost estimates. These costs generally are difficult to estimate on a first order basis. Northrop Grumman maintains a cost databank for a multitude of aircraft and related subsystems and technologies, but the majority of costs are related to systems in production. Available development costs pertain to total aircraft and could not be used as part of this report as a test of reasonableness for the development cost estimates. Future studies may derive development-production cost relationships that may be applied to AHS systems. The PRICE H model was selected as the best method to estimate development costs given the limited details. However, based on the Northrop Grumman cost analyst's experience, development costs appear understated for the hardware systems even though the majority of these systems utilize mature technology. This implies that development costs expenditures for businesses would increase and gain more of the AHS check-in total cost distribution.

Software development and maintenance assumptions used to estimate costs also need further study. A better assessment of the amount of existing BIT, command/control, and processing software from current applications is required to refine the software estimates. Software development has traditionally been a major cost driver in the development of military systems, but based on the Northrop Grumman cost analyst's experience, software cost estimates appear overstated. Cost sensitivity analyses were not performed as part of this report due to limited time and budget but must be addressed in future studies. Cost benefits for each AHS check-in concept were not examined in this report but should be subject to quantification in future studies.

3.4.3.2 Other Costs

3.4.3.2.1 Command Control Center

A control center that monitors, controls, and processes data from AHS check-in sites will be required. This center will most likely monitor and control more than check-in sites, i.e., portions of the AHS, but this analysis will dedicate the control center to AHS check-in to provide a first order estimate of costs required.

Cost estimates for the command control center were based on an analogous control center utilized by the Los Angeles Department of Transportation. Discussions with a senior transportation planner revealed the control center monitors and controls approximately 130 square kilometers (50 square miles) comprised of 400 controlled intersections. It is a 464.5 square meter (5000 square foot) facility which houses various control hardware, consoles, displays, and communication hardware. The planner quoted costs of $300K for the facilities which include items such as lighting and raised computer floors; $300K for control hardware; $100K for communication hardware that link to RF hubs within the controlled area; and $25K for each display device (3 utilized).

The number of control centers derived for this analysis was based on an assumption that the control center's coverage is configured to receive signals in an area that is approximately 27 kilometers long by 5 kilometers wide. Since 850 freeway kilometers need to be monitored, thirty one control centers were included in this analysis to cover the AHS check-in function. Subsequent analysis may want to relate the number of control centers required as a function of number of sites it can monitor rather than as a function of surface area. Development costs were not available from the planner and Northrop Grumman models are not suited to estimate facilities. Therefore, to account for some level of development, an equivalent value of one prototype facility with its associated hardware was used as the development estimate.

Also required as part of the command control center is software to control and process information from the check-in sites. Northrop Grumman engineering estimated 2.5M lines of code (LOC) will be required for this application. Costs to develop this software were estimated using the REVIC model (see appendix for description of the model). The command center software was broken into modules of no more than 100,000 LOC each to simulate a more realistic programming process. The software was characterized as a data processing application with normal math routines, some new algorithms, moderate interfaces, and a large database. The staff developing this software is assumed to have normal experience in developing similar software and will utilize modern programming practices with tools in a fully integrated environment. Command center software reliability was characterized as being moderately critical. REVIC produced results of 24,867 man-months to develop the command center software. REVIC's default labor rate of $73/hour and 152 hours/man-month was used to calculate development costs of $276M. Maintenance of this software for 2 years was calculated using the model's default change traffic factor of 15 percent per year. Maintenance costs totaled $82M for 2 years.

3.4.3.2.2 Traffic Control Displays

Each check-in site will have a traffic control display showing real-time traffic conditions for safe AHS entrance. Costs for these displays were assumed to be analogous to traffic condition displays currently utilized on the LA freeway system. Quotes from LA DOT of $220K each were used in this analysis. To account for some level of development, an equivalent value of one prototype traffic control display was used as the development estimate. Cost drivers for this system were not identified but there is a high probability that a less expensive system can be utilized. Research into less expensive systems performing the same function should be investigated.

3.5 Electric Vehicles

A number of AHS system approaches are being addressed for electric vehicles, some of which are described in Calspan's Representative System Configurations. The backbone of electric vehicle systems is a bank of batteries. Currently, lead-acid batteries are being used, but the search for a superior battery with less weight and ability to hold charge continues. Regardless of the power system for a vehicle, the entry interface remains virtually the same. Many systems will actually require little change. The main difference in checking these vehicles will be in some of the vehicle's sensor systems, such as the gas gauge sensor. In its place will be some sort of indication device for how much energy remains and/or how long in time the vehicle can continue to operate. The safety check validation procedures will require upgrades to include electric drive vehicles. The safety aspect of the vehicle will remain the same for brakes, tires, steering control, etc. The added equipment to the electric vehicle will require a new system interface to the on-board systems. The new vehicle type interface (personality card) will make the electric drive vehicle look the same as others to the infrastructure.

3.6 Evolution

As stated in the analysis assumptions, a fully automated AHS is assumed to be operational by the year 2010. However, as section 1.4.3 described earlier, AHS deployment will occur as an evolutionary process rather than a revolutionary process. Therefore, the progression of AHS check-in technologies and how they may be integrated into the overall AHS is of interest. Figures 3-38a and 3-38b show how the check-in of an AHS might evolve in conjunction with the overall AHS.

	No Automation (Today)	Dedicated ICC Lane
AHS*	• HOV Lanes • Traffic Warning & Freeway Condition Signs • Ramp Metering	• Communication between Vehicles and the Roadway • Driver Steers the Vehicle • Sensors for Traffic Flow • Lateral Blind Spot Sensor
Check-In Only	• System Scanner to Check Fuel, Oil, Coolant, Service Check Reminder, etc. • Some BIT for Maintenance and Safety	• Sensor Self-Test Diagnostics: -- Brakes -- Acceleration -- Distance -- Closing Rate -- Blind Spot • Transponder
	NO CHECK-IN REQUIREMENTS	VERIFICATION REQUIRED

* MAIN SOURCE: Data here is primarily from “AHS Evolution”, USC Center for Advanced Transportation

Figure 3-38a. Possible AHS Evolution

	Multiple ICC Lanes	Fully Automated
AHS*	• Vehicle-to-Vehicle Communication • “Hands Off” Steering in a Single Lane • Longitudinal Collision Avoidance • Sensors Provide Lateral Collision Warnings • Look-Ahead Data Required by Sensors or Transponders on the Roadway	• Vehicle Enters Lane and Merges Automatically • Vehicles can Change Lanes with Automated Lateral Collision Avoid. • Vehicles Treated as “Packets” • Vehicle Routed by Roadway • Vehicle Tells the Roadway Position and Speed
Check-In Only	• Self-Test Diagnostics: Directional Sensors, Tracking, Transponders, Look-Ahead • Expanded Communication (Dynamic Valid.) • Fail-Safe System Confirmation and Vehicle Performance Monitoring • Vehicle and Driver Certification Required	• Self-Test Diagnostics: -- Situational Awareness • Dynamic Testing as Required • Driver and Vehicle Alertness • Trip Information Entry
	VERIFICATION REQUIRED	
	CERTIFICATION REQUIRED	

* MAIN SOURCE: Data here is primarily from “AHS Evolution”, USC Center for Advanced Transportation

Figure 3-38b. Possible AHS Evolution

Many technologies that will be required for check-in are available today and used extensively in the aircraft industry, such as BIT, ROM, and on-board strain gauge devices. Additionally, the automotive industry is already including potential check-in technologies (i.e. BIT) in their designs, which would make the transition to AHS-compatible vehicles more cost effective. The use of Smart cards is also becoming popular, especially in the role of automated toll collecting. In fact, over 60% of the technologies required for the recommended AHS check-in system are currently mature (i.e. BIT, operator keys, Smart Card, ROM, and strain gauge devices).

The introduction of a dedicated intelligent cruise control (ICC) lane is the first step toward an AHS. Verification of key systems, such as the braking system and ICC-related sensors, is required to ensure that these systems are operational and performing within required ranges. Some states, such as Florida, mandate safety inspections for vehicles as a part of the registration process. They are also considering dynamic testing to assess a vehicle's braking system at this time, which again suggests that the transition of current concepts and applications can be easily applied to an AHS operation.

In the next stage (see figure 3-38b), certification of the vehicle and the driver is required for operation in the AHS. In this phase, the "hands off" feature of the AHS is implemented, which indicates a need for driver training as to the rules and regulations of utilizing the AHS. This step is the most critical in the evolutionary path of the AHS due to the system's non-traditional nature, therefore, it is necessary that both the driver and vehicle are certified. For technological requirements during this stage, in-vehicle displays should be available (see IVHS timeline graph reference) to allow for sophisticated driver interaction at check-in for specific inputs, such as selecting a route.

The last phase is the implementation of the fully automated AHS. Considering check-in, audio input capability, and physical condition, sensors will enable the user to efficiently input travel data and also will allow the system to check the driver for alertness. These technologies are estimated to be available around the year 2000 (IVHS timeline reference).

In summary, although the path to a fully automated AHS will be evolutionary, the corresponding technologies required for check-in will progress in parallel with the overall system to ensure a smooth transition to each phase of the AHS deployment.

SECTION 4

CONCLUSIONS

4.1 Key Results

A sophisticated AHS check-in system is technologically feasible by the year 2010 considering the types of technologies currently available and other emerging technologies applicable to automated check-in. A review of the philosophies, methodologies, procedures, techniques, and processes involved in the flight testing of advanced air vehicles suggests application to AHS check-in of ground vehicles. Based on lessons learned from flight test programs, advanced aircraft data system, instrumentation, and data acquisition technologies can be instrumental in the development of smart car systems.

In order to simplify the task of adding AHS compatible equipment to vehicles while minimizing the cost, existing vehicle capabilities applicable to AHS operation should be exploited as much as possible, especially to support BIT. Automobile manufacturers are currently including vehicle health monitoring systems, primarily in high-end models, in their designs which indicates that an AHS vehicle can take advantage of on-board systems. Programmability of these on-board systems is essential to support evolution of the AHS and corresponding modifications to the vehicle and external support systems. For example, the integration of software upgrades must be easily attained. In addition, systems should be modular to facilitate ease in troubleshooting and maintenance.

The time required to perform the AHS check-in function is critical in terms of traffic flow efficiency, user acceptance, and safety. If the check-in station approach is utilized, the time to check-in can be significantly reduced if the number of available stations exceeds two. Otherwise, the resultant vehicle queues would disrupt the system both on and off the AHS (i.e. arterial street run-on). Ideally, check-in should be as transparent to the operator as possible, and therefore functions assessed by AHS that require additional operator tasks or actions beyond current driving requirements should be minimized. Depending upon the check-in scenario selected, these operator functions may include additional monitoring (including vehicle and infrastructure systems), communications (verbal input, auditory feedback), operator-initiated check-in (stopping at a check-in station, smart card insertion), and destination and route selection. Safety issues arise whenever driver required functions divert attention from the driving task. Utilizing technologies such as ROM and audio input can significantly increase the safety of the system as well as reduce the time required for a vehicle to check-in. Further, concurrent tasks must be paired so as to optimize use of operator resources so that these tasks do not interfere with other tasks. In order to limit resource conflict to the maximum extent possible, tasks should be performed prior to vehicle operation (e.g. in-vehicle smart card insertion, destination/route selection, built-in-test of on-board equipment).

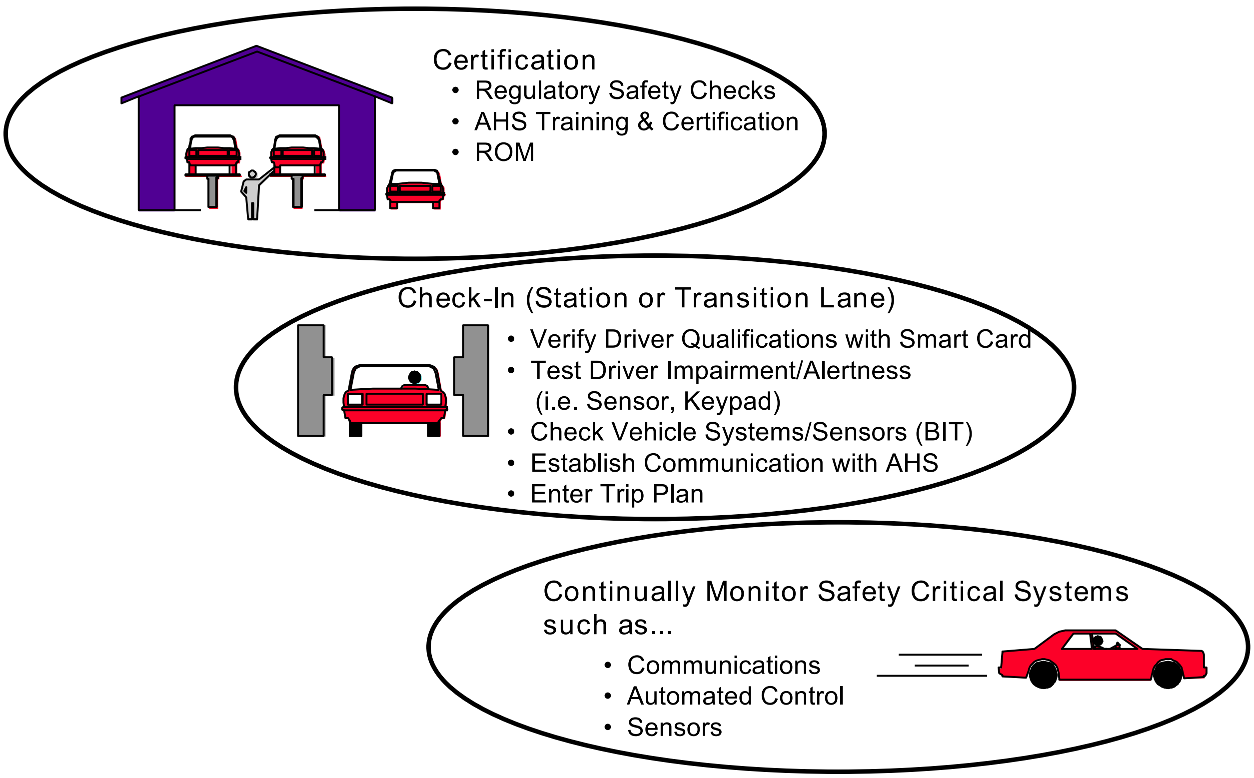

Figure 4-1. Most Likely Recommendation

4.2 Recommendation

In considering the key results described in the previous section, if a recommendation was to be made relative to a check-in implementation approach, it would be as shown in figure 4-1. There is a definite need for vehicle certification as part of the overall check-in process to ensure a vehicle's safe operation on the AHS. The certification station would test for AHS-related components on the vehicle as well as standard equipment necessary for safe operation, especially the BIT system, communications, braking and steering systems, and all automated control systems. The record of a vehicle's safety inspection and status can be saved on a ROM chip within the vehicle for use when requesting access to the AHS. In addition, the driver should maintain some responsibility for the condition of the vehicle. Figure 4-2 shows the certification phase of check-in more detail. From this information, it can be seen that periodic certification should build upon existing infrastructure processes, such as current vehicle smog and safety checks, which will minimize the cost to agencies.

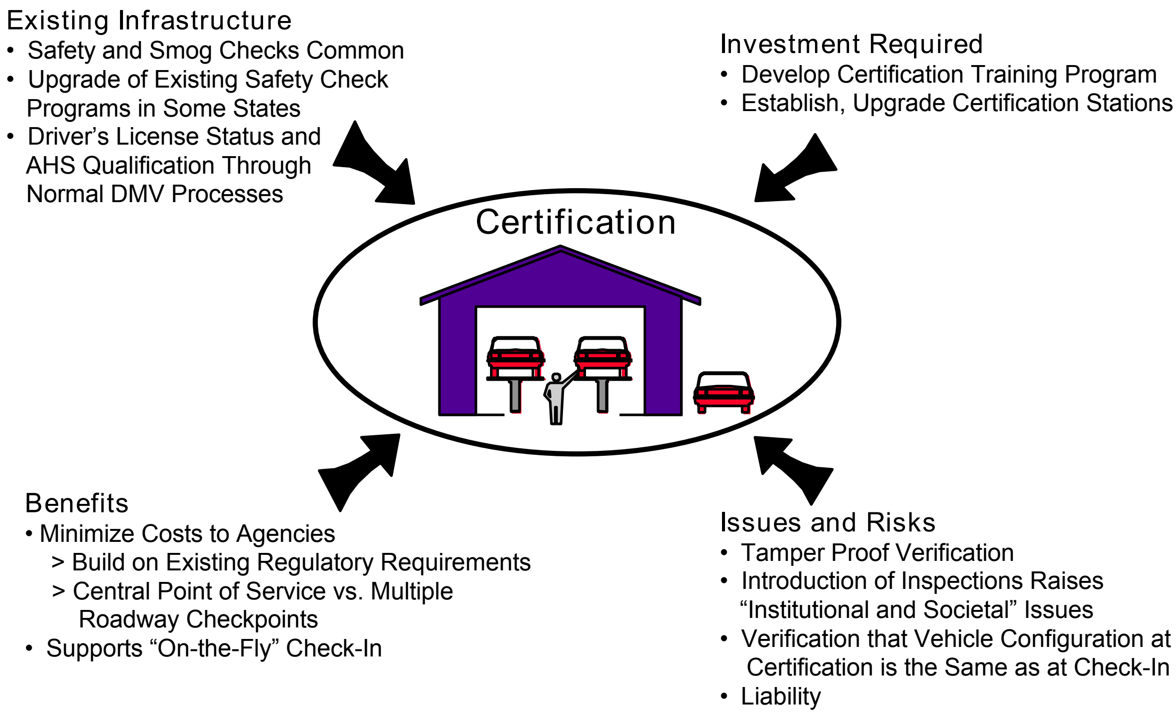

Figure 4-2. Considerations for AHS Vehicle Certification

After a vehicle passes its AHS safety inspection, which may occur twice a year depending on miles driven, several factors must be addressed when the driver actually requests check-in, such as establishing communication with the AHS and the control center. Also, driver impairment must be assessed; the best way of obtaining this information is through the use of a physical condition sensor. Travel information (i.e. destination and route selection) can also be input at this time preferably by audio input. However, it is preferred that travel-related information is entered prior to requesting check-in to decrease the AHS access time. The use of smart cards will store information concerning the driver, such as driver's license number and AHS training certification. Operator keys should be on-board the vehicle primarily as a back-up method for entering data such as a driver's license number, training information, and travel plans.

Figure 4-3 shows that some additional instrumentation will be required for check-in related functions such as measuring the weight of the vehicle, determining the tire pressure, and checking for positive hitch and safety chain contact. However, there are many existing systems and technologies that are applicable to the AHS as well, especially BIT.

