Precursor Systems Analyses of Automated Highway Systems

RESOURCE MATERIALS

Automated Check-In

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PRECURSOR SYSTEMS ANALYSES

OF

AUTOMATED HIGHWAY SYSTEMS

Activity Area B

Automated Check-In

Results of Research

Conducted By

Delco Systems Operations

FOREWORD

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

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

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

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

Original signed by:

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

NOTICE

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16. Abstract Requirements for an effective check-in system for vehicles wishing to enter an Automated Highway System are analyzed in depth. The critical vehicle and driver functions are defined. Several methods for validating each function are proposed and analyzed. Infrastructure facilities are proposed to accomplish these tasks efficiently. This study identified many significant issues and risks; these are catalogued in the report.		
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EXECUTIVE SUMMARY

The Automated Highway System (AHS) is quite sensitive to vehicle malfunctions of a type which are common on a non-automated highway. Furthermore, the AHS vehicle has a variety of specialized equipment which is not required on a typical roadway and is also likely to fail occasionally. If vehicles were not screened for possible malfunctions before they were allowed on the automated highway, there would be an unacceptable incidence of highway shutdown and accidents. Therefore the notion of a system which inspects and approves vehicle entry, a check-in system, makes sense for an AHS. In this report, the functions which must be checked are catalogued and methods of validation are specified. Accompanying issues and risks associated with the check-in facility are presented and the subject of driver check-in is discussed.

This analysis is divided into five tasks, however not all tasks are of equal weight, and several topics are covered in the first two tasks, while the last three tasks are very specific to single subjects which are of considerable importance to the study.

Check-In Function Catalogue

The first task was to identify all of the vehicle and driver functions which might need to be tested before the vehicle was officially approved at the check-in station. These functions might not require actual test at the site, but would require evaluation at some location and subsequent acknowledgment at the on-ramp that they were approved. The study divided the system functions that require validation into vehicle and driver operations. The vehicle functions were characterized according to the criticality of the function. A study of public service vehicle check-in activities that would require check-in operations was also made. Infrastructure tasks that would be conducted at check-in were listed in order to complete the set of tasks that a check-in station might perform.

Among the standard vehicle functions that require inspection were engine, brake, and steering operations. These are critical functions, as are the specific AHS control functions, which include lateral and longitudinal sensors, automatic controllers for brakes, engine, and steering, and the communications and data processing system which supports automated operations and relays instructions between vehicles and between vehicles and the roadside.

Vehicles that were carrying external loads, vehicles with loose or damaged equipment, and the current energy supply and available range of the vehicle are functions which were considered to be less critical. The energy supply and available range must be determined as part of the check-in procedure, since the available energy might be found to be insufficient to take the vehicle to the first off-ramp. Windshield wipers, headlights, and other equipment are

of critical importance to a driver but this equipment provides no routine assistance to an automated system and therefore was given a low criticality ranking.,

Licensing functions associated with the driver or the vehicle were catalogued in a separate table. Included in this table were the physical condition of the driver as determined by in-vehicle sensors, special licenses for AHS, and the driver medical record. These properties were correlated with their potential impact on driver privacy and with their importance to the AHS.

Functions associated specifically with public service vehicle entry to an automated highway were catalogued. Special service, not available to a private vehicle entry, may be provided at the check-in station. During routine operation, the public vehicle should be inspected in the same manner as any other vehicle. When there is an emergency, however, public safety vehicles should not be deterred from entering the AHS by a time-consuming check-in process. Therefore in table 3 the vehicle type and the nature of the mission of the vehicle was correlated with the type of service that the check-in station would provide.

Infrastructure check-in functions were evaluated separately. These include notification to the driver of check-in approval or rejection and also a description of the reason for rejection and any information which might cause deterioration and rejection in the future. Other information, similar to standard Intelligent Transportation System (ITS) traveler information, must also be provided to the driver regarding highway safety and travel time compared to other transportation modes.

Check-In Validation

A description of possible validation methods for each of the functions described in the catalogue was the next task. Validation approval, which is evaluation of the results of the validation operations, is conducted at a special check-in station. Validation operations occur at the check-in station or during routine inspection, for example at a dealer’s service department, or while the vehicle is under manual control (continuous in-vehicle test). Each function described in the catalogue, and its subfunctions in many cases, was analyzed with respect to the three types of validation operations and a description of the validation procedure and its relative merit was presented.