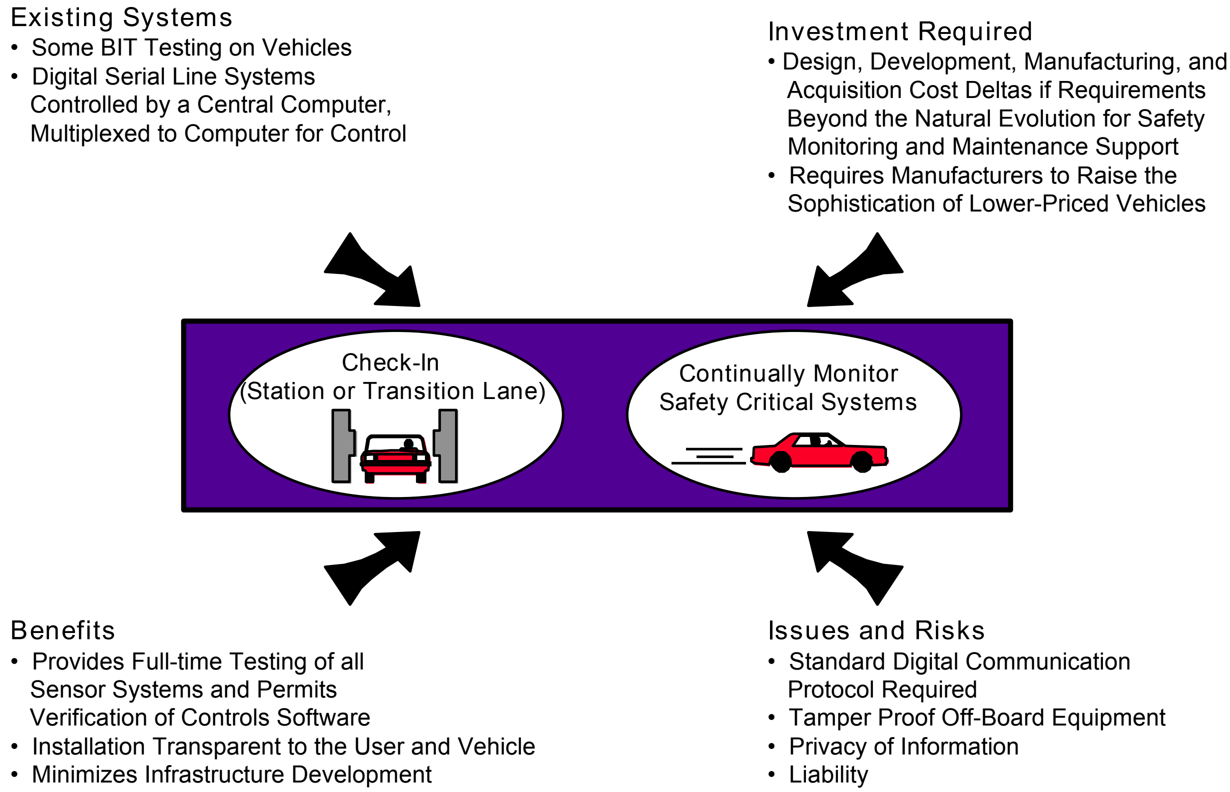

Figure 4-3. Considerations of Actual Check-in and AHS Operation

In addition, safe operation of the AHS will require the continuous check of safety critical vehicle systems including longitudinal and lateral control, communications, and key sensors associated with lane keeping and relative position if in a platoon.

4.3 Issues and Risks

There are several issues and risks associated with this recommendation as well as with the AHS check-in concept in general.

In requiring a certification station, an issue arises concerning trainingand regulation necessary to operate these "service" stations to ensure system safety checks are performed in a consistent and legal manner. Currently, there are problems with smog certification stations issuing false smog check certificates for high emission vehicles. However, this is a pollution problem and not a safety problem as a fraudulent AHS certification would be; it imposes a much greater hazard to society. Each station must have the capability of programming a vehicle's ROM chip in order to store check-in specific vehicle data, such as AHS certification status. The frequency of required certification may also be unacceptable to the public.

One of the biggest issues with check-in and the AHS in general is standardization. This problem covers several aspects of the operation from communication, interstate AHS compatibility, individual vehicle performance capability, and data protocol down to vehicle BIT systems. If the instrumentation system is non-standardized between different vehicles, data acquisition is potentially impossible. Therefore, interfacing hardware will be required to allow communication between the data acquisition system and the instrumentation system. Low-end vehicles may not have the same level of sophistication of other vehicles due to cost constraints, which may also affect the reliability of the AHS and compatibility with check-in. Additionally, retrofit of non-AHS vehicles for AHS compatibility must be available to the maximum extent possible so as not to exclude potential AHS users.

As mentioned in section 4.2, on-board vehicle AHS equipment is encouraged since it is the most convenient and supports on-the-fly check-in. Therefore, it can take advantage of emerging trends in the automotive industry. Although this may be a cost concern to drivers, the ramification of off-board system failure may be a more prevalent concern. If an off-board system fails, it is quite possible that an entire entry point is closed, thus disrupting the travel of countless vehicles along the AHS.

The use of smart cards is becoming more common as a means of storing information. However, in the context of check-in, there may be problems associated with lost or stolen cards, safety (insertion while the vehicle is moving), forgotten cards, and the time it takes to locate the card during check-in. Although the last problem cannot be helped, the other issues can be addressed by providing a back-up input system in the form of operator keys.

Testing the driver impairment and/or alertness viaa physical condition sensor may have a high cost since the technology is still in a developmental stage. However, if driver interaction was used to accomplish this function, the possibility of driver distraction may present a safety problem. Although it is a more expensive method than utilizing driver interaction, a physical condition sensor has greater accuracy and the time required to obtain the information is much smaller. A related problem outside the scope of this activity is how to direct an impaired driver and/or unsafe vehicle after being identified as such at check-in. If it is necessary to physically restrict the driver from entering the AHS, this will significantly impact the AHS concept selection.

The audio input device must be able to account for fluctuations in audio delivery (different accents, etc.). It must also be able to handle potential "clutter" caused by the vehicle (engine noise), weather (rain), or vehicle occupants (conversation). Using audio input will also be impossible for hearing impaired drivers, therefore a back-up system in the form of operator keys is necessary.

Once the vehicle is permitted access to the AHS, there is a liability and safety issue associated with possible false "go" assessment from the check-in system giving AHS access approval. The probability of this occurring can only be addressed relative to a detailed system design.

Existing BIT devices for the automotive industry are generally not as reliable as in the aircraft industry. For example, today's in-vehicle diagnostic systems experience frequent false alarms. Designing BIT systems to higher standards that will meet AHS safety goals may drive costs into an unacceptable range. However, the automobile manufacturers are already moving in the direction of ultra reliable BIT systems.

Both on-board and off-board AHS equipment must be tamperproof. This also applies to a certification station where a driver should not have the ability to change vehicle components in order to receive the AHS certification approval only to return unsafe equipment onto the vehicle. For example, the same set of new tires is utilized on several vehicles so that certification is passed by all.

The application of the unique physical signature technology is essential for validation of AHS certification and training, driver's license, and insurance. This differs from verification of these items, which could be accomplished with a smart card. Although the verification of check-in data would probably require a PIN code, it is not a fool-proof method for assuring a driver's identity. However, the question remains, "what level of positive identification is necessary?" In all likelihood, it may be sufficient enough to have only the smart card and PIN, similar to the use of ATM cards today.

There is also the issue of privacy of information. To what extent should the system be able to access a driver's personal information, such as retrieving the address from the driver's license, determining travel origins and destinations, or identifying an impaired driver. Should the proper authorities be notified if an intoxicated driver is discovered or if the driver is determined to be wanted for a serious crime? Whatever is decided, the public should be informed of the information that might be accessed so that there is a choice whether to use the AHS.

SECTION 5

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*Regulations and technical data provided

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Ford Motor Corporation: R&D Center, Dealer Service Facility (Visit)

General Motors Corporation: R&D Center, Dealer Service Facilities-Buick, Chevrolet, Oldsmobile (Visits)

Honda Corporation: Torrance R&D Center (Visit), Service Training Office, Dealer Service Facility (Visit)

Toyota Corporation: R&D Center, Los Angeles Service Center, Dealer Service Facility (Visit)

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California Highway Patrol, Information Services

California Highway Patrol, Commercial Inspection Services, Karen Weaver

CalTrans, Traffic Operations, Dave Nakao, Senior Transportation Planner

CalTrans, Structural Design, Mr. Hulmy

Cubic, Automatic Revenue Collection Group, Joel Talley, Regional Marketing Manager

Douglas, Robert; Caltrans District Traffic Engineer

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SECTION 6

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WHATs vs. HOWs Legend	
Strong ●	9
Moderate ◐	3
Weak ○	1

	Importance	Regulatory	Certification Station	On-Board Diagnostics	Read Only Memory	Operator Keys	Smart Cards	Built In Test (BT)	Driver Interaction	Std. Vehicle Instrumentation	Add-On Instrumentation	Unique Physical Signature Sensor	Physical Condition Sensors	Bar Code Scanner (Laser)	Audio Input	Driver Awareness	Off-Board Diagnostics	Laser	Smart Card	Optical Scanner	Audio Input	IR Sensors	Bar Code Scanner (Laser)	Optical Sensor (Image Processor)	Radar	Inductive Loop	Scale/Skid Plate	Magnetic Sensor
Trip Plan																												
Destination	7				○	●	○		●						●				○		●							
Preferred Route	7				○	●	○		●						●				○		●							
Time Arrival	7				○	●	○		○						●				○		●							
Est. Fuel Req.	5				○	●	○		○						○				○		○							
Selected Rte.	7				○	●	○		●						●				○		●							
Driver Qualifications																												
Driver's Lic./Training	9				○	●	●					●		●	○				●	◐	○		●	○				
Impairment/Alertness	9								●				●		◐						◐							
Outst. Tolls/Tick.	1																											
Vehicle Characteristics																												
Vehicle Type	9				●	●	●		◐		○				◐				●	●	◐	○	●	○			○	
Entry Weight	9				●	◐	●				●				◐				●	●	◐		●				●	
Occupancy	1																											
Cargo Type	5				●	◐	●		◐										●				●					
Weight Distr.	5										●																●	
Dimensions	9				●	●	●		◐						◐			●	●		◐	○		●	●			
Fuel Type	3				●	◐	●		●						◐				●		◐		●	●				
Vehicle Regulatory																												
Registration	1																											
Insurance	1																											
Annual Safety Chk	5				●	◐	●		○										●	●			●					
Smog Cert.	1																											
AHS Syst. Cert.	9				●	◐	●		○										●	●			●					
Sch. Maint. Cert	7				●	◐	●		○										●	●			●					
Permits	1																											
Law Enfor. Rpt.	1																											
Safety Systems																												
Airbags	1																											
Seat Belts	1																											
Doors Ajar	1																											
Windshield Visib.	1																											
Lights	7		○					●								●						●		●				
Wipers	7		○					●								●								●				
Mirrors	1																											
Emergency Exits	1																											
Hitch & Safety Chains	9							●			●					◐		◐				◐		●		◐		

Emergency Exits	1																							
Hitch & Safety Chains	9					●			●					◑	◑				◑		●		◑		
Warnings/Advisories	9	○				●			◑					●											
BIT System	9	●																							
Steering/Braking																									
Braking System	9	●				●			●					◑					●		○	●		●	
Steering System	9	●				●			●					◑					○		○			◑	●
Automated Control Systems																									
Actuators	9	●				●		◑	●																
Sensors	9	●				●																			
Comm. Equip.	9	◑				●																			
Operator Interface	9	●				●	●																		
Comp. System/Software	9	●				●																			
Syst. Integration	9	●				●																			
Propulsion & Drive Train																									
Trans. Fld. Press.	1																								
Tire Press./Cond.	9	●							●					●	●				◑		●	◑			
Wheel Align./Bal.	3	●												●	●							○		●	
Suspension	3	●				◑			●					◑	◑										
Engine Performance	5	●				●		●						◑											
Cool. Temp./Lvl.	3							●											●						
Fuel Level	5							●																	
Charge (Elect. Vehicle)	5					●																			
Alt. & Elect. Syst.	3	●				●																			
Oil Pressure	3							●																	
Driver Information Systems																									
Gauges	3	◑				●								●											
Speedometer	3	◑				●																			
Enunciator Panel	9	◑				●			◑					●											
Emergency Incident Response																									
Spare Tire	1																								
First Aid Kit	1																								
Flares/Reflect.	1																								
Comm.	1																								
Fire Extinguisher	1																								
Technical Importance		950	546	654	618	1197	480	171	621	81	81	81	383	528	225	618	378	383	252	504	432	192	27	270	81
Rank		2	7	3	5	1	10	19	4	20	20	20	12	8	17	5	14	12	16	9	11	18	24	15	20
Maximum Value = 1197.0 — Technical Importance Minimum Value = 0.0																									

APPENDIX A

Information Analysis Documentation

Rating Scale: 9 - Critical 7 - Desirable 5 - Useful 3 - Ambivalent 1 - Unimportant

Check-In Category: Automated Control Systems	Component: Actuators
Importance Rating: 9 Rating Factors: • Actuator performance is critical to maintain lateral and longitudinal control of the vehicle on the AHS.	

Check-In Category: Automated Control Systems	Component: Sensors
Importance Rating: 9 Rating Factors: • Sensor performance is critical to maintain lateral and longitudinal position of the vehicle on the AHS. • Critical to collision warning.	

Check-In Category: Propulsion & Drive Train	Component: Tire Pressure/Condition
Importance Rating: 9 Rating Factors: • Identifying the vehicle tire pressure and condition is critical because tires must have adequate pressure and be in good condition to safely maintain high speed operations required on the AHS.	

Check-In Category: Vehicle Regulatory	Component: AHS System Certification
Importance Rating: 9 Rating Factors: • AHS systems specifically checked out and certified to be functioning adequately is critical to safe operation.	

Information Analysis Documentation

Rating Scale: 9 - Critical 7 - Desirable 5 - Useful 3 - Ambivalent 1 - Unimportant

Check-In Category: Automated Control Systems | Component: Communication Equipment

Importance Rating: 9

Rating Factors:

- Identifying the vehicle is equipped with the proper communication devices is critical because the equipment is needed to interact with other vehicles on the AHS or with the AHS itself.

Check-In Category: Automated Control Systems | Component: Operator Interface

Importance Rating: 9

Rating Factors:

- Identifying the vehicle has a properly working operator interface is critical because the interface is needed for the driver to interact with the AHS.

Check-In Category: Automated Control Systems | Component: Computer System

Importance Rating: 9

Rating Factors:

- Assessing the status of the computer system is critical because the system maintains data and controls other systems necessary for the vehicle to operate on the AHS.

Check-In Category: Automated Control Systems | Component: System Integration

Importance Rating: 9

Rating Factors:

- System integration is critical in order to ensure information derived from multiple sources is available.

Information Analysis Documentation

Rating Scale: 9 - Critical 7 - Desirable 5 - Useful 3 - Ambivalent 1 - Unimportant

Check-In Category: Driver Qualifications	Component: Driver's License/Training

Importance Rating: 9

Rating Factors:

- Identifying the driver is licensed and has the proper training is critical to prevent unqualified and potentially unsafe drivers from entering the AHS.
- May not be critical if the driver is totally removed from vehicle operation while on the AHS.

Check-In Category: Driver Qualifications	Component: Impairment/Alertness

Importance Rating: 9

Rating Factors:

- Identifying whether the driver is in any way impaired or not alert is critical in order to protect the safety of all operators on the AHS and the public and property along it's path.
- May not be critical if the driver is totally removed from vehicle operation while on the AHS.

Check-In Category: Steering/Braking	Component: Braking System

Importance Rating: 9

Rating Factors:

- Identifying the braking system capabilities is critical to assess the ability of the vehicle to stop after traveling at high speeds and respond effectively to roadway "turbulence" especially if traveling in platoons.

Check-In Category: Steering/Braking	Component: Steering System

Importance Rating: 9

Rating Factors:

- Accurate and responsive steering is critical for maintaining proper lane control to movement on the highway, especially in light of the potential for narrower lanes.

Information Analysis Documentation

Rating Scale: 9 - Critical 7 - Desirable 5 - Useful 3 - Ambivalent 1 - Unimportant

Check-In Category: Safety Systems	Component: Hitch & Safety Chains

Importance Rating: 9

Rating Factors:

- Identifying whether the vehicle towing a trailer has a hitch that is properly attached or has the proper safety chains is critical to ensure safe operations on the AHS.

Check-In Category: Safety Systems	Component: Warnings/Advisories

Importance Rating: 9

Rating Factors:

- Identifying whether the warning and advisory systems are working is critical because these systems warn the driver about situations that can effect the vehicle and surrounding vehicles on the AHS.
- Three classes should be functional : yellow caution light, red warning light and a auditory critical warning and light.

Check-In Category: Vehicle Characteristics	Component: Vehicle Type

Importance Rating: 9

Rating Factors:

- Identifying vehicle type is critical to assess performance capability of that vehicle and its interaction on the AHS. (i.e. the difference between a sports car and a commercial vehicle must be reflected so that the system can calculate appropriate parameters for safe operation on the AHS.)
- Vehicles will most likely have an AHS capability rating, such as AHS capable, AHS compatible, or Non-AHS compatible, of which only the first two ratings will be allowed on the AHS.

Check-In Category: Vehicle Characteristics	Component: Gross Weight

Importance Rating: 9

Rating Factors:

- Identifying the vehicle gross weight is critical to assess braking performance.
- Determines whether commercial vehicles exceed the intended road capacity.

Information Analysis Documentation

Rating Scale: 9 - Critical 7 - Desirable 5 - Useful 3 - Ambivalent 1 - Unimportant

Check-In Category: Vehicle Characteristics	Component: Dimensions

Importance Rating: 9

Rating Factors:

- Identifying the vehicle dimensions is critical to determine the spacing in between vehicles on the AHS and whether the vehicle will sufficiently clear all the bridges and overcrossings along the route.

Check-In Category: Driver Information Systems	Component: Enunciator Panel

Importance Rating: 9

Rating Factors:

- Identifying whether the enunciator panel is working is critical because this is the main system which provides warnings to the driver.

Information Analysis Documentation

Rating Scale: 9 - Critical 7 - Desirable 5 - Useful 3 - Ambivalent 1 - Unimportant

Check-In Category: Trip Plan	Component: Preferred Route

Importance Rating: 7

Rating Factors:

- Identifying a preferred route is desirable for user acceptance and to identify where the vehicle should be placed on the AHS.

Check-In Category: Trip Plan	Component: Selected Route

Importance Rating: 7

Rating Factors:

- Identifying an selected route is desirable to allow the vehicle operator the prerogative of route planning (i.e. operator may choose a scenic route or one that goes through safer neighborhoods).
- This information allows the system to place the vehicle in the proper lane in order to maximize over all traffic flow.

Check-In Category: Trip Plan	Component: Time Arrival

Importance Rating: 7

Rating Factors:

- Identifying the vehicle time of arrival is desirable to assess traffic flow and identify the section of route that would meet the requirement.
- This information can be used by commercial vehicles trying to meet specific deadlines.

Check-In Category: Trip Plan	Component: Destination

Importance Rating: 7

Rating Factors:

- Identifying the vehicle destination is desirable to provide useful information to the AHS (i.e. the best route to optimize traffic flow, which lane and/or platoon to place the vehicle in on the AHS and if the is enough fuel to complete the trip, vehicle at proper check-in point, ect.
- Highway could operate with driver interaction which tells the system to change highway or take the next offramp.

Information Analysis Documentation

Rating Scale: 9 - Critical 7 - Desirable 5 - Useful 3 - Ambivalent 1 - Unimportant

Check-In Category: Safety Systems	Component: Lights

Importance Rating: 7

Rating Factors:

- Identifying whether the vehicle lights are working is desirable for safer night or other low visibility operations.
- Can be left as driver responsibility. Some doubt as to drivers ability to recognize one light out on a well lit highway section or entry point.

Check-In Category: Safety Systems	Component: Wipers

Importance Rating: 7

Rating Factors:

- Identifying whether the vehicle wipers are working is desirable to ensure safer operations in the rain and snow.
- Could assume driver responsibility.
- Low probability of motor failure.
- Difficult to asses condition of the rubber blades.

Check-In Category: Vehicle Regulatory	Component: Scheduled Maintenance Certificate

Importance Rating: 7

Rating Factors:

- Identifying whether the vehicle has had scheduled maintenance is desirable to provide information to the system on the reliability of the vehicle.
- This check serves as a regulator for system states that degrade gracefully.

Information Analysis Documentation

Rating Scale: 9 - Critical 7 - Desirable 5 - Useful 3 - Ambivalent 1 - Unimportant

Check-In Category: Propulsion & Drive Train	Component: Engine Performance

Importance Rating: 5

Rating Factors:

- Identifying actual engine performance is useful to ensure the vehicle can meet the performance criteria of the AHS, i.e. acceleration rate and cruise speed.
- Current maintenance certificate could override need.
- Driver could be responsible for maintaining the vehicle.

Check-In Category: Propulsion & Drive Train	Component: Fuel Level

Importance Rating: 5

Rating Factors:

- Identifying fuel level is useful to determine whether the vehicle is in danger of running out of gas or can make a desired destination.
- Driver can be responsible for making these decision as well.

Check-In Category: Vehicle Regulatory	Component: Annual Safety Check

Importance Rating: 5

Rating Factors:

- Identifying whether the vehicle has had an annual safety check is useful to provide some indication of the vehicle safety status.
- Most current state safety checks consist of only a visual inspection and do not check critical systems.

Check-In Category: Vehicle Characteristics	Component: Cargo Type

Importance Rating: 5

Rating Factors:

- Identifying the vehicle cargo type is useful to identify hazardous materials in case of an accident.
- Also allows special routing to avoid highly populated areas.
- Special permits are already required for hazardous material transport.

Information Analysis Documentation

Rating Scale: 9 - Critical 7 - Desirable 5 - Useful 3 - Ambivalent 1 - Unimportant

Check-In Category: Trip Plan	Component: Estimated Fuel Required

Importance Rating: 5

Rating Factors:

- Identifying the estimated fuel required is useful to determine whether the vehicle can make its desired destination.
- The driver can be responsible for making this decision as well.
- Fuel stops can be programmed as needed.

Check-In Category: Vehicle Characteristics	Component: Weight Distribution

Importance Rating: 5

Rating Factors:

- Severe problems would be noticeable prior to AHS entry.
- Can impact the braking performance of large vehicles.

Information Analysis Documentation

Rating Scale: 9 - Critical 7 - Desirable 5 - Useful 3 - Ambivalent 1 - Unimportant

Check-In Category: Propulsion & Drive Train	Component: Coolant Temperature & Level

Importance Rating: 3

Rating Factors:

- Overheating can be identified by the enunciator panel and alert the driver to the problem before the AHS entry point.

Check-In Category: Propulsion & Drive Train	Component: Alternator & Electrical System

Importance Rating: 3

Rating Factors:

- The enunciator panel can alert the driver to any problems with the alternator and electrical system prior to arriving at the AHS entry point.

Check-In Category: Driver Information Systems	Component: Gauges

Importance Rating: 3

Rating Factors:

- Operational gauges provide the driver useful information but are not necessary to enter or operate on an AHS.

Check-In Category: Driver Information Systems	Component: Speedometer

Importance Rating: 3

Rating Factors:

- An operational speedometer provides the driver speed information but is not necessary to enter or operate on an AHS.
- Importance rating would increase if driver is required to manually maintain a certain speed during transition or on the entry ramp.

Information Analysis Documentation

Rating Scale: 9 - Critical 7 - Desirable 5 - Useful 3 - Ambivalent 1 - Unimportant

Check-In Category: Propulsion & Drive Train	Component: Oil Pressure

Importance Rating: 3

Rating Factors:

- The enunciator panel can alert the driver when the pressure falls below a certain point.
- Increases user cost.

Check-In Category: Propulsion & Drive Train	Component: Wheel Alignment & Balance

Importance Rating: 3

Rating Factors:

- Improper wheel alignment and balance does not pose a safety threat to the drivers or other vehicles on the AHS unless it goes beyond the ability of the driver or automated control systems ability to correct and maintain control of the vehicle.
- Severe alignment and balance problems will be noticeable prior to the entry point.

Check-In Category: Propulsion & Drive Train	Component: Suspension

Importance Rating: 3

Rating Factors:

- Vehicle suspension is highly unlikely to pose a safety threat to the drivers or other vehicles on the AHS.
- Severe problems will be noticeable to the driver prior to AHS entry.

Check-In Category: Vehicle Characteristics	Component: Fuel Type

Importance Rating: 3

Rating Factors:

- Checking the vehicle fuel type could support effective accident response by identifying the type of potential spill.

Information Analysis Documentation

Rating Scale: 9 - Critical 7 - Desirable 5 - Useful 3 - Ambivalent 1 - Unimportant

Check-In Category: Propulsion & Drive Train	Component: Transmission Fluid Pressure

Importance Rating: 1

Rating Factors:

- Enunciator panel can alert the driver to the problem.
- Statistically this problem does not occur that often.

Check-In Category: Emergency Incident Response	Component: Fire Extinguisher

Importance Rating: 1

Rating Factors:

- Identifying the presence of a fire extinguisher provides no significant data for entry or operation on an AHS.

Check-In Category: Emergency Incident Response	Component: Spare Tire

Importance Rating: 1

Rating Factors:

- Identifying the presence of a spare tire provides no significant data for entry or operation on an AHS.

Check-In Category: Emergency Incident Response	Component: First Aid Kit

Importance Rating: 1

Rating Factors:

- Identifying the presence of a first aid kit provides no significant data for entry or operation on an AHS.

Information Analysis Documentation

Rating Scale: 9 - Critical 7 - Desirable 5 - Useful 3 - Ambivalent 1 - Unimportant

Check-In Category: Emergency Incident Response	Component: Flares & Reflectors

Importance Rating: 1

Rating Factors:

- Identifying the presence of flares and reflectors provides no significant data for entry or operation on an AHS.

Check-In Category: Emergency Incident Response	Component: Communication Equipment

Importance Rating: 1

Rating Factors:

- Identifying the presence of communication equipment in addition to the AHS communication system provides no significant data for entry or operation on an AHS.

Check-In Category: Driver Qualifications	Component: Outstanding Tolls/Tickets

Importance Rating: 1

Rating Factors:

- Identifying whether the driver has outstanding tolls or tickets provides no significant data for entry or operation safely on an AHS.
- Outstanding tolls does not necessarily disqualify a driver from using an AHS.

Check-In Category: Vehicle Regulatory	Component: Law Enforcement Reports

Importance Rating: 1

Rating Factors:

- Identifying whether the driver has outstanding warrants or the vehicle is stolen provides no significant data for entry or operation on an AHS.

Information Analysis Documentation

Rating Scale: 9 - Critical 7 - Desirable 5 - Useful 3 - Ambivalent 1 - Unimportant

Check-In Category: Vehicle Regulatory	Component: Registration

Importance Rating: 1

Rating Factors:

- Identifying whether the vehicle is registered provides no significant data for entry or operation on an AHS.

Check-In Category: Vehicle Regulatory	Component: Insurance

Importance Rating: 1

Rating Factors:

- Identifying whether the driver and vehicle are insured provides no significant data for entry or operation on an AHS.

Check-In Category: Vehicle Regulatory	Component: Smog Certification

Importance Rating: 1

Rating Factors:

- Identifying whether the vehicle meets smog emission standards provides no significant data for entry or operation on an AHS.

Check-In Category: Vehicle Characteristics	Component: Occupancy

Importance Rating: 1

Rating Factors:

- Identifying vehicle occupancy provides no significant data for entry or operation on an AHS.
- May be more important if preferential treatment is given for high occupancy vehicles (i.e. special high speed lanes).

Information Analysis Documentation

Rating Scale: 9 - Critical 7 - Desirable 5 - Useful 3 - Ambivalent 1 - Unimportant

Check-In Category: Safety Systems	Component: Doors Ajar

Importance Rating: 1

Rating Factors:

- Identifying whether the vehicle doors are ajar provides no significant data for entry or operation on an AHS.
- Driver can monitor and correct.

Check-In Category: Safety Systems	Component: Windshield Visibility

Importance Rating: 1

Rating Factors:

- Assessing windshield visibility provides no significant data for entry or operation on an AHS.
- Driver must have had adequate visibility to get to the check in point.

Check-In Category: Safety Systems	Component: Mirrors

Importance Rating: 1

Rating Factors:

- Identifying whether vehicle mirrors are properly adjusted provides no significant data to enter or operate on an AHS.
- Driver can note and adjust.

Check-In Category: Safety Systems	Component: Emergency Exits

Importance Rating: 1

Rating Factors:

- Identifying whether the vehicle has emergency exits provides no significant data to enter or operate on an AHS.

Information Analysis Documentation

Rating Scale: 9 - Critical 7 - Desirable 5 - Useful 3 - Ambivalent 1 - Unimportant

Check-In Category: Vehicle Regulatory	Component: Permits

Importance Rating: 1

Rating Factors:

- Identifying whether the vehicle and operator have required permits (i.e. hazardous materials) provides no significant data for entry or operation on an AHS.

Check-In Category: Safety Systems	Component: Airbags

Importance Rating: 1

Rating Factors:

- Identifying whether the vehicle is equipped with airbags provides no significant data for entry or operation on an AHS.

Check-In Category: Safety Systems	Component: Seat Belts

Importance Rating: 1

Rating Factors:

- Identifying whether the vehicle is equipped with seat belts provides no significant data for entry or operation on an AHS.

APPENDIX B

The following is from an AHS write-up received from the MITRE corporation. It was sent out to user survey participants prior to attending the focus groups. Following this write-up are the actual user survey questions and responses from the focus groups.

WHAT IS HIGHWAY AUTOMATION?

EVOLVING TRANSPORTATION NEEDS

The American public expects a national transportation system that is both safe and efficient, and provides them with great mobility (that is, they can get where they want to go when they want to)--all while improving quality of the environment and reducing fuel consumption. These expectations create great pressures on the nation's transportation system to continue evolving to meet society's needs.

Much of this pressure is on the nation's highway system. For example, the driving public wants a roadway system that is safe, pleasurable, and has adequate capacity so that congestion is held to a minimum. Similarly, businesses and local transit companies want a roadway system that is inexpensive and reliable and provides access to its customers and suppliers. Today's system is not keeping up with these increasing demands:

- Safety

  Driver error causes, or contributes to, 91% of all accidents; the cost of fatalities and accidents is now over $137 Billion annually.

- Capacity

  Traffic volume on the nation's highways has increased between 38 and 54 percent for each of the last three decades; 70% of urban Interstate rush hour trips are in congestion--this is expected to be 80% by the year 2000; today's congestion costs the nation over $100 Billion annually.

RESPONDING TO THE NEEDS

The US Department of Transportation has a research program that is looking at ways to improve all forms of surface transportation including rail, transit and highway travel. One objective is to avoid, where possible, adding more lanes to today's urban highways because of the cost and impact on society. There are at least two ways in which this can be accomplished:

- Reduce Use of Highways

  This can occur in two ways:

  -- Improved Public Transit - Improved service and better information are being encouraged; the addition of urban rail systems is also an option, although this can be expensive. The impact on number of vehicles on the road varies from area to area.

-- Increase Carpools and Work-at-Home Programs - Highway demand can be reduced by encouraging more carpooling and encouraging work-at-home jobs; the extent to which congestion is reduced depends on the extent of public and business cooperation

- Improve Highway Safety and Efficiency

  One major research area is the Intelligent Vehicle/Highway System (IVHS) program. The Federal Highway Administration (FHWA) is responsible for this effort; the National Highway Traffic Safety Administration (NHTSA) and the Federal Transit Administration (FTA) are cooperating with the FHWA as are many universities and private companies. Areas of research include:

  -- Improve Highway Safety - Programs are looking at all aspects of highway safety for buses, cars and trucks, including how to reduce driver error; however, as long as the driver has control, there will be errors.

  -- Improve Highway Efficiency - There are several efforts aimed at doing this; however, major improvements are not possible because of the limitations of human drivers.

AUTOMATED VEHICLE CONTROL TECHNOLOGY

Part of the IVHS program is an area of research called Advanced Vehicle Control Systems (AVCS) that is focused on reducing driver error in avoiding collisions. Included in this area are warning systems as well as systems that apply electronic sensing and control to assume partial control of the vehicle in dangerous situations. This Partial Vehicle Control is based on the fact that electronic systems can react faster than humans and can react more consistently and correctly in responding to a potential danger. This is why electronic control systems are used in airplanes, spacecraft and power plants. Examples of two Partial Vehicle Control Systems that could be a vehicle include (1) an "Intelligent Cruise Control" that keeps a vehicle a safe distance from the vehicle in front; and (2) a "Lane-Keeping Control" that maintains a vehicle's position within its lane. These systems are being designed to enhance vehicle safety on today's roads.

Researchers believe that the greatest benefit of vehicle control technology will come when a specific highway lane is reserved for vehicles that are operating exclusively with Intelligent Cruise Control and Lane-Keeping Control. This would ensure that vehicles move at uniform speed and at safe distances between vehicles (where the distance is based on electronic rather than human response times). It would eliminate human-caused accidents. The integration of these control capabilities into a single systems is called Full Vehicle Control since it would allow hands-off and feet-off vehicle operation.

By eliminating the human-caused accidents, a very large improvement in safety may be possible--far more than would be possible in a lane where vehicles are controlled by the drivers. Roadside controls would ensure that accidents would not occur, except in unusual situations (for example, a deer jumps in the road or there is a system malfunction); then, the system would respond rapidly and correctly to avoid or minimize crashes.

Initial studies have also shown that a Full Vehicle Control system lane may have double the capacity of other highway lanes. This is because the traffic flow will be at a constant speed and will not be impacted by drivers with limited skills, inattentiveness (such as "rubber necking"), and over-aggressive tendencies. It would also permit vehicles to operate at closer spacing than they can today, thereby increasing capacity per lane. In short, Full Vehicle Control is expected to significantly improve highway efficiency, safety, mobility, and trip reliability. Because of this potential, the FHWA is conducting a research effort to determine the feasibility of using Full Vehicle Control technology to modernize the nation's highways; the FHWA calls this project the Automated Highway System (AHS) program.

HOW AN AUTOMATED HIGHWAY SYSTEM (AHS) OPERATES

Special lanes would be set up for vehicles equipped to operate on the AHS; these lanes could be similar to the HOV lanes on many of today's highways. Drivers with AHS-equipped vehicles would enter into the AHS lane; drivers without AHS-equipped vehicles would not be allowed to enter. Once in the lane, control of the vehicle would be assumed by the AHS system, much as the gas pedal is controlled by today's cruise control. The driver would indicate which exit is desired; when the vehicle arrives at that exit, the vehicle would be moved into the exit by the system and the driver would resume control of the vehicle. While in the AHS lane, the driver would not be allowed to control the vehicle; the driver could relax, look at the scenery or read a book.

THE BUILDERS AND USERS OF AHS

There are many ways in which AHS may evolve and its technology be applied. Any AHS implementation will be planned by state, regional or local transportation planners. The choice of an AHS would represent their belief that AHS technology is an effective use of their transportation funds for the circumstances in their state, region, or city. An AHS implementation will be in concert with, and fully compatible with, other programs aimed at reducing pollution through the use of alternative fuel sources, increased transit use and ride-sharing. An AHS must be viewed as one part of an overall balanced effort aimed at improving transportation moving toward a cleaner environment. For these reasons, the common AHS system standards may be installed in different ways across the nation. Below, a few of the possibilities are described.

- Transit Vehicles First

  This approach assumes that separate lanes would be set up for transit vehicles on certain highways; for example, a reversible express bus lane could be established on a major artery in a large urban area. The use of AHS technology would allow the vehicles to operate more efficiently and safely, and with greater trip predictability; the exits could correspond to parking lots and/or to terminal points for local transit vehicles.

- Passenger Vehicles First

  As more and more drivers use Intelligent Cruise Control and Lane-Keeping Control, the transportation planners would decide to dedicate a separate lane to these drivers so that the benefits of high safety efficiency can be realized.

- High Occupancy Vehicles Only in Rush Hour

  The transportation planners could decide that only vehicles with multiple passengers, including transit vehicles as well as van-pool and car-pool vehicles, could use the AHS lanes in rush hour.

- Commercial Vehicles First

  In areas of high truck traffic such as between major east coast cities, separate lanes would be established for the heavy vehicles; as with the transit vehicle lane, the AHS technology would ensure safe, efficient movement of goods with far greater trip predictability. The lanes could be extended into nearby docking facilities. Most trucks would be moved off of the passenger vehicle lanes.

- Dense Urban Areas

  If pollution continued to increase in a major urban area, the transportation planners could decide to restrict center-city access to only vehicles with alternative fuel sources, and/or of limited size; such a policy, albeit extreme by today's standards, could be supported with AHS technology.

Automated Highway Systems (AHS)
Check-in Survey

"The Automated Highway System (AHS) vision can be summarized as a system of instrumented vehicles and highways that provide fully automated (i.e. "hands off") operation at better levels of performance than today. It is deployable to both urban and rural areas and preserves the ability of instrumented vehicles to operate on roadways."

Check-in Scenarios

Different check-in scenarios have been proposed. We would like to know your feelings about some of the options currently being considered.

1. What is most important to you when merging onto a highway or into a new traffic lane (e.g. safety, flow of traffic, personal comfort, etc.)?

Majority Opinions:

Safety
-- looks safe
Traffic flow
-- match the speed of traffic
-- getting on the lane quickly without affecting flow
-- speed merging capability
-- easy access

****

2. A check-in station (similar to today's metered on-ramps) may provide drivers fully automated check-in through the use of sensors or allow drivers to interact via "smart card" insertion. How do you feel about the use of a check-in station which may require vehicles to slow down or stop prior to entering the automated lane?

Majority Opinions:

Stopping is Acceptable
-- similar to stops prior to entering freeway (i.e. ramp metering) - if waiting time is greater than 10-30 seconds, it's too much
-- if there is increased performance, don't mind stopping
-- stopping okay to screen out non-automated vehicles
Prefer not to stop
-- concern for long delays - waiting period
-- depend on how long the wait would be
-- cause more pollution whenever you stop/slow down
-- don't want to impede flow of traffic
Completely automated better

-- cards may be forgotten/misplaced/searching for while in line
-- zero driver interaction so system doesn't slow you down

Other Opinions:

No stopping is a must
Would there be several stations?
How would you stop someone from getting on?
Use a tire tread pop-up to discourage illegal usage

****

3. A transition lane may provide fully automated check-in "on-the-fly." How do you feel about the use of a transition lane for check-in?

Majority Opinions:

Prefer transition lane
-- most dangerous thing about a freeway is entering and exiting
-- transition lane is already on the road so that a user does not have to get off the freeway just to get onto a ramp for the AHS (like the check-in station scenario)
-- transition lanes are a must
-- easier to transition from freeways
-- prefer not to stop on transition lane
-- concerned about non-AHS vehicles easily entering the AHS lane

Other Opinions:

Optimum would be a combination of both a station and transition lane
Separate the manual and automated highways - don't mix apples and oranges
If it increases congestion because there would be a reduction in manual lanes, this is not acceptable
Will there have to be both a station and lane? Prefer not

****

4. How do you feel about the use of an obstacle course prior to check-in to verify a driver's or the automated vehicle's current capability (e.g. driver is not intoxicated, steering and brakes are safe)?