The special check-in stations were categorized according to their functionality. A validation station is defined as a minimal site at which information is communicated from the vehicle to the station and the vehicle is notified that it has either passed or failed the check-in evaluation. No delay is involved with this operation. The data communicated from the vehicle includes all information from the built-in-testing equipment and from the last routine inspection. This communication may range from a complete release of data to nothing more than notification from the vehicle computer data system that the vehicle is healthy.

At a remote special check-in facility, the vehicle undergoes several minutes of rigorous inspection and is then certified to enter the automated highway. This type of station is associated principally with a highway which is divided into automated and non-automated lanes. Since both equipped and unequipped vehicles can enter the highway, testing must be done before the automated vehicle enters the roadway and the results would be transmitted to a verification station (probably a beacon at the roadside) before the transition to the automated lane took place.

Another type of check-in station, one that is located at the on-ramp to a dedicated automated highway and is designed to evaluate vehicle functionality while the vehicle is at rest, is similar to the remote facility except that the inspection must be of shorter duration in order to prevent the buildup of queues. Visual inspection is routine at such a station.

The final type of facility is a dynamic test area which compares vehicle performance after control has been transferred to the automated system with a standard for acceptable automated vehicle performance. The test is done while the vehicle is gaining speed to enter the automated highway and includes some on ramp curvature to demonstrate automated steering. If the vehicle fails the test, it is automatically steered off the ramp and into a lot for rejected vehicles.

After the test facilities had been defined, the function validation tests were developed. High force (emergency) braking, for example, would be tested during routine inspection, during the manual driving cycle, and as part of the dynamic testing done at the on-ramp. This procedure was followed for every vehicle function or subfunction unless one or more tests was not applicable. In the case of vehicle functions such as carrying an external load, which cannot be determined from built-in-tests, the condition was detected by an observer at a static check-in station or by an optical detector at the on-ramp and connected to a validation station. Included in this validation methodology catalogue were vehicle communications, vehicle specifications, data processing, and the less critical functions.

The validation techniques were demonstrated in a set of scenarios which attempted to illustrate how successful vehicle check-in would function. There are seven separate scenarios and each scenario is done for all three representative system configurations if the scenario applies to all representative system configurations (RSC's). Both successful entries and check-in failures are covered, as are situations in which the failed vehicle attempts to enter the automated highway. The effect of a loss of communications is described and a mitigation scenario is developed. An automated method for detecting external loads is also discussed.

The effect of a delay associated with a check-in facility at an on-ramp which required that vehicles come to a full stop and be inspected while at rest was investigated. It was found that a significant delay at such a station when entering traffic was heavy would create a long queue that could only be reduced by a reduction in entry traffic. The benefits of such a facility in comparison to a combination of a validation station and a dynamic check-in facility are not obvious. It is recommended that, because of the delay associated with this facility, this type of station not be considered as part of an AHS.

A special analysis of communications and data loading feasibility determined that, for a properly equipped vehicle compatible with the automated highway, the communications and data requirements of a check-in facility would be met. In general, during dynamic check-in the communications between the vehicle and the station are comparable to the communications load during routine operation on the automated highway, except that there is no vehicle-to-vehicle communications. Concerns about falsifying data in the vehicle computer or illegally modifying a critical piece of electronic equipment were addressed. Encrypting the information in the vehicle computer was suggested as a means of preventing such tampering.

Driver functional validation may be required because of health considerations or because of a concern that the same driver, when released into the non-automated traffic stream, may cause an accident for which the automated system would be liable. A special license for driving on an automated highway may be necessary in order to avoid major liability concerns after an incident has occurred. Privacy is a major concern, although equivalent privacy is yielded in everyday life. Liability and privacy remain major unresolved issues.

Issues And Risks Associated With Vehicle Check-In

Many additional issues and risks were identified but were not addressed in detail. There are many issues related to the use of non-standard equipment or multiple versions of the same hardware or software. Equipment such as headlights, the parking brake, and windshield wipers are not considered to be required AHS equipment. However, these equipment can be important in certain emergency scenarios. A check-in requirement for these functions is a significant unresolved issue. Another general area of concern is the control and interception of vehicles which fail check-in but attempt to enter the automated highway illegally.