Unanimous Opinions:

No obstacle course!
-- driver would be irritated to have so slow down to enter the test
-- what happens when a car fails, does a tow truck have to come and get it out of the way?
-- should not be needed (given certification requirements, etc.)
-- viewed as an impediment to the system
-- don't want the extra steps
-- waste of time

****

5. Which method of check-in do you prefer?

Majority Opinions:

Transition lane (roughly two-thirds of participants favored transition lane)
-- worried about manual cars getting into AHS
-- more options to get into the AHS

Other Opinions:

Check-In station

-- trade-off's are acceptable for stopping and getting added benefits of less congestion

Drivers with short trips may view AHS as an inconvenience

Neither method - would like to see the AHS in the right-hand lane so that there would be entry/exit without disrupting manual traffic.

****

Check-in Criteria

AHS check-in may require certain vehicle and/or driver criteria is met prior to entering the automated lane. We would like to know how you feel about some of the potential requirements for AHS check-in.

6. Should AHS check-in require that a driver meets certain minimum driving requirements (i.e., valid driver's license, insurance, certification training) for highway access?

Majority Opinions:

Driver's license should be required

-- special category for operating a more complex system

-- it is your privilege to drive, not your right

AHS certification

-- reasonable to have certification training

-- just as truck drivers and other classifications of vehicle drivers require special training, this system should have training as well

Other Opinions:

No additional requirements than already needed for driving today

Driver's license, registration, no parking tickets, outstanding warrants

Training, Driver's license, insurance (all on same card)

Thumbprint for ID, but needs to happen "on-the-fly"

"Big Brother" fear - wouldn't like others to know background

Adds layer of complexity to require additional information

Wouldn't feel any safer about other drivers knowing that they've been checked - no value added

****

7. What kind of training would you accept, if any, to use AHS check-in? How can training best be provided to you?

Majority Opinions:

Some minimal training is acceptable, but not the preference

-- minimum familiarization should be required - including highway interfaces

Offer training through the DMV

-- no more than one hour

-- have training at the DMV during driver's license renewal - program into magnetic strip on license

Other Opinions:

Standardization of training? What if different vehicles have slightly different AHS equipment - much like various cruise control devices today? Dealer should demonstrate equipment when you decide to purchase your car - or from manufacturer
System should be obvious, no training required (i.e. via use of signs)
Private training only
-- a private consortium with a profit basis would yield a better product in all aspects of AHS
Training should be offered privately and publicly
Provide training by video, local high school, DMV

****

8. Should AHS training certification be required as part of your driver's license test and shown on your driver's license?

Majority Opinions:
Yes, if you're going to use it
-- AHS-compatible vehicle and training - on magnetic strip

Other Opinions):
Training certification required during transition phase, but automatic when fully automated
Yes, someday you'll use it
Yes, everyone should know even if they don't use it
Afraid of overstepping bounds - "Big Brother"
Should be private - no connection with DMV

****

9. What factors do you consider before having your vehicle maintained (e.g. cost, convenience, preventative maintenance, only when it's broken or required)?

Majority Opinions:
Cost
Preventative maintenance (especially if it's a new car)

Other Opinions:
Convenience
When something breaks

****

10. How often, in time or miles, would you be willing to have your vehicle inspected for minimum safety requirements of critical systems such as brakes, steering, AHS systems, etc.?

Majority Opinions:
Every two years - same as smog testing
-- considering other drivers, at least every 2 years
-- probably will cost about $100, so 2 years

Other Opinions:
Six months is okay if it doesn't cost too much and doesn't take too much time
Once a year is not inconvenient if done with other things (i.e.tune-up, etc.)
-- more than once a year is too much

At least once a year! Several states already have mandatory annual safety inspections, such as Florida
Every 5 years
Should not be required
More frequent maintenance done by themselves (oil changes, etc)
Should be based more on miles than on time

****

11 How much would you be willing to spend for the additional maintenance and/or repair to keep your vehicle's critical systems and AHS check-in components in safe and working order?

Majority Opinions:

$100-200 a year
-- assuming AHS available for use (i.e. benefits are a advertised)
-- $200 a year maximum

Other Opinions:

Whatever it takes to keep the system working
$25-$75 per month (i.e. $300-$900 per year)
Zero cost - why should it break? Not anticipating regular maintenance for this.

****

12. Should safety inspections be mandated? Why or Why not?

Unanimous Opinions:

Yes
-- should be mandatory - confidence in other driver's vehicles
-- concern about safety
-- all cars should meet some minimum requirement
-- like smog checks
-- yes, because people don't take care of their cars. Need to consider your safety and other people's current poor maintenance of cars
-- there are those in society that will not adhere to requirements unless they're forced to do so

****

Check-in Information

AHS may require certain vehicle and/or driver information for check-in. We would like to know your feelings about releasing personal information.

13. What types of information would you allow AHS to verify for check-in (i.e., driver's license number, insurance, training certification, vehicle registration and license, vehicle maintenance records, etc.)?

Majority Opinions:

Any information relating to driving is okay to check plus criminal record
-- driver's license
-- destination
-- AHS-compatible vehicle and vehicle meets standards
-- check if vehicle is stolen (off registration number?)

-- maintenance information should be handled via expiration
-- driver registration
-- certification and vehicle capabilities
-- last maintenance/inspection date

Other Opinions:
Any personal information should remain private

****
14. Should the proper authorities or agencies be allowed to use check-in information for statistical purposes or locating drivers (including criminals or intoxicated drivers)?

Majority Opinions:
Yes for intoxicated drivers
-- good idea, but what about false alarms
-- how would you enforce it? - prevention/elimination from highways
Yes for criminals
-- you do not have to use the AHS - there is a choice
Statistical information released only on a collective basis, not individually
-- no junk mail!
-- no names, no addresses to outsiders

Other Opinions:
AHS may be safest place for intoxicated drivers - What's to prevent from getting on the manual freeway?
Prefer not to let authorities utilize information
No, authorities have no right to your privacy, they may check the vehicle and that's all. If they need to locate you, they have the means to do that other than through the AHS

****
Driver Interaction

The AHS check-in infrastructure may be fully automated, verifying that a vehicle or driver meets a certain set of criteria prior to entering the automated lane; or it may allow for driver interaction, providing the driver the ability to override certain non-critical criteria. We would like to know your preference for allowing the infrastructure to control check-in or allowing driver interaction in certain areas of check-in.

15. As a driver, do you always have a specific destination or route in mind prior to getting on the freeway or highway?

Majority Opinions:
No
-- most often know where they want to go, but sometimes go by landmarks, signs, etc
-- .destination-yes route-no
-- as a real estate appraiser, might get a phone call, may not know the off-ramp, and will be looking at the map while driving
-- what if my destination is San Francisco from Los Angeles? How specific would my destination input have to be?

Other Opinions:

Yes (approximately one-third responded "yes")

****

16. Should AHS require the selection of a destination or route prior to check-in or merely provide planning as an option?

Majority Opinions:

Provide destination input requirement as an option only

-- Sometimes just want to drive - should not be required

Other Opinions:

Require a destination input

-- allow system to provide suggestion of route

-- the system needs the input for traffic flow planning and management

-- make the requirement changeable

-- select, but ability to interrupt

****

17. As a user of AHS check-in, would you prefer the infrastructure to control your ability to enter the system (e.g. verification of driver's license, insurance, training certification, minimum safety requirements, etc.), or would you prefer to control some aspects of the check-in yourself (e.g. Smart card insertion, override of such requirements as fuel level or destination)? Specify which aspects.

Majority Opinions:

Less interaction the better

-- user interaction may cause delays

-- engage the system manually, everything else automated

No overriding the fuel requirement, given a destination

Other Opinions:

No overriding

-- concern of other drivers - what would others override?

Override fuel, if don't have gas will just change destination

Insertion of the Smart Card is a good idea so that vehicles may not enter the AHS without the card - this would circumvent bootleg vehicles.

****

Check-in Equipment and Costs

In the future, the cost of operating your vehicle will increase significantly due to tighter emissions regulations, higher fuel costs, maintenance costs, insurance costs, etc. While, most transportation initiatives involve encouraging mass transit usage (i.e. getting rid of single passenger trips), the AHS is one of the only major initiatives aimed at improving efficiency and capacity of existing roadways without reducing the number of private vehicles on the road.

AHS-compatible equipment will be required for check-in. Equipment can be either on-board your vehicle, off-board equipment built into the infrastructure, or a combination of both on-board and off-board equipment. We would like to know your feelings about the associated costs for check-in equipment.

18. What benefits or limitations (e.g. convenience of use, geographical areas of availability, accessibility) of AHS affect the amount you are willing to pay for on-board or off-board check-in components?

Majority Opinions:

Accessibility of AHS, convenience, and "advertised benefits"
-- easy to use, higher speed, safety, smooth transition

Other Opinions:

Depends on other sources of transportation (MetroLink, etc)

****

19. If on-board components are required for use of AHS check-in, what dollar amount (or percentage cost increase) would you be willing to pay to modify or buy a vehicle with AHS-compatible components?

Majority Opinions:

Between $500-$1,000
-- if the benefit is high

Other Opinions:

5-10% increase in purchase cost
$2,000-$10,000
No more than $500
$50
If user traveled a long distance, they would pay more
Will it cost more in different areas?
As an additional package at car dealer when buying a car - add to car payment

****

20. Should drivers not accessing AHS but benefiting from reduced traffic and potential pollution/congestion costs be required to absorb some of the check-in infrastructure costs? Why or why not?

Majority Opinions:

Users of AHS should pay
-- pay through vehicle registration
-- user of system should pay per mile - like a toll

Other Opinions:

Users of highways should pay for it - non-AHS users benefit too
-- this benefits all drivers - automated or not - so general tax is okay

****

21. What sources of revenue should be used to build, repair, and maintain the check-in infrastructure (e.g. transportation taxes, energy taxes, other tax revenues, highway tolls, increases in vehicle registration fees, user fees, etc.)? What dollar amount or increase would you accept?

Majority Opinions:

Use tolls
-- users should pay by the mile
-- 2 cents per use (toll)

<u>Other Opinions:</u>
Pay through registration
-- 10% of registration costs
1-2 cents per gallon (i.e. gas tax)
Gas tax, but what about electric cars? Should there be an "energy tax"
-- electric tax vs. gas tax ---> perceived inequity since they won't be the same
Gas tax is most fair
Concerns about administrative fees with tolls, registration, etc.
Pass on savings to users from marketing companies that utilize (and purchase) the statistical information collected on the AHS
Annual fee
Run the AHS through a private consortium

****
22. Considering the issues of cost, taxes, maintainability, reliability, driver interaction, etc., would you prefer to have the AHS-compatible equipment on-board your own vehicle or in the infrastructure? Which issue(s) have the greatest impact on your answer?

Unanimous Opinions:
As much off-board as possible
-- cost is biggest driver - decreased purchase price of the vehicle
-- off-board reduces duplication on cars
-- tamper resistant problems with on-board equipment
-- individual less pained if more equipment is in the road
-- more safety, less reliability on the drivers, take responsibility out of driver's hands, liability on economy

****
Summary

The potential benefits of AHS include improvements in safety, traffic throughput, air quality, fuel efficiency, use of time, and comfort. The potential costs may include development and maintenance of AHS-compatible equipment (on-board and off-board), costs associated with vehicle safety maintenance and training.

23. Which benefits of AHS are most important to you?

<u>Majority Opinions:</u>
Use of time
-- frustration level goes down - less stress
Safety

<u>Other Opinions:</u>
Comfort
Convenience
Concern about loss of driving freedom

Fuel efficiency
No traffic (traffic throughput), that's why you're on the system, safety next
Training hassle

****
24. Which costs have the greatest impact on your choice to use AHS?

Majority Opinions:
Initial cost (equipment required on vehicle)

Other Opinions:
Maintenance cost

****
25. Considering these benefits and costs, would you use our AHS?

Unanimous Opinion:
Yes!