Applications To Representative System Configurations

There are interesting variations to the check-in system specifications which allow the development of the check-in system requirements. These are indicated in the table in this task, and the consequences are discussed primarily in Check-In Validation.

Component And System Failure Questionnaire

After reviewing the available literature regarding vehicle systems failure it was concluded that a survey of vehicle system failure modes and frequency of failures was needed. This survey would relate only to loss of functionality which could be associated directly to failure on an automated highway. A list of questions which had not been answered in any previous failure survey was developed. The result of this survey would be a comprehensive list of component details which fail and the likelihood that they would fail if they were not detected at check-in. A sample set of questions for brake failure was produced in order to demonstrate what information is required to identify the preferred method of testing for each brake component, and hence for each component of each vehicle system.

INTRODUCTION

The only requirements for operation on a typical highway are a valid driver's license and vehicle registration and a currently functioning vehicle. The first two items are intended to demonstrate that the driver/vehicle system will not be a hazard to highway safety or the flow of traffic on the roadway. The situation is more complex on an automated highway because the AHS is more sensitive to malfunctions of the driver/vehicle system and because the equipment is more complex and requires inspection far more often than it would receive if the driver brought the vehicle to a station only when the routine maintenance schedule suggested that it should be done.[1, 2] In fact, check-in, the operation which determines the fitness and eligibility of the vehicle/driver system to function successfully on an AHS, will almost certainly include some level of acknowledgment of capability every time the driver requests to be admitted to the automated highway.[3]

The check-in activity intersects all other activities in the Precursor Systems Analysis program. Successful check-in operations reduce malfunctions, increase safety, and directly and indirectly impact system cost. Check-in affects roadway design and the manner in which the roadway connects to non-automated highways, and roadway operations includes check-in facility operations. If the check-in level of activity is intense, the level of check-out activity and system liability are reduced, but the additional land use and demand on the individual to meet check-in requirements associated with comprehensive check-in are negative social factors. Finally, the maintenance and performance characteristics of vehicles, including alternate propulsion, transit, and commercial vehicles, are the principal functions which must be tested before the vehicle is approve to enter the automated highway.

This study has several objectives. It must result in a definition of the logical functions which should be evaluated during check-in. It should discover and define methods for validating the condition of these functions. From this analysis a list of issues and risks should be derived which will lead to a more comprehensive, perhaps quantitative, functional system specification. Another goal of the study of check-in systems is the definition of the limitations of a check-in system. This will lead eventually to trade-off studies in the areas of cost and time delay.

During the course of this study, several possible methods of check-in were analyzed. One method is stationary check-in, in which the vehicle is parked and the vehicle functionality and legality are inspected manually (using sophisticated electronic instruments). This is done routinely as a separate activity at a service station or at a dealer's service department, it may also be part of the check-in operation at an on-ramp, and it may be done at a remote site before every check-in, especially if the vehicle will be operating in a mixed flow lane or on a parallel lane automated/non-automated highway. Another method is labeled continuous check-in, and utilizes the comprehensive self-test system available in the vehicle to gather information about the health of the vehicle. This information is conveyed by means of a two-way communications system to a verification station, a facility located at the entrance to an AHS on-ramp, in order to receive entry approval. The final method is dynamic check-in. During transit on the on-ramp (there may be circumstances in which this could be done just

before on-ramp entry) the vehicle is placed under automatic control and maneuvered on the ramp to test the functionality of the automated system.
The first topic covered in this report is the cataloguing and ranking of all vehicle and driver functions and documents which might impact safety or operation on the automated highway. Consideration was given to the criticality of the function and to its subfunctions which also required consideration in order to understand all aspects of the dependence of AHS operation on the function. Public service vehicles were included in the study in order to identify their special needs and the additional service that such vehicles might require in an emergency.

An extensive consideration of different methods of validating each function is discussed next in this report. For each function, stationary, continuous, and dynamic validation techniques were applied in order to compare their effectiveness for that function. The techniques were associated with different types of check-in station and the notion of a validation station was developed, based on the current and projected capability of the vehicle to check itself and store the results of the inspection. Some properties which impact AHS operation could only be determined by visual inspection and this was noted in the report. The pros and cons of driver check-in have also been discussed, with emphasis on the unresolved trade-off between invasion of privacy and system liability.