****

APPENDIX C

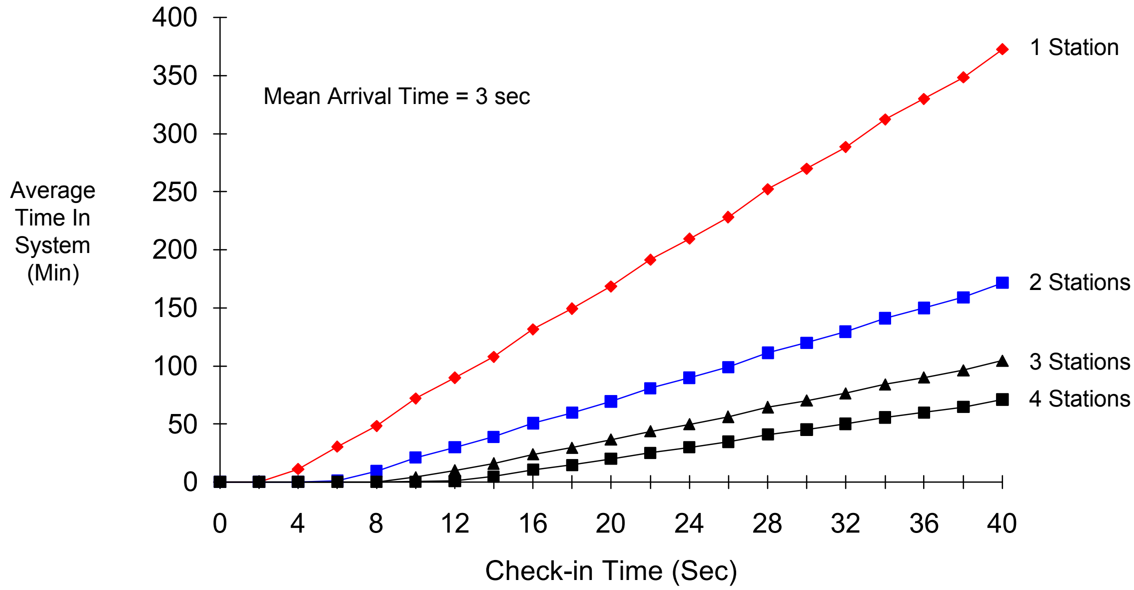

Figure C-1. Average Time In System vs Check-in Time

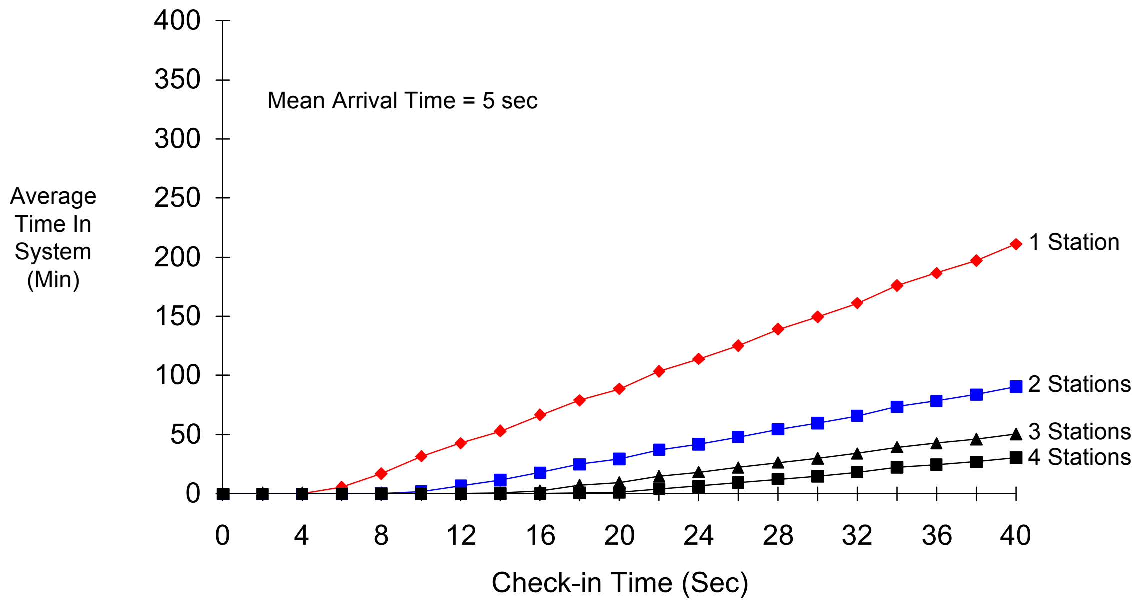

Figure C-2. Average Time In System vs Check-in Time

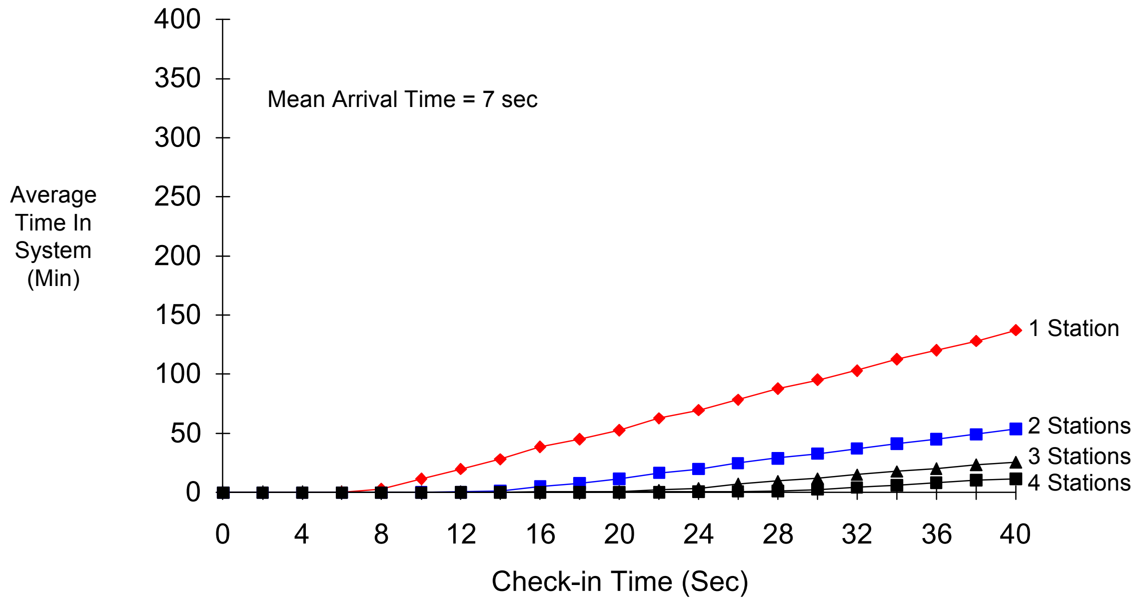

Figure C-3. Average Time In System vs Check-in Time

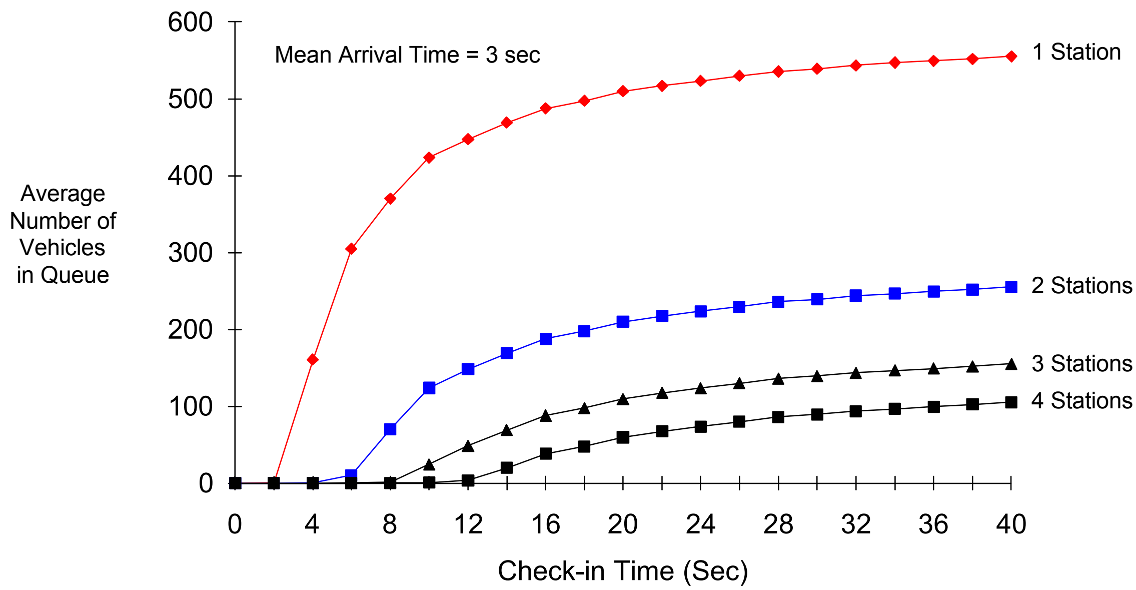

Figure C-4. Average Number Vehicles in Queue vs Check-in Time

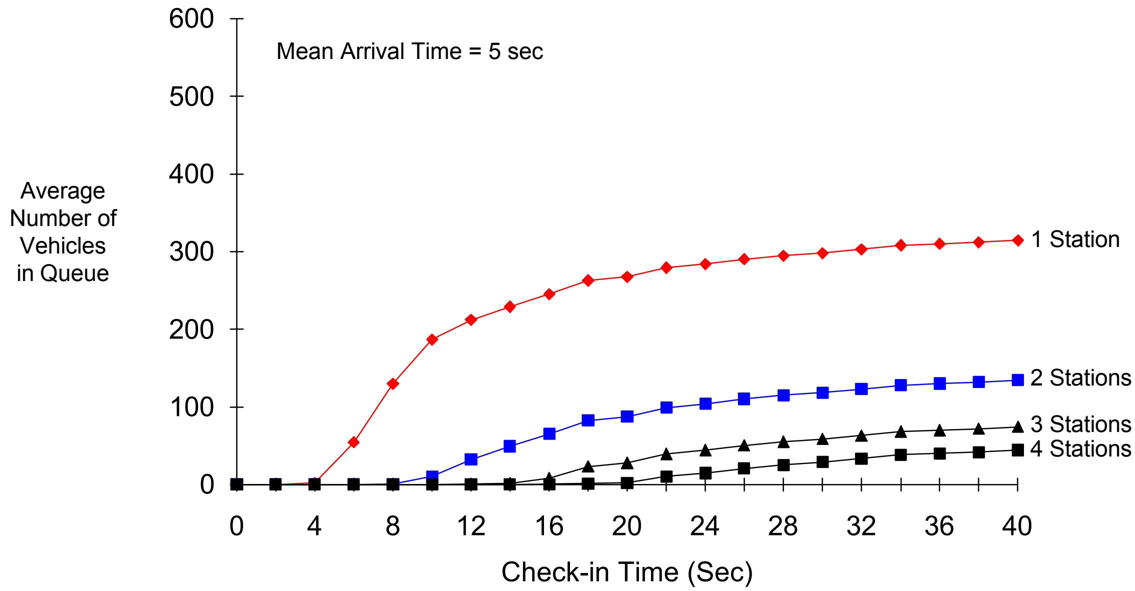

Figure C-5. Average Number Vehicles in Queue vs Check-in Time

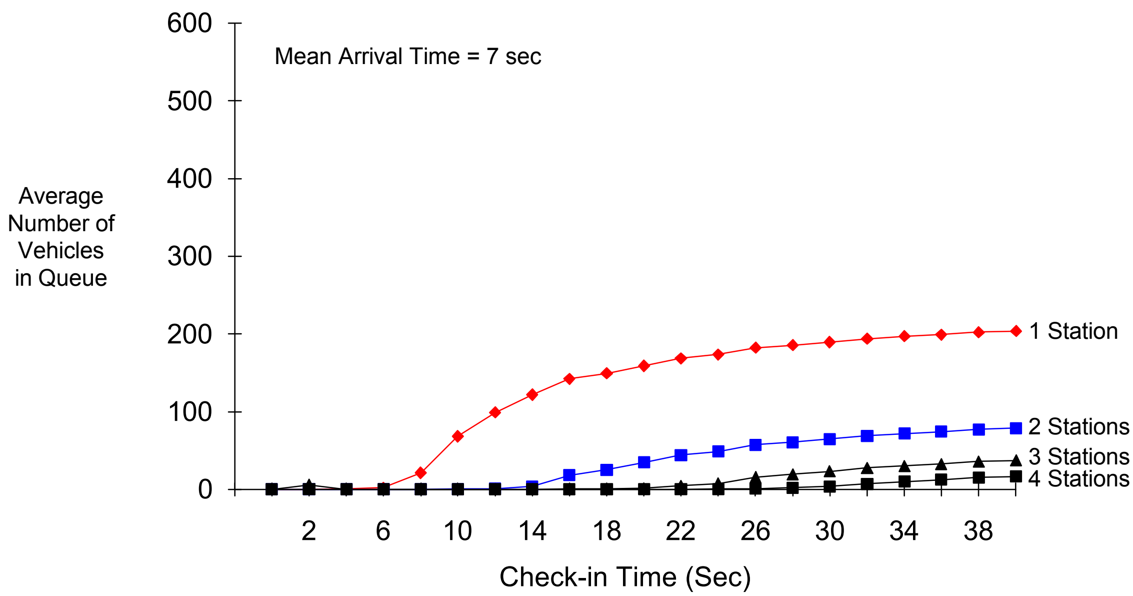

Figure C-6. Average Number Vehicles in Queue vs Check-in Time

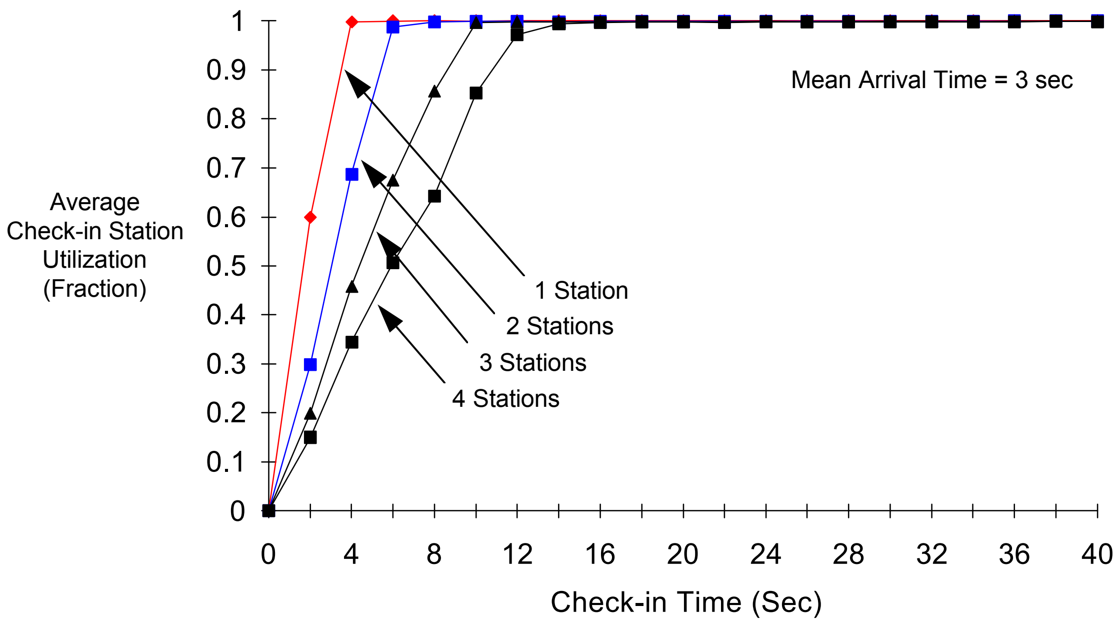

Figure C-7. Check-in Station Utilization vs Check-in Time

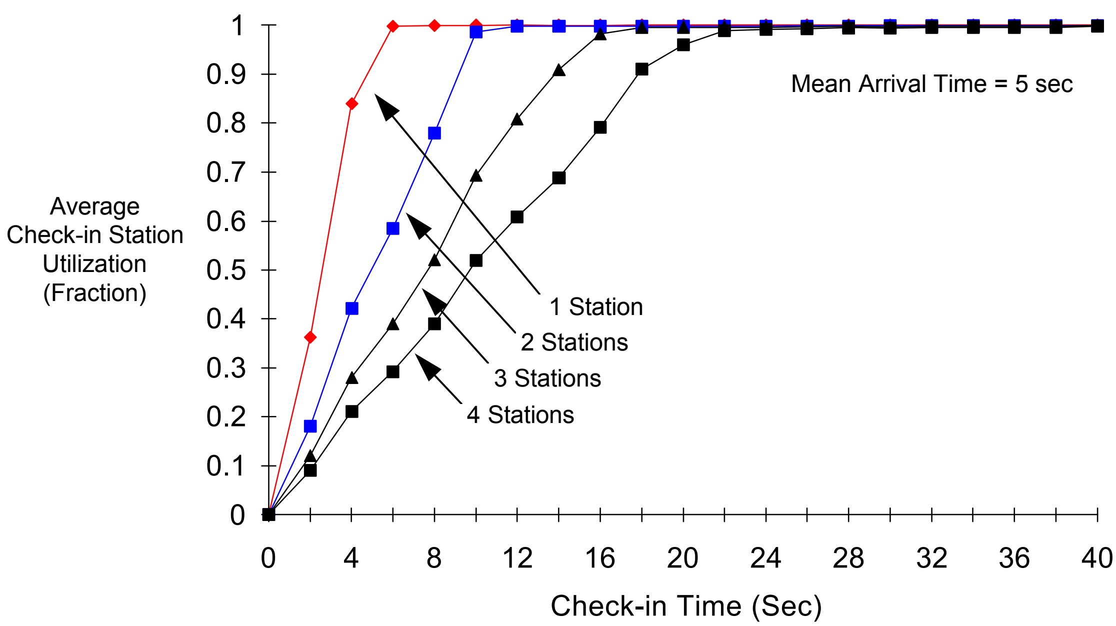

Figure C-8. Check-in Station Utilization vs Check-in Time

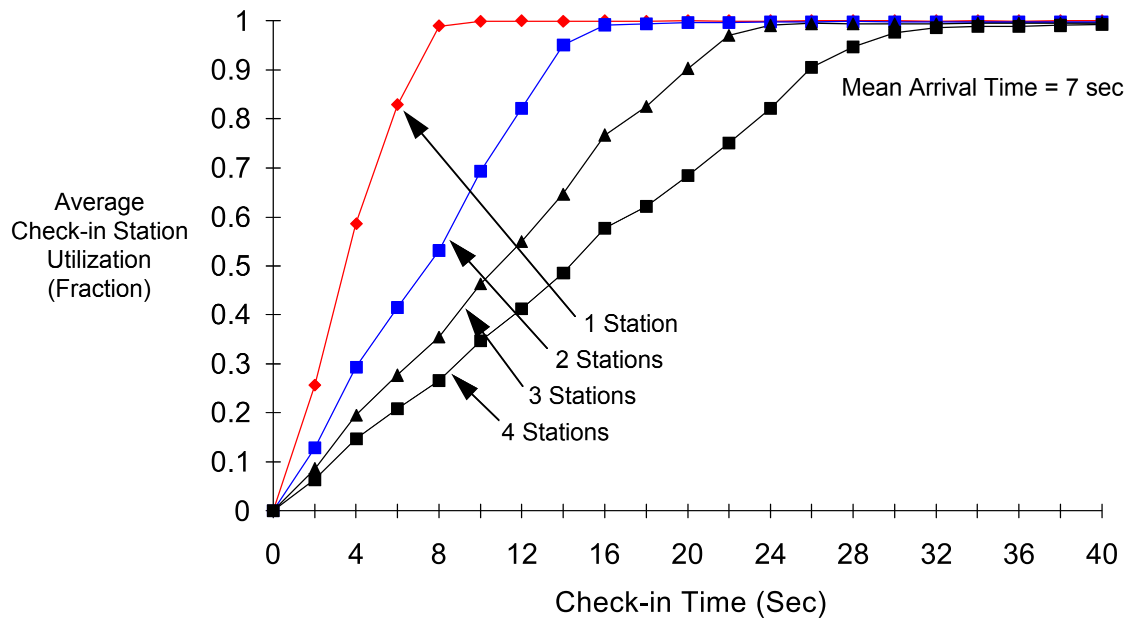

Figure C-9. Check-in Station Utilization vs Check-in Time

APPENDIX D

Baseline - Time to Check-in

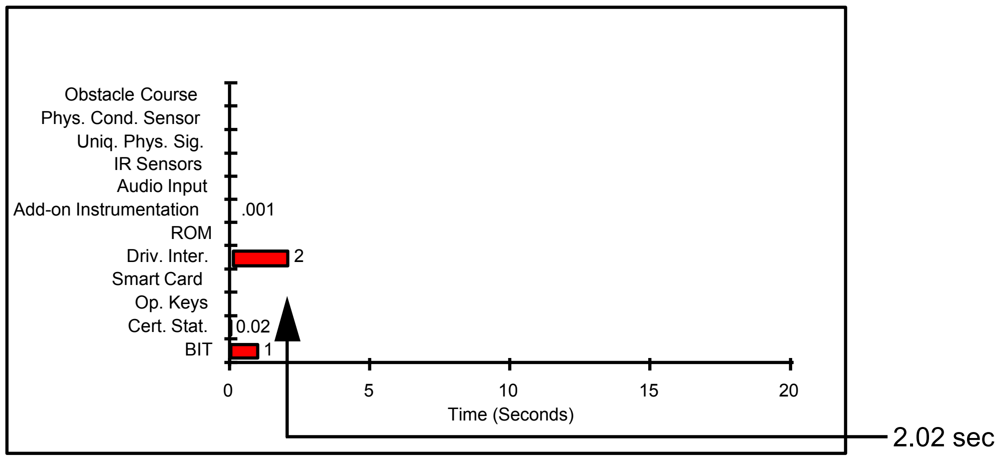

Figure D-1. Before Check-in

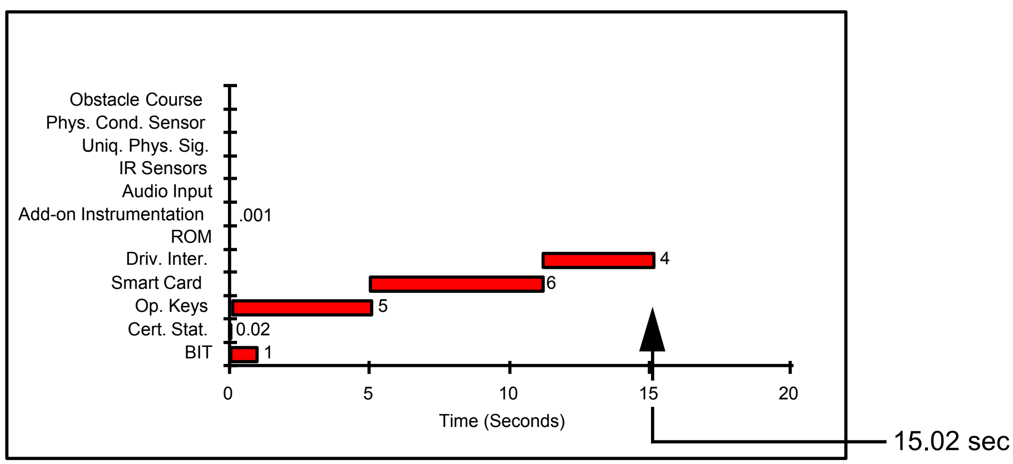

Figure D-2. During Check-in

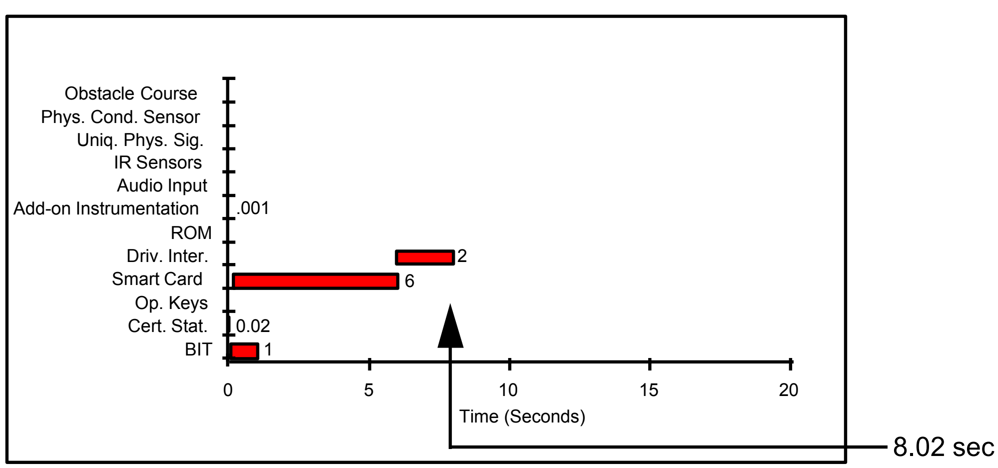

Figure D-3. After Check-in

Alternative 1 - Time to Check-in

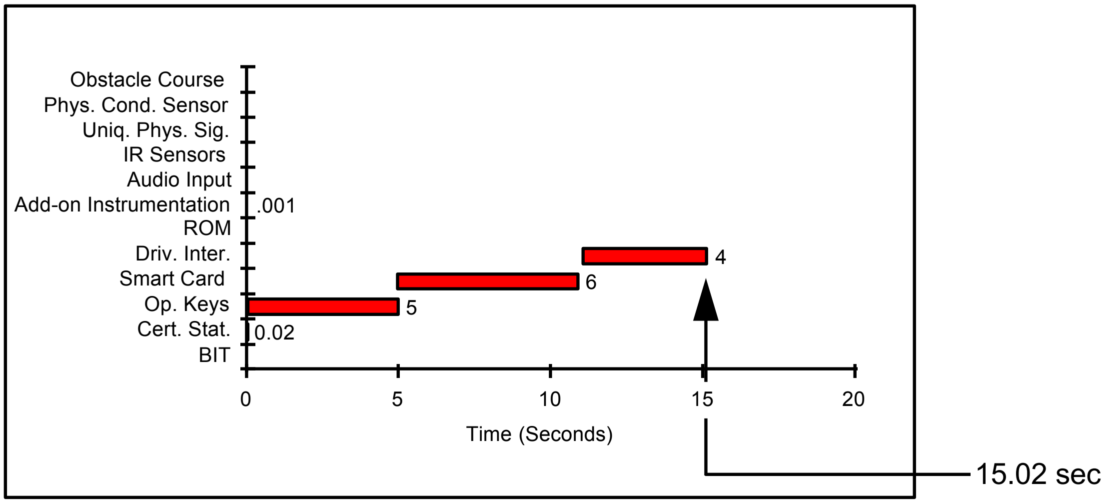

Figure D-4. Before Check-in

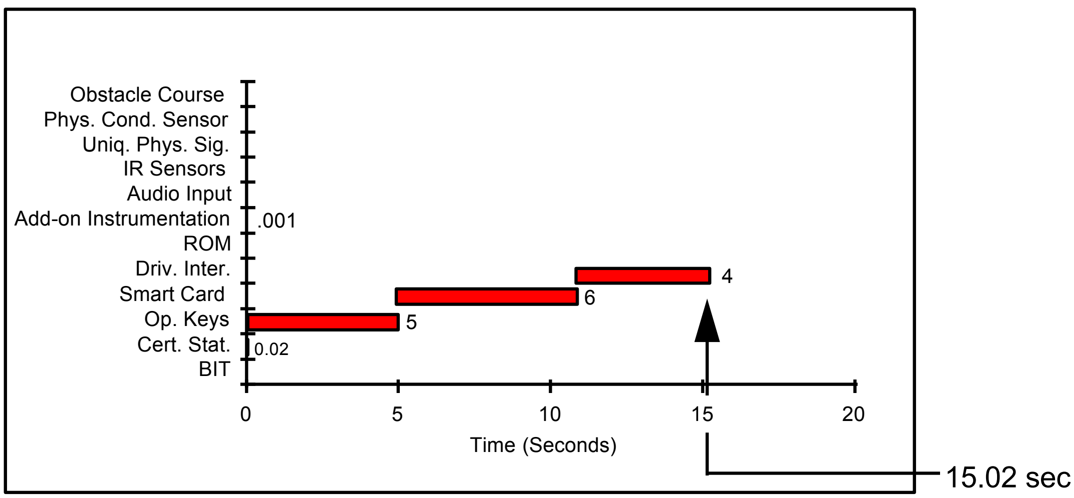

Figure D-5. During Check-in

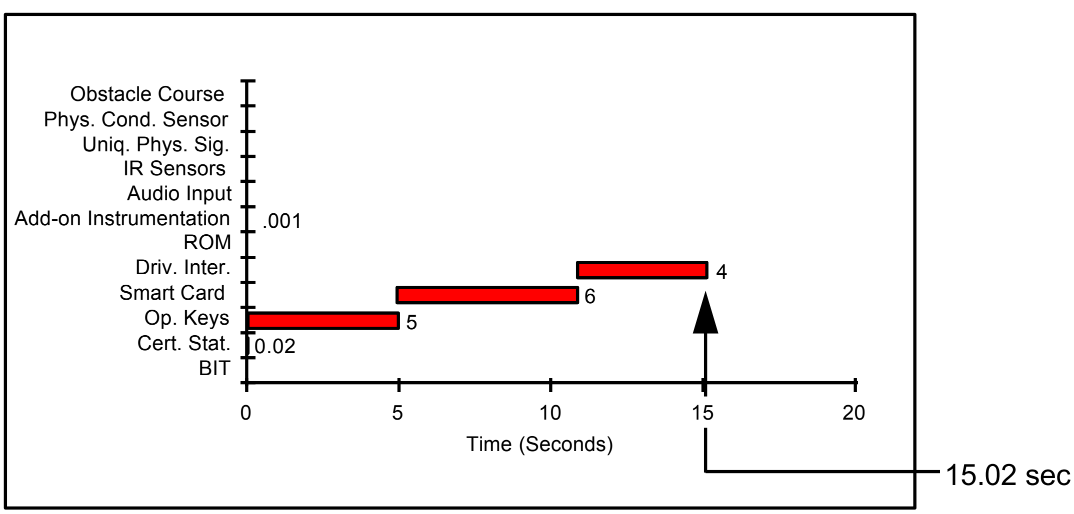

Figure D-6. After Check-in

Alternative 2 - Time to Check-in

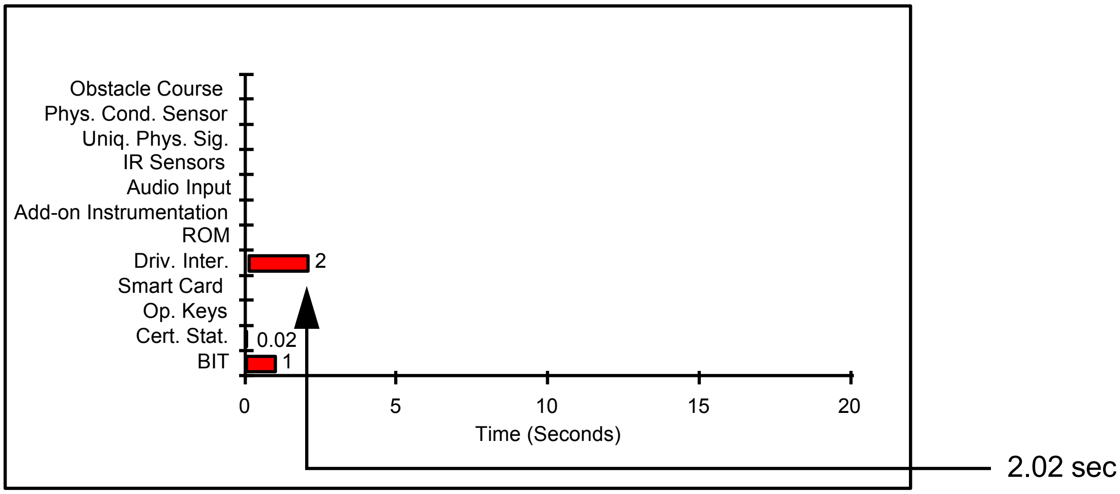

Figure D-7. Before Check-in

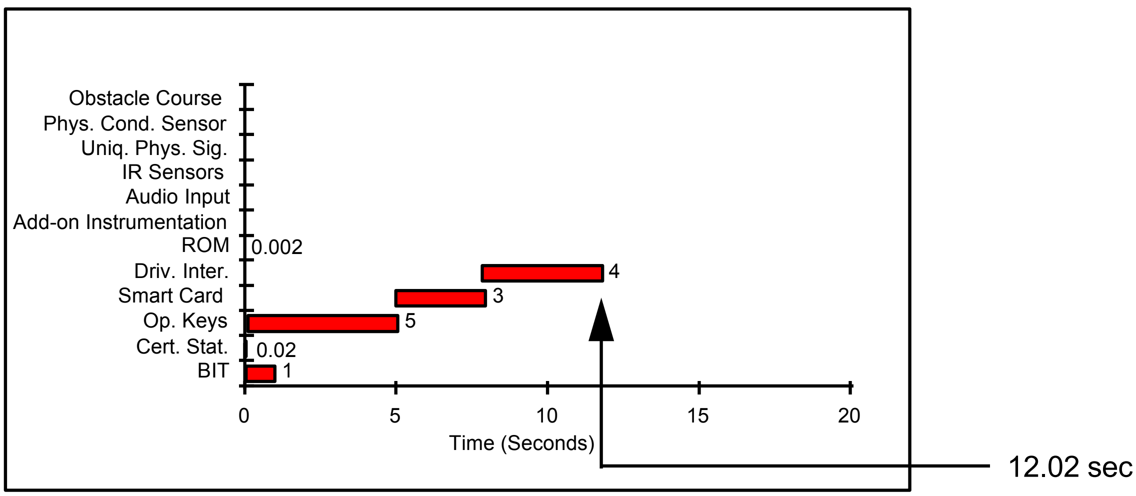

Figure D-8. During Check-in

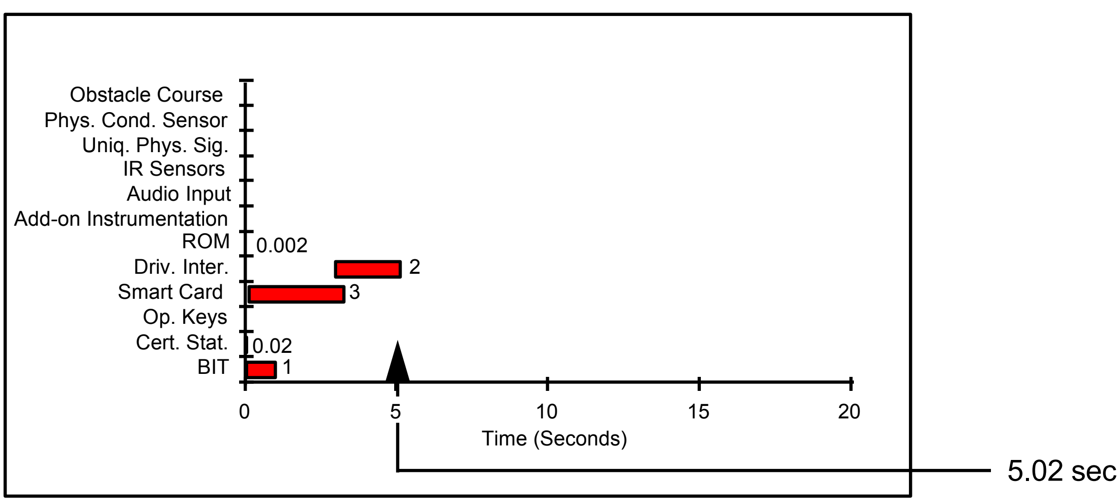

Figure D-9. After Check-in

Alternative 3 - Time to Check-in

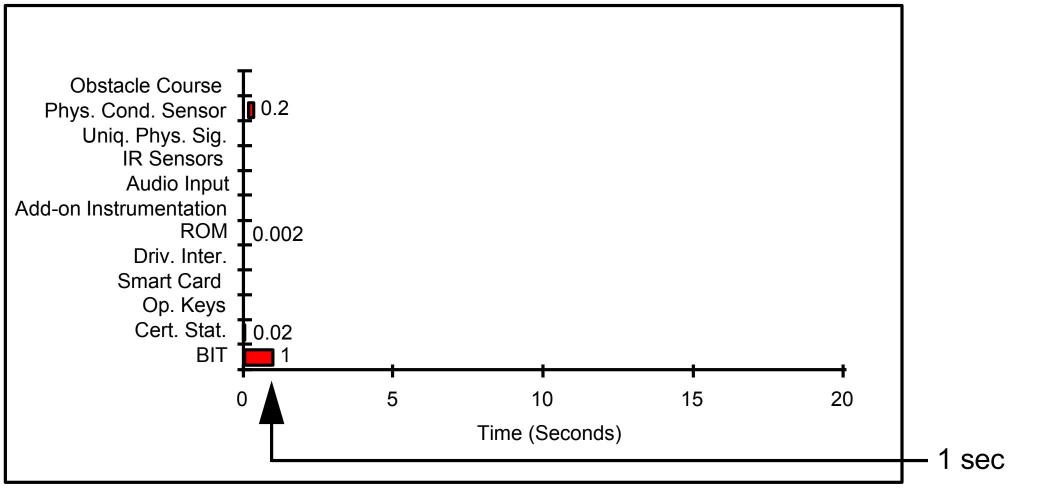

Figure D-10. Before Check-in

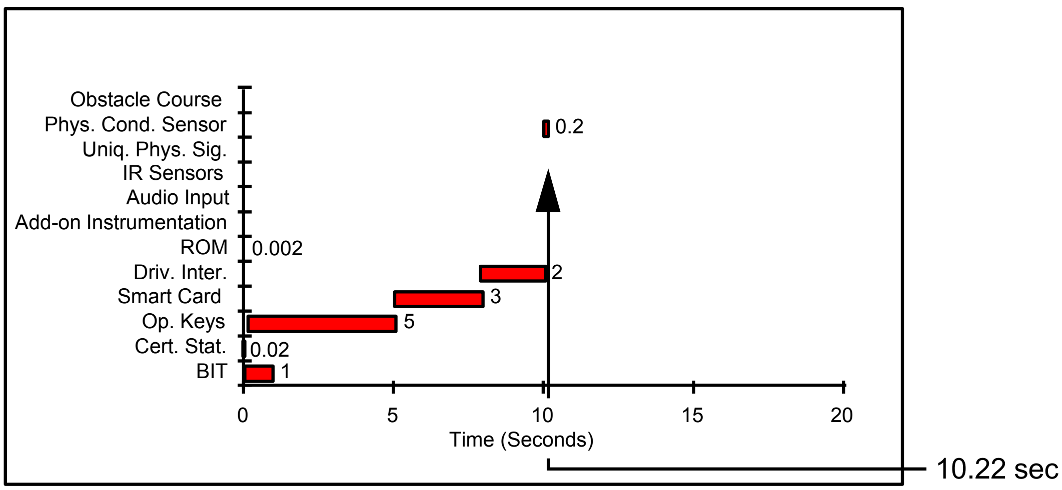

Figure D-11. During Check-in

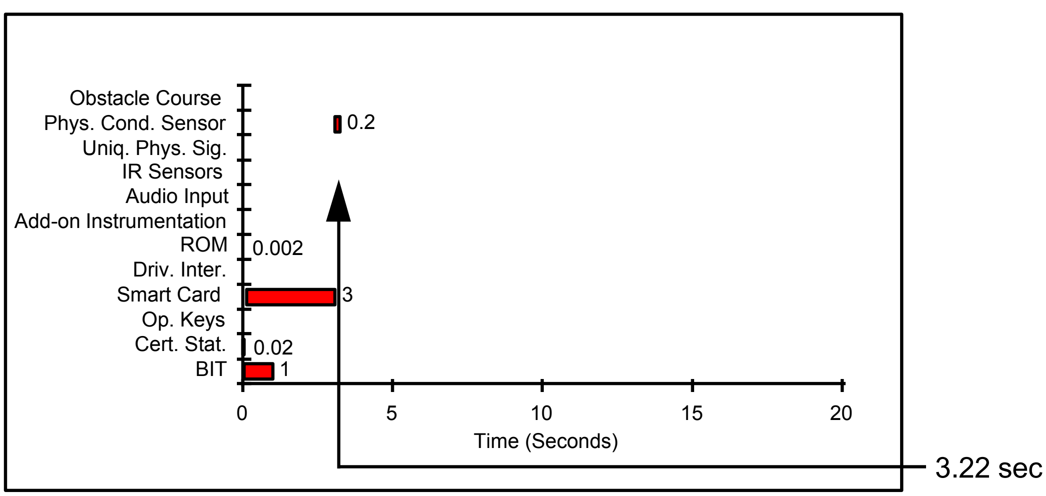

Figure D-10. After Check-in

Alternative 4 - Time to Check-in

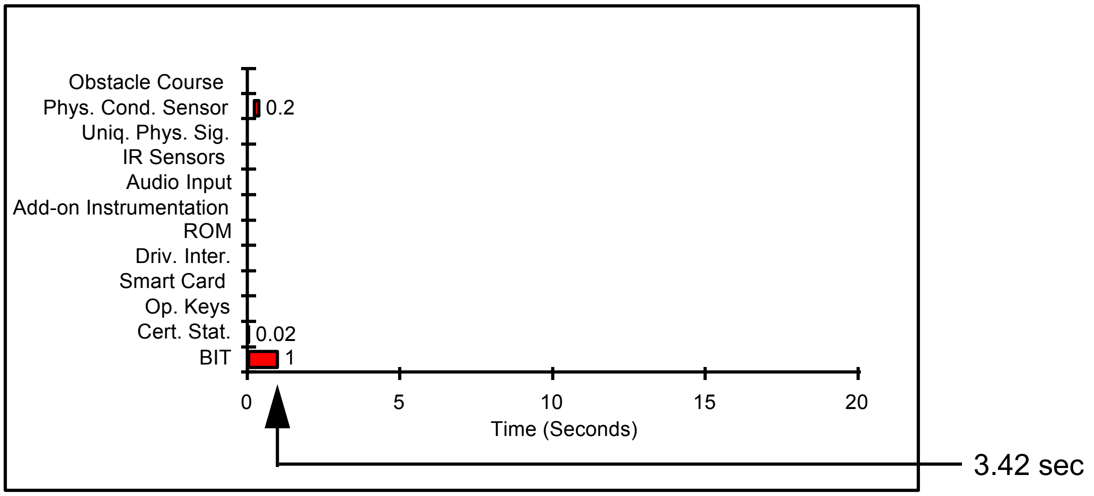

Figure D-13. Before Check-in

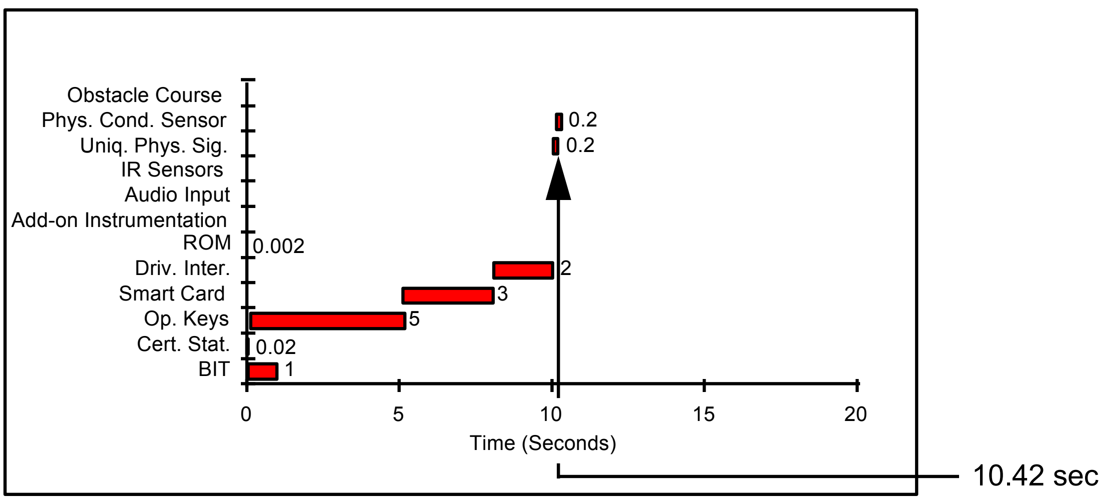

Figure D-14. During Check-in

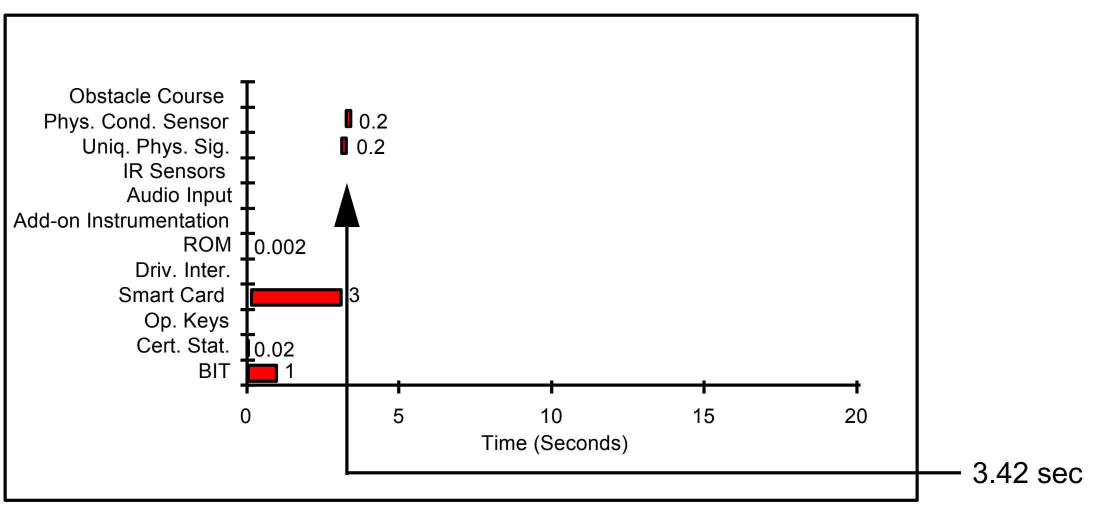

Figure D-15. After Check-in

Altenative 5 - Time to Check-in

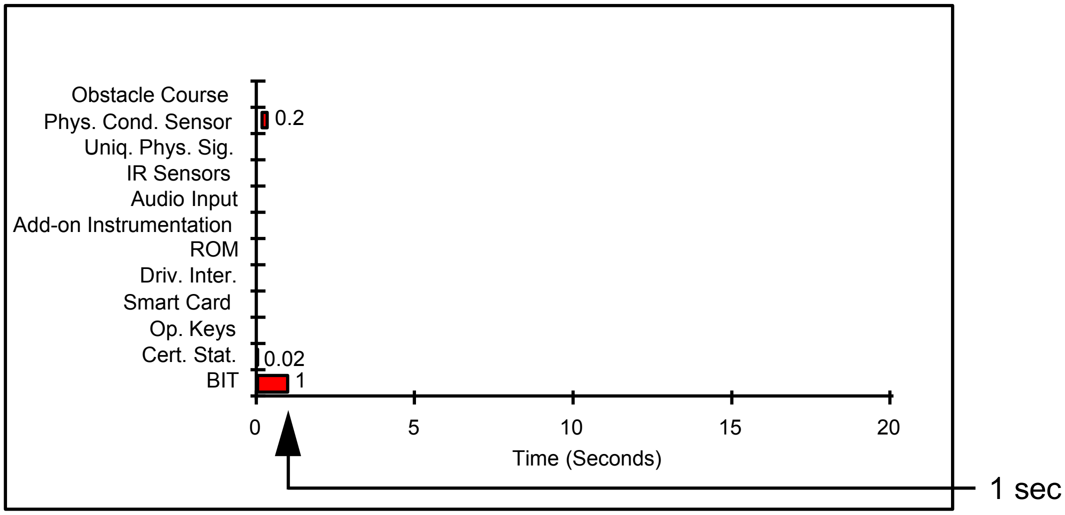

Figure D-16. Before Check-in

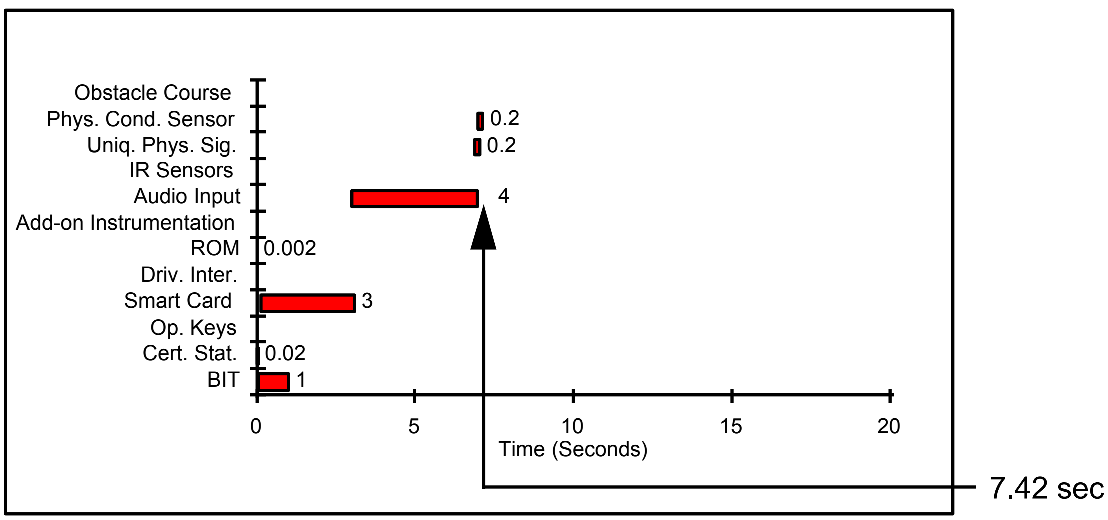

Figure D-17. During Check-in

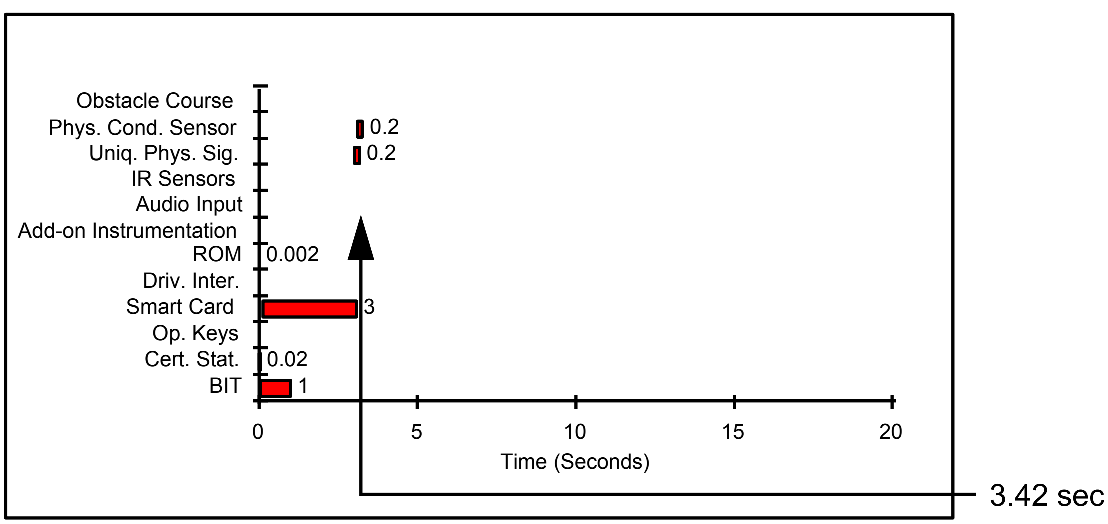

Figure D-18. After Check-in

Alternative 6 - Time to Check-in

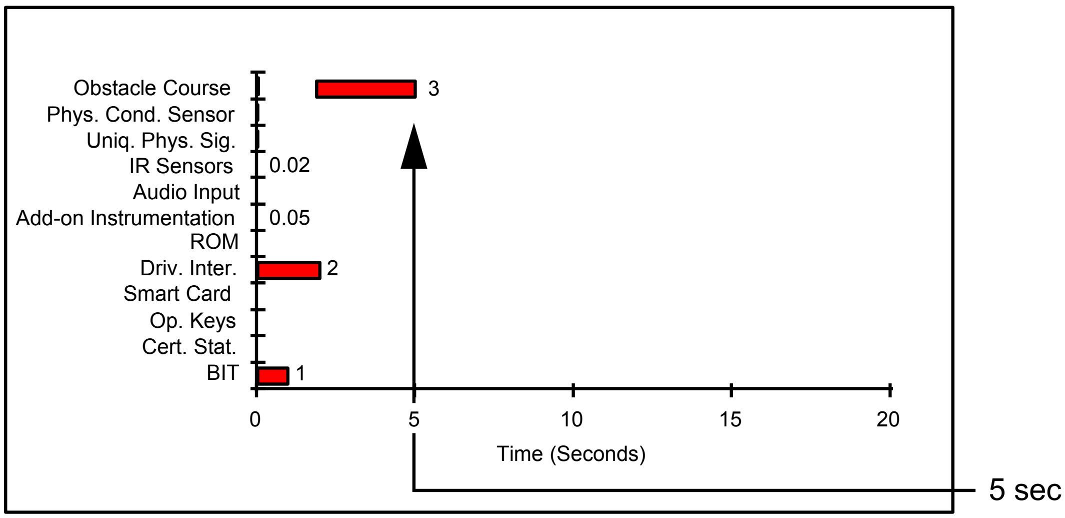

Figure D-19. Before Check-in

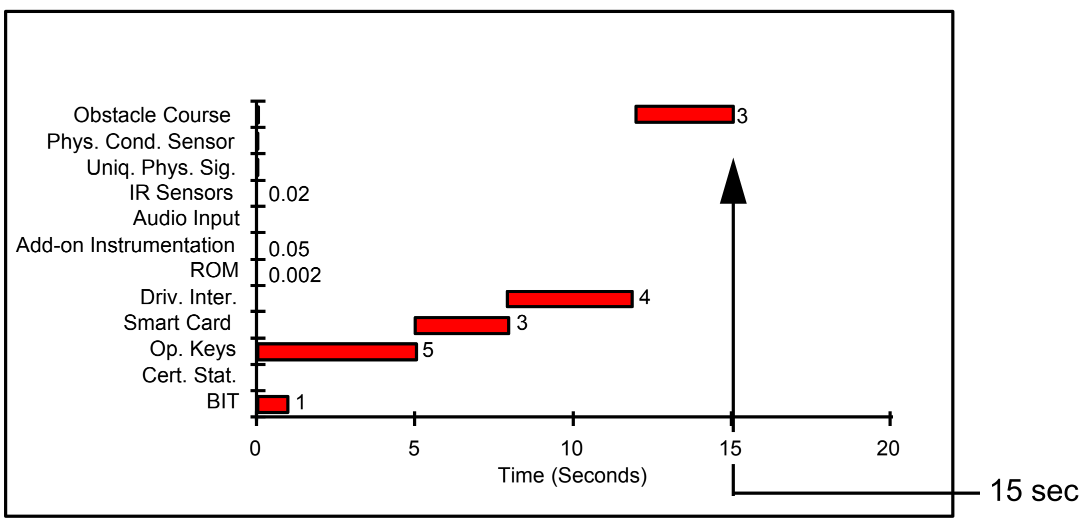

Figure D-20. During Check-in

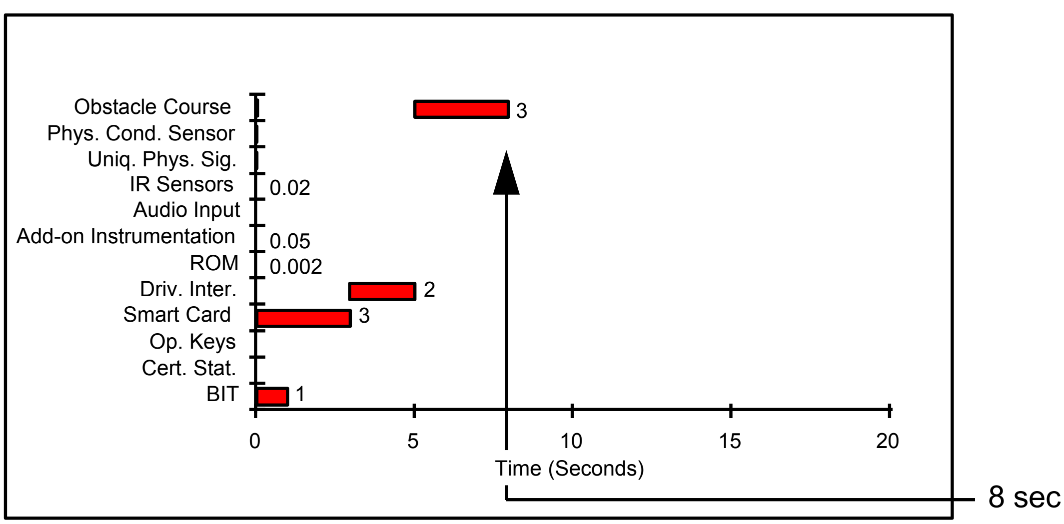

Figure D-21. After Check-in

APPENDIX E

SUPPORTING COST DATA

E.1 General

Included in this Appendix are detailed cost data sheets to support cost summaries shown in previous sections, and brief descriptions of the PRICE H and REVIC cost models.

E.1 Data Sheets

Cost details which were used to generate the summary figures for each AHS design alternative shown in Section 3.3 are shown in Figures E-1 through E-7.

E.2 Cost Models

Two main models were utilized to generate cost estimates. The PRICE H model was used to calculate development and production hardware costs and integration costs. The REVIC model was used to estimate software development and maintenance costs.

E.2.1 PRICE H Model