A list, and accompanying discussion, of remaining issues and risks has also been compiled. There is also additional discussion of the impact of check-in delay on the automated highway capacity and the apparent redundancy inherent in stationary check-in stations at on-ramps. A separate discussion of communications and data processing functionality and operations is presented. Finally, a brief discussion of a possible survey to assess the absolute value of the reliability of different vehicle components that are necessary to automated highway operation is presented. There are likely to be many vehicle systems which will not fail on the roadway because their imminent failure is easily detected during routine inspection. Also, some vehicle system failures may already be detected by the self-test system currently in the vehicle, which is therefore sufficiently trustworthy for AHS application.

REPRESENTATIVE SYSTEM CONFIGURATIONS

The representative system configurations (RSC's) were generated very early in this Precursor Systems Analyses of AHS program. These RSC's are used throughout the various areas of analysis whenever a diversity of system attributes is required by the analysis at hand. The RSC's identify specific alternatives for 20 AHS attributes within the context of three general RSC groups. Additions to the RSC specifications have been made which refer to their check-in attributes and these are documented in table 8 located in task 4 of this report.

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

TECHNICAL DISCUSSION

Task 1. Check-In Function Catalogue

The following is a list and accompanying description of the various vehicle-specific and human functions which must be satisfied in order to safely and efficiently process entry of a vehicle onto the AHS. The actual description of the entranceway design may be found in Activity J–AHS Exit/Entry Implementation. The details of entrance implementation are described in Activity J and, where appropriate, here in this activity. On occasion, some reference to the method of validating an individual check-in function may be made in this task, however it should be noted that actual discussion of validation of functions is reserved for a separate section and preliminary discussion of validation is only made for the purpose of defining the function itself.

Categories of vehicle check-in functions that were previously identified in the research summary have been redefined. All vehicle operating property categories, whether general condition or AHS-specific condition, have been grouped into a single vehicle-specific check-in category. A list of broad functions in this category is given in table 1. These will be described in detail in the text and some indication of how to perform these functions may, incidentally, be found there.

A second category (table 2) consists of the institutional description of the car and of the driver, including such items as the driver's license description and the vehicle registration and the description of the driver's current capacity to operate a vehicle, which will be required in some emergency situations and at exit from the automated highway. A third category is all emergency, transit, and official vehicles. A discussion of special vehicle priority functions is accompanied by a list of functions in table 3. A fourth category, which was not included in the research summaries, consists of all infrastructure functions which are part of check-in and the discussion of the functions is accompanied by table 4.

Vehicle Specific Check-In Functions

The functions which must be checked are listed in the first column of table 1. The next column describes the type of check-in as inspection, continuous, or dynamic. A test procedure performed every six months at an inspection station would be considered inspection, although it might include some road testing. A dynamic test is one performed at the time of check-in, typically at or on the entryway, and while the vehicle is moving. Continuous tests are those which may be made during vehicle operation before the vehicle reaches the on-ramp. The results are coupled with inspection results and transmitted to the check-in station at the time that entry is requested. The third column identifies those functions which are already tested during routine vehicle maintenance versus those which will require the development of special testing procedures. Some special testing procedures may be developed in the course of time without any special impetus from an automated highway system.

Table 1. Vehicle Specific Check-In Functions

FUNCTION	CHECK-IN TEST TYPE (DYNAMIC, CONTINUOUS, OR INSPECTION)	EXISTING MAINTENANCE TEST PROCEDURE	SPECIFIC TO AHS OR TYPE OF ROADWAY	VARIATION WITH DEPLOYMENT PROGRESSION	CRITICALITY SCALE (1-10)
Vehicle Specifications (Type, Speed, Size, etc.)	Inspection	No	Yes	Addition	4 (Each RSC Requires Different Specs)
Brakes	Continuous/ Inspection	Yes	No	More Complex	10 (RSC Differences)
Tires/Wheels	Continuous/ Inspection	No	No	Continuous Test Added	8
Engine	Continuous/ Inspection	Yes	No	More Complex	7 (RSC Differences)
Vehicle/Body Condition	Continuous/ Inspection	Yes	No	More Complex	7
Transmission	Inspection	Yes	No	None	6
Steering	Continuous/ Inspection	Yes	No	More Complex	10
Visibility Enhancement (Headlights, Wipers)	Inspection	Yes	No	None	3
Wheel Speed Sensor	Dynamic	No	Yes (Ice/Snow)	Addition	6
Vehicle Speed Sensor	Dynamic	No	No	Addition	6
Fuel/Gasoline (Quantity)	Dynamic/ Inspection	Yes	No (but the test is)	Improvement	4