The PRICE (Parametric Review of Information for Costing and Evaluation) Hardware Model is a computerized method for deriving cost estimates of electronic and mechanical hardware assemblies and systems. It was developed by and for RCA in the early 1960's. It is currently owned by Martin Marietta. PRICE H was first used rigorously in the mid to late 1960's and early 1970's, especially to estimate avionics and space system costs. Interest in the model grew to the extent that arrangements were made for leasing PRICE H analysis outside of RCA. Commercial operations began in 1975, with an average of over 175 new users of the model trained each year.

PRICE H has been designed to estimate cost and schedule for both commercial and government hardware development efforts with a minimal amount of hardware information. This feature makes it a useful tool for cost estimation of programs in the conceptual stage of development, since the model uses its internally generated values for any missing input variables in order to estimate cost. PRICE H permits rapid and early "probable cost" evaluations based on project scope, program composition, and demonstration organizational performance. Operational and testing requirements are incorporated, together with technology growth and inflation.

PRICE H is a model that contains an extensive series of cost estimating relationships (CERs), or equations, to derive cost estimates. These equations relate input variables to cost. Each specific set of input parameters uniquely defines the hardware for cost modeling. The resultant cost output is determined from the mathematical equations alone. PRICE H does not perform the function of a table look-up model. In addition to cost, the Model derives typical schedules for the work to be accomplished. Schedule constraints which have been imposed are examined within the model, and costs are adjusted to account for apparent acceleration or stretch-out.

PRICE H is equipped with many features designed to facilitate the model's use and extend its capabilities. Input parameters may be modified at any time to answer "what if" questions. Off-the-shelf, customer furnished and vendor supplied hardware elements may be described and integrated. Special supporting elements are provided for Calibration, Modification, Hardware/Software integration, element integration, and system level integration.

PRICE H is applicable to all aspects of hardware acquisition, from development, production, purchased, furnished, or modification of existing equipment. PRICE H estimates the costs associated with design, drafting, project management, documentation, sustaining engineering, special tooling and test equipment , and of course material, labor, and overhead. Costs to integrate subassemblies into a system and to test the system for required operation are also estimated by the model. Costs for field test, site construction, and software are not estimated by the PRICE Hardware model but can be included in the overall estimate if known.

The underlying principle of PRICE H is that all estimates involve comparative evaluation of new requirements in light of analogous histories. PRICE H has been designed for use by managers and analysts to assist them in translation experience and judgment into cost estimates. PRICE methodology provides a convenient way of reducing empirical data to a few principal variables which describe the significant technological and cost differences between individual projects and organizations.