Table 1. Vehicle Specific Check-In Functions (Continued)

FUNCTION	CHECK-IN TEST TYPE (DYNAMIC, CONTINUOUS, OR INSPECTION)	EXISTING MAINTENANCE TEST PROCEDURE	SPECIFIC TO AHS OR TYPE OF ROADWAY	VARIATION WITH DEPLOYMENT PROGRESSION	CRITICALITY SCALE (1-10)
Antilock Brake System	Dynamic/ Inspection	Yes	No	None	6
Vehicle System Processors/ Computers	Continuous/ Inspection	Yes	No	More Complex	10
Communications	Dynamic/ Inspection	No	Yes	Major Addition	10
Automatic Brakes and Controller	Dynamic/ Inspection	No	Yes (AHS only)	Major Addition	10
Automatic Drivetrain Controller	Dynamic/ Inspection	No	Yes (AHS only)	Addition	10
Automatic Steering and Controller	Dynamic/ Inspection	No	Yes (AHS only, roadway for trucks)	Major Addition	10
Vehicle Longitudinal Position/Distance Sensor	Dynamic/ Inspection	No	Yes, but similar to the ACC sensor	More Complex	10
Vehicle Lateral Position/Distance Sensor	Dynamic/ Inspection	No	Yes	Addition	10 None for RSC 1

The fourth column contrasts those functions which are standard with any vehicle with those which are developed for an AHS and might also vary depending on the design of the roadway. The testing procedures for some functions will have to be developed as deployment of the AHS occurs. Existing test procedures could become more complex as the system evolves. This variation is documented in the fifth column. The functions in this table are all important to the safe, efficient operation of the highway, however some functions are more critical to AHS vehicle safety than others, and this relative comparison is made in column 6. Since there is some variation in criticality according to the RSC, this variation is indicated in column 6 where it exists.

Further description of these functions shall be provided in the accompanying text. In addition, descriptions of current standard vehicle system status monitoring functions, where applicable, will be provided. However, in considering the existence of testing, the routine nature of some tests, and the fact that some equipment has been on the highway since the development of the automobile, it seems appropriate to question the likelihood of the standard equipment failing. If a piece of equipment has been utilized for several years without causing a single accident, is it necessary to test that equipment dynamically? Adequate statistics for the item may be lacking, however, and if so statistics should be acquired in order to determine the necessity for dynamic testing and/or more comprehensive scheduled testing, given the sensitivity of the AHS to certain equipment failures. The cost of dynamic, as well as routine, testing and the use of backup, redundant systems are clearly considerations in the specification of validation alternatives.

Vehicle Specifications

Most of the standard descriptors of the vehicle wishing to enter the automated roadway are included in this list. Nearly all of the data is inserted at the factory, however some information could be added during routine maintenance or by the driver. The information consists of:

Factory Data–

- Type of vehicle, such as light truck, small car, sedan, limousine, or truck and trailer (manufacturer and model as necessary).
- Emergency vehicle, including specific agency and priority (an emergency on the AHS is not rated the same as an emergency at another destination).
- Public vehicle, such as a bus or police car (non-emergency use).
- Commercial vehicle.
- Vehicle weight.
- Vehicle size (height, width, wheel base, length).
- Vehicle model year.
- Gasoline vs. an alternate fuel (this is specific to the roadway).[4]
- Speed rating, including acceleration and deceleration capability on level ground and for one or more uphill grades, as determined at the factory.
- Airbags (number and location)–this is informative, but not required, data.
  Level of automation equipment (from none to high performance automation).