E.2.2 REVIC Model

REVIC (REVised Intermediate COCOMO) predicts the development life-cycle costs for software development from requirements analysis through completion of the software acceptance testing and maintenance life-cycle for fifteen years. It is similar to the intermediate form of the COnstruction COst MOdel (COCOMO) described by Dr. Barry W. Boehmn in his book , Software Engineering Economics. Intermediate COCOMO provides a set of basic equations calculating the effort (manpower in man-month and hours) and schedule (elapsed time in calendar months) to perform typical software development projects based on an estimate of the lines of code to be developed and a description of the development environment.

Equations in the model predict the manpower in man-months (MM) and schedule based on the estimated lines of code to be developed and the product of a group of environmental factors. These variables attempt to attempt to account for the variations in the total development environment such as programmer's capabilities, application experience, timing and memory constraints, product reliability and complexity, data base size, and programming practices. These factors tend to increase or decrease the total effort and schedule.

						% DISTRIBUTION OF TOTAL $			
BASELINE		DEVELOPMENT $	PRODUCTION UNIT $	O & M $ (2 YEARS)	TOTAL $	DEV	PROD	O & M (2 YEARS)	TOTAL
USER	SMART VEHICLE								
	QTY		550,910						
	TRANSPONDER		37						
	DATA ENTRY PAD	DEVELOPMENT $	216						
	SMART CARD	IN BUSINESS	15						
	ADD-ON INSTRUMENTATION		440						
	INTEGRATION		91						
	CERTIFICATION			220,364,000					
	EQUIPMENT MAINTENANCE			44,017,709					
	TOTAL $	0	440,177,090	264,381,709	704,558,799	0.00%	33.90%	20.36%	54.26%
	UNIT $		799	480					
BUSINESS	SMART VEHICLE								
	TRANSPONDER	51,300							
	DATA ENTRY PAD	148,000							
	SMART CARD	23,900	PRODUCTION $						
	SMART CARD READER	129,000	IN USER						
	ADD-ON INSTRUMENTATION	0							
	TOTAL $	352,200							
	COMMAND CONTROL CENTER								
	FACILITIES								
	CONTROL HARDWARE	300,000							
	COMMUNICATIONS HW	100,000	PRODUCTION $						
	DISPLAY DEVICES (3)	25,000	IN GOVT						
	TOTAL $	425,000							
	CHECK-IN RAMP								
	ROADSIDE READER	322,500	PRODUCTION $						
	TRAFFIC CONTROL DISPLAY	220,000	IN GOVT						
	TOTAL $	542,500							
	CERTIFICATION CENTER	1,924,800	66,782	4,791,609					
	QTY		1,435						
	TOTAL $	1,924,800	95,832,170	4,791,609					
	TOTAL $	3,244,500	95,832,170	4,791,609	103,868,279	0.25%	7.38%	0.37%	8.00%
GOVT	INFRASTUCTURE								
	QTY		31						
	CONTROL CENTER		24,070,588						
	FACILITIES	DEVELOPMENT $	300,000						
	CONTROL HARDWARE	IN BUSINESS	300,000						
	COMMUNICATIONS HW		100,000						
	DISPLAY DEVICES (3)		75,000						
	TOTAL $	0	24,845,619	9,938,248					
	CHECK-IN RAMP								
	QTY		176						
	ROADSIDE READER	DEVELOPMENT $	9,789						
	TRAFFIC CONTROL DISPLAY	IN BUSINESS	220,000						
	SMART CARD READER		121						
	INTEGRATION		18,804						
	MAINTENANCE			17,509,466					
	TOTAL $	0	43,773,664	17,509,466					
	SOFTWARE								
	ROADSIDE	28,974,110		7,313,747					
	CONTROL CENTER	275,926,048		81,732,400					
	TOTAL $	304,900,158		89,046,147					
	TOTAL $	304,900,158	68,619,283	116,493,860	490,013,302	23.48%	5.28%	8.97%	37.74%
PUBLIC	INFRASTRUCTURE								
		PROVIDES FUNDS FOR GOVT							
TOTAL $	TOTAL $	308,144,658	604,628,543	385,667,178	1,298,440,379	23.73%	46.57%	29.70%	100.00%

Figure E-1. Baseline Cost Data Sheet

						% DISTRIBUTION OF TOTAL $			
ALTERNATIVE 1		DEVELOPMENT $	PRODUCTION UNIT $	O & M $ (2 YEARS)	TOTAL $	DEV	PROD	O & M (2 YEARS)	TOTAL
USER	SMART VEHICLE								
	QTY		550,910						
	TRANSPONDER		37						
	ROM	DEVELOPMENT $	59						
	SMART CARD	IN BUSINESS	15						
	ADD-ON INSTRUMENTATION		440						
	INTEGRATION		37						
	EQUIPMENT MAINTENANCE			32,393,508					
	TOTAL $	0	323,935,080	32,393,508	356,328,588	0.00%	38.42%	3.84%	42.27%
	UNIT $		588	59					
BUSINESS	SMART VEHICLE								
	TRANSPONDER	51,300							
	ROM	331,800							
	DATA ENTRY PAD	148,000	PRODUCTION $						
	ADD-ON INSTRUMENTATION	0							
	SMART CARD	23,900	IN USER						
	SMART CARD READER	129,000							
	TOTAL $	684,000							
	COMMAND CONTROL CENTER								
	FACILITIES								
	CONTROL HARDWARE	300,000							
	COMMUNICATIONS HW	100,000	PRODUCTION $						
	DISPLAY DEVICES (3)	25,000	IN GOVT						
	TOTAL $	425,000							
	CHECK-IN RAMP								
	ROADSIDE READER	322,500	PRODUCTION $						
	TRAFFIC CONTROL DISPLAY	220,000	IN GOVT						
	TOTAL $	542,500							
	CERTIFICATION CENTER	0	0						
	QTY		0						
	TOTAL $	0	0						
	TOTAL $	1,651,500	0		1,651,500	0.20%	0.00%	0.00%	0.20%
GOVT	INFRASTUCTURE								
	QTY		31						
	CONTROL CENTER		24,070,588						
	FACILITIES	DEVELOPMENT $	300,000						
	CONTROL HARDWARE	IN BUSINESS	300,000						
	COMMUNICATIONS HW		100,000						
	DISPLAY DEVICES (3)		75,000						
	TOTAL $	0	24,845,619	4,969,124					
	CHECK-IN RAMP								
	QTY		176						
	ROADSIDE READER		9,789						
	DATA ENTRY PAD	DEVELOPMENT $	216						
	SMART CARD READER	IN BUSINESS	121						
	TRAFFIC CONTROL DISPLAY		220,000						
	INTEGRATION		18,804						
	MAINTENANCE			17,524,672					
	TOTAL $	0	43,811,680	17,524,672					
	SOFTWARE								
	ROADSIDE	28,974,110		7,313,747					
	CONTROL CENTER	275,926,048		81,732,400					
	TOTAL $	304,900,158		89,046,147					
	TOTAL $	304,900,158	68,657,299	111,539,943	485,097,400	36.17%	8.14%	13.23%	57.54%
PUBLIC	INFRASTRUCTURE								
		PROVIDE FUNDS FOR GOVT							
TOTAL $	TOTAL $	306,551,658	392,592,379	143,933,451	843,077,488	36.36%	46.57%	17.07%	100.00%

Figure E-2. Alternative 1 Cost Data Sheet

ALTERNATIVE 2		DEVELOPMENT $	PRODUCTION UNIT $	O & M $ (2 YEARS)	TOTAL $	% DISTRIBUTION OF TOTAL $ DEV	PROD	O & M (2 YEARS)	TOTAL
USER	SMART VEHICLE								
	QTY		550,910						
	TRANSPONDER		37						
	ROM	DEVELOPMENT $	59						
	DATA ENTRY PAD	IN BUSINESS	216						
	SMART CARD		15						
	SMART CARD READER		121						
	ADD-ON INSTRUMENTATION		440						
	INTEGRATION		110						
	CERTIFICATION			220,364,000					
	EQUIPMENT MAINTENANCE			54,980,818					
	TOTAL $	0	549,808,180	275,344,818	825,152,998	0.00%	39.56%	19.81%	59.37%
	UNIT $		998	500					
BUSINESS	SMART VEHICLE								
	TRANSPONDER	51,300							
	DATA ENTRY PAD	148,000							
	ROM	331,800							
	SMART CARD	23,900	PRODUCTION $						
	SMART CARD READER	129,000	IN USER						
	ADD-ON INSTRUMENTATION	0							
	TOTAL $	684,000							
	COMMAND CONTROL CENTER								
	FACILITIES								
	CONTROL HARDWARE	300,000							
	COMMUNICATIONS HW	100,000	PRODUCTION $						
	DISPLAY DEVICES (3)	25,000	IN GOVT						
	TOTAL $	425,000							
	CHECK-IN RAMP								
	ROADSIDE READER	322,500	PRODUCTION $						
	TRAFFIC CONTROL DISPLAY	220,000	IN GOVT						
	TOTAL $	542,500							
	CERTIFICATION CENTER	1,924,800	66,782	4,791,609					
	QTY		1,435						
	TOTAL	1,924,800	95,832,170	4,791,609					
	TOTAL $	3,576,300	95,832,170	4,791,609	104,200,079	0.26%	6.89%	0.34%	7.50%
GOVT	INFRASTUCTURE								
	QTY		31						
	CONTROL CENTER		3,100,000						
	FACILITIES	DEVELOPMENT $	300,000						
	CONTROL HARDWARE	IN BUSINESS	300,000						
	COMMUNICATIONS HW		100,000						
	DISPLAY DEVICES (3)		75,000						
	TOTAL $	0	3,875,031	1,550,012					
	CHECK-IN RAMP								
	QTY		176						
	ROADSIDE READER		9,789						
	TRAFFIC CONTROL DISPLAY	DEVELOPMENT $	220,000						
	INTEGRATION	IN BUSINESS	18,722						
	MAINTENANCE			17,495,174					
	TOTAL $	0	43,737,936	17,495,174					
	SOFTWARE								
	ROADSIDE	28,974,110		7,313,747					
	CONTROL CENTER	275,926,048		81,732,400					
	TOTAL $	304,900,158		89,046,147					
	TOTAL $	304,900,158	47,612,967	108,091,334	460,604,459	21.94%	3.43%	7.78%	33.14%
PUBLIC	INFRASTRUCTURE								
		PROVIDES FUNDS FOR GOVT							
TOTAL $	TOTAL $	308,476,458	693,253,317	388,227,760	1,389,957,535	22.19%	49.88%	27.93%	100.00%

Figure E-3. Alternative 2 Cost Data Sheet

						% DISTRIBUTION OF TOTAL $			
ALTERNATIVE 3		DEVELOPMENT $	PRODUCTION UNIT $	O & M $ (2 YEARS)	TOTAL $	DEV	PROD	O & M (2 YEARS)	TOTAL
USER	SMART VEHICLE								
	QTY		550,910						
	TRANSPONDER		37						
	ROM	DEVELOPMENT $	59						
	DATA ENTRY PAD	IN BUSINESS	216						
	SMART CARD		15						
	ADD-ON INSTRUMENTATION		440						
	PHYSICAL CONDITION SENSOR		733						
	INTEGRATION		174						
	CERTIFICATION			220,364,000					
	EQUIPMENT MAINTENANCE			92,222,334					
	TOTAL $	0	922,223,340	312,586,334	1,234,809,674	0.00%	51.21%	17.36%	68.57%
	UNIT $		1,674	567					
BUSINESS	SMART VEHICLE								
	TRANSPONDER	51,300							
	ROM	331,800							
	DATA ENTRY PAD	148,000	PRODUCTION $						
	SMART CARD	23,900	IN USER						
	SMART CARD READER	129,000							
	ADD-ON INSTRUMENTATION	0							
	PHYSICAL CONDITION SENSOR	1,190,300							
	TOTAL $	1,874,300							
	COMMAND CONTROL CENTER								
	FACILITIES								
	CONTROL HARDWARE	300,000							
	COMMUNICATIONS HW	100,000	PRODUCTION $						
	DISPLAY DEVICES (3)	25,000	IN GOVT						
	TOTAL $	425,000							
	CHECK-IN RAMP								
	ROADSIDE READER	322,500	PRODUCTION $						
	TRAFFIC CONTROL DISPLAY	220,000	IN GOVT						
	TOTAL $	542,500							
	CERTIFICATION CENTER	1,924,800	66,782	4,791,609					
	QTY		1,435						
	TOTAL $	1,924,800	95,832,170	4,791,609					
	TOTAL $	4,766,600	95,832,170	4,791,609	105,390,379	0.26%	5.32%	0.27%	5.85%
GOVT	INFRASTUCTURE								
	QTY		31						
	CONTROL CENTER		3,100,000						
	FACILITIES		300,000						
	CONTROL HARDWARE	DEVELOPMENT $	300,000						
	COMMUNICATIONS HW	IN BUSINESS	100,000						
	DISPLAY DEVICES (3)		75,000						
	TOTAL $	0	3,875,031	1,550,012					
	CHECK-IN RAMP								
	QTY		176						
	ROADSIDE READER		9,789						
	TRAFFIC CONTROL DISPLAY	DEVELOPMENT $	220,000						
	SMART CARD READER		121						
	INTEGRATION	IN BUSINESS	18,804						
	MAINTENANCE			17,509,466					
	TOTAL $	0	43,773,664	17,509,466					
	SOFTWARE								
	ROADSIDE	28,974,110		7,313,747					
	CONTROL CENTER	275,926,048		81,732,400					
	TOTAL $	304,900,158		89,046,147					
	TOTAL $	304,900,158	47,648,695	108,105,625	460,654,478	16.93%	2.65%	6.00%	25.58%
PUBLIC	INFRASTRUCTURE								
		PROVIDES FUNDS FOR GOVT							
TOTAL $	TOTAL $	309,666,758	1,065,704,205	425,483,568	1,800,854,531	17.20%	59.18%	23.63%	100.00%

Figure E-4. Alternative 3 Cost Data Sheet

ALTERNATIVE 4		DEVELOPMENT $	PRODUCTION UNIT $	O & M $ (2 YEARS)	TOTAL $	% DISTRIBUTION OF TOTAL $ DEV	PROD	O & M (2 YEARS)	TOTAL
USER	SMART VEHICLE								
	QTY		550,910						
	TRANSPONDER		37						
	ROM	DEVELOPMENT $	59						
	DATA ENTRY PAD	IN BUSINESS	216						
	SMART CARD		15						
	SMART CARD READER		121						
	ADD-ON INSTRUMENTATION		440						
	PHYSICAL CONDITION SENSOR		733						
	UNIQUE PHYSICAL SIGNATURE		W/ PHYS COND SENSOR						
	INTEGRATION		192						
	CERTIFICATION			220,364,000					
	EQUIPMENT MAINTENANCE			99,879,983					
	TOTAL $	0	998,799,830	320,243,983	1,319,043,813	0.00%	52.17%	16.73%	68.90%
	UNIT $		1,813	581					
BUSINESS	SMART VEHICLE								
	TRANSPONDER	51,300							
	ROM	331,800							
	DATA ENTRY PAD	148,000	PRODUCTION $						
	SMART CARD	23,900	IN USER						
	SMART CARD READER	129,000							
	ADD-ON INSTRUMENTATION	0							
	PHYSICAL CONDITION SENSOR	1,190,300							
	UNIQUE PHYSICAL SENSOR	W/PHYS COND SENSOR							
	TOTAL $	1,874,300							
	COMMAND CONTROL CENTER								
	FACILITIES								
	CONTROL HARDWARE	300,000	PRODUCTION $						
	COMMUNICATIONS HW	100,000	IN GOVT						
	DISPLAY DEVICES (3)	25,000							
	TOTAL $	425,000							
	CHECK-IN RAMP								
	ROADSIDE READER	322,500	PRODUCTION $						
	TRAFFIC CONTROL DISPLAY	220,000	IN GOVT						
	TOTAL $	542,500							
	CERTIFICATION CENTER	1,924,800	66,782	4,791,609					
	QTY		1,435						
	TOTAL $	1,924,800	95,832,170	4,791,609					
	TOTAL $	4,766,600	95,832,170	4,791,609	105,390,379	0.25%	5.01%	0.25%	5.51%
GOVT	INFRASTUCTURE								
	QTY		31						
	CONTROL CENTER		24,070,588						
	FACILITIES		300,000						
	CONTROL HARDWARE	DEVELOPMENT $	300,000						
	COMMUNICATIONS HW	IN BUSINESS	100,000						
	DISPLAY DEVICES (3)		75,000						
	TOTAL $	0	24,845,619	9,938,248					
	CHECK-IN RAMP								
	QTY		176						
	ROADSIDE READER		9,789						
	TRAFFIC CONTROL DISPLAY	DEVELOPMENT $	220,000						
	INTEGRATION	IN BUSINESS	18,722						
	TOTAL $	0	43,737,936	17,495,174					
	SOFTWARE								
	ROADSIDE	28,974,110		7,313,747					
	CONTROL CENTER	275,926,048		81,732,400					
	TOTAL $	304,900,158		89,046,147					
	TOTAL $	304,900,158	68,583,555	116,479,569	489,963,282	15.93%	3.58%	6.08%	25.59%
PUBLIC	INFRASTRUCTURE								
		PROVIDES FUNDS FOR GOVT							
TOTAL $	TOTAL $	309,666,758	1,163,215,555	441,515,161	1,914,397,474	16.18%	60.76%	23.06%	100.00%

Figure E-5. Alternative 4 Cost Data Sheet

		DEVELOPMENT $	PRODUCTION UNIT $	O & M $ (2 YEARS)	TOTAL $	% DISTRIBUTION OF TOTAL $ DEV	PROD	O & M (2 YEARS)	TOTAL
ALTERNATIVE 5									
USER	SMART VEHICLE								
	QTY		550,910						
	TRANSPONDER		37						
	ROM		59						
	DATA ENTRY PAD	DEVELOPMENT $	216						
	SMART CARD	IN BUSINESS	15						
	SMART CARD READER		121						
	STRAIN GAUGES/ADD-ON INST		440						
	PHYSICAL CONDITION SENSOR		733						
	UNIQUE PHYSICAL SIGNATURE		W/ PHYS COND SENSOR						
	AUDIO INPUT		1,154						
	INTEGRATION		427						
	CERTIFICATION			220,364,000					
	EQUIPMENT MAINTENANCE			176,401,382					
	TOTAL $	0	1,764,013,820	396,765,382	2,160,779,202	0.00%	63.98%	14.39%	78.37%
	UNIT $		3,202	720					
BUSINESS	SMART VEHICLE								
	TRANSPONDER	51,300							
	ROM	331,800							
	DATA ENTRY PAD	148,000							
	SMART CARD	23,900							
	SMART CARD READER	129,000	PRODUCTION $						
	ADD-ON INSTRUMENTATION	0	IN USER						
	PHYSICAL CONDITION SENSOR	1,190,300							
	UNIQUE PHYSICAL SENSOR	W/PHYS COND SENSOR							
	AUDIO INPUT	928,400							
	TOTAL $	2,802,700							
	COMMAND CONTROL CENTER								
	FACILITIES								
	CONTROL HARDWARE	300,000							
	COMMUNICATIONS HW	100,000	PRODUCTION $						
	DISPLAY DEVICES (3)	25,000	IN GOVT						
	TOTAL $	425,000							
	CHECK-IN RAMP								
	ROADSIDE READER	322,500	PRODUCTION $						
	TRAFFIC CONTROL DISPLAY	220,000	IN GOVT						
	TOTAL $	542,500							
	CERTIFICATION CENTER	1,924,800	66,782	4,791,609					
	QTY		1,435						
	TOTAL $	1,924,800	95,832,170	4,791,609					
	TOTAL $	5,695,000	95,832,170	4,791,609	106,318,779	0.21%	3.48%	0.17%	3.86%
GOVT	INFRASTUCTURE								
	QTY		31						
	CONTROL CENTER		24,070,588						
	FACILITIES	DEVELOPMENT $	300,000						
	CONTROL HARDWARE	IN BUSINESS	300,000						
	COMMUNICATIONS HW		100,000						
	DISPLAY DEVICES (3)		75,000						
	TOTAL $	0	24,845,619	9,938,248					
	CHECK-IN RAMP								
	QTY		176						
	ROADSIDE READER		9,789						
	TRAFFIC CONTROL DISPLAY	DEVELOPMENT $	220,000						
	INTEGRATION	IN BUSINESS	18,722						
	MAINTENANCE			17,495,174					
	TOTAL $	0	43,737,936	17,495,174					
	SOFTWARE								
	ROADSIDE	28,974,110		7,313,747					
	CONTROL CENTER	275,926,048		81,732,400					
	TOTAL $	304,900,158		89,046,147					
	TOTAL $	304,900,158	68,583,555	116,479,569	489,963,282	11.06%	2.49%	4.22%	17.77%
PUBLIC	INFRASTRUCTURE								
		PROVIDES FUNDS FOR GOVT							
TOTAL $	TOTAL $	310,595,158	1,928,429,545	518,036,560	2,757,061,263	11.27%	69.95%	18.79%	100.00%

Figure E-6. Alternative 5 Cost Data Sheet

ALTERNATIVE 6		DEVELOPMENT $	PRODUCTION UNIT $	O & M $ (2 YEARS)	TOTAL $	% DISTRIBUTION OF TOTAL $ DEV	PROD	O & M (2 YEARS)	TOTAL
USER	SMART VEHICLE								
	QTY		550,910						
	TRANSPONDER		37						
	ROM		59						
	DATA ENTRY PAD		216						
	SMART CARD	DEVELOPMENT $	15						
	SMART CARD READER	IN BUSINESS	121						
	ADD-ON INSTRUMENTATION		440						
	INTEGRATION		110						
	CERTIFICATION			220,364,000					
	EQUIPMENT MAINTENANCE			54,980,818					
	TOTAL $	0	549,808,180	275,344,818	825,152,998	0.00%	38.64%	19.35%	57.99%
	UNIT $		998	500					
BUSINESS	SMART VEHICLE								
	TRANSPONDER	51,300							
	ROM	331,800	PRODUCTION $						
	DATA ENTRY PAD	148,000	IN USER						
	SMART CARD	23,900							
	SMART CARD READER	129,000							
	ADD-ON INSTRUMENTATION	0							
	TOTAL $	684,000							
	COMMAND CONTROL CENTER								
	FACILITIES								
	CONTROL HARDWARE	300,000							
	COMMUNICATIONS HW	100,000	PRODUCTION $						
	DISPLAY DEVICES (3)	25,000	IN GOVT						
	TOTAL $	425,000							
	CHECK-IN RAMP								
	ROADSIDE READER	322,500							
	IR SCANNER	2,364,300							
	IR SCANNER PROCESSOR	252,700	PRODUCTION $						
	TRAFFIC CONTROL DISPLAY	220,000	IN GOVT						
	TOTAL $	3,159,500							
	CERTIFICATION CENTER	1,924,800	66,782	4,791,609					
	QTY		1,435						
	TOTAL $	1,924,800	95,832,170	4,791,609					
	TOTAL $	6,193,300	95,832,170	4,791,609	106,817,079	0.44%	6.73%	0.34%	7.51%
GOVT	INFRASTUCTURE								
	QTY		31						
	CONTROL CENTER		24,070,588						
	FACILITIES	DEVELOPMENT $	300,000						
	CONTROL HARDWARE	IN BUSINESS	300,000						
	COMMUNICATIONS HW		100,000						
	DISPLAY DEVICES (3)		75,000						
	TOTAL $	0	24,845,619	9,938,248					
	CHECK-IN RAMP								
	QTY		176						
	ROADSIDE READER		9,789						
	IR SCANNER	DEVELOPMENT $	17,533						
	IR SCANNER PROCESSOR	IN BUSINESS	5,378						
	TRAFFIC CONTROL DISPLAY		220,000						
	INTEGRATION		19,349						
	MAINTENANCE			17,790,080					
	TOTAL $	0	44,475,200	17,790,080					
	SOFTWARE								
	ROADSIDE	28,974,110		7,313,747					
	CONTROL CENTER	275,926,048		81,732,400					
	TOTAL $	304,900,158		89,046,147					
	TOTAL $	304,900,158	69,320,819	116,774,475	490,995,452	21.43%	4.87%	8.21%	34.51%
PUBLIC	INFRASTRUCTURE								
		PROVIDES FUNDS FOR GOVT							
TOTAL $	TOTAL $	311,093,458	714,961,169	396,910,901	1,422,965,529	21.86%	50.24%	27.89%	100.00%

Figure E-7. Alternative 6 Cost Data Sheet