Maintenance Data–

- Last maintenance and inspection date and next required date.
- Check list of all routine maintenance and inspections.
- Tire ages and types (snow tires, studded tires) and speed ratings.

Operator Furnished Data–

- Emergency equipment (snow chains, fire extinguisher, spare tire, tool kit, first aid equipment, and signaling flare) –this is informative, but not required, data.
- Number of passengers–for the sake of possible toll collection.
- Cargo data input during loading (Estimated weight is needed for tax and roadway safety purposes, weight distribution for a trailer, and hazard information is required if the cargo is potentially hazardous).

The amount of information needed for this function is anticipated to increase with time. Failure to obtain some elements of this data could result in an accident, whereas other data is definitely not critical to roadway operation. It is not clear that a situation would ever arise in which any of the emergency equipment except the first aid kit would ever be useful on the AHS. The snow chains are required if the vehicle will exit the AHS onto an icy or snow packed road. Changing a flat tire on a functioning automated road would be suicidal. This emergency equipment is primarily of value in the event that the AHS ceases to function at all and the driver finds it necessary to operate his vehicle manually. This scenario is not the same as a particular malfunction management technique that would turn over control of the vehicle to the driver in certain specified situations.

Vehicle Brakes

Although brake failure is a critical malfunction, the incidence of brake failure on an highway is not great.[5] Statistics are definitely needed to allow the true risk of brake failure to be determined. Because of the critical effect that a brake failure would have on an automated highway, especially one utilizing Semi-autonomous vehicles in closely spaced platoons, dynamic testing as well as standard routine testing will be required. If the hand brake is used as a backup automated braking system, then the condition of the parking brake will be included as part of the routine maintenance.

Currently, most routine testing is essentially visual inspection of brake wear (pads and lining) and brake fluid level. It may be necessary to generate the greater reliability necessary for an AHS by expanding the detail of the tests to include the actual measurement of the current system compliance and measurement of the master cylinder effectiveness.

Dynamic tests of the brakes, as distinct from tests of the antilock brake system (ABS) or the automatic actuator system, need to acquire the brake pad force or wheel speed as a function of the applied pedal force or the force generated by an equivalent actuator. The results would be compared with expected data for a similar system that was in good repair.

Vehicle Tires And Wheels

Although tires and wheels are inspected routinely, blowouts still occur frequently on highways and other roadways. Most, but not all, of the failures are associated with objects on the road. Statistics that break out the causes and frequency of dynamic tire failures are needed here. Very few failures (blowouts) occur within seconds of contact between a tire in good repair and an object that can cause failure. Therefore the number of failures can be reduced significantly by monitoring the tire pressure on the AHS and by inspecting the tire as it enters the roadway. Currently, there is no certified method for detecting the presence of a nail in a tire, and this must certainly be a check-in function requirement. Damage to a wheel, loss of a wheel nut, or separation of a wheel or hubcap from a car must also be considered. There is not likely to be a risk-free method for maneuvering around roadway debris, therefore shedding of parts from the wheel is a more serious hazard than on a non-automated highway. Hence the condition of the tires and wheels is a critical element of the vehicle check-in.

There are several parameters which should be inspected routinely in order to avoid tire and wheel hazards. At the time of standard maintenance, the tire pressure, tire wear and other visual signs of damage, wheel alignment, bolt tightness, strut condition, and gross alignment should be determined. Dynamic information which could be acquired at the time the vehicle attempts to enter the AHS will probably be restricted to the readings from the tire inflation monitor, which will indicate tire pressure only. Some visual information might be obtained, but it is not likely to be a routine part of dynamic check-in. Tire friction coefficient, related to tire wear, and tire rolling radius are also important parameters. These could be determined indirectly (corresponding to their utility in the automated system) by evaluating wheel travel distance and wheel torque during routine maintenance.

Vehicle Engine

The condition of the engine is critically important on an automated highway for several reasons. Engine failure creates vehicle malfunction on a longer time scale than brake failure. However, the results are likely to shut down the highway until the stalled vehicle can be towed away. Without design consideration, damage to a gasoline engine can cause locking of the steering wheel (power steering is assumed), which could cause steering malfunction. If electric drive is used to power the automated steering, then the engine functionality becomes less critical, but electric system reliability becomes more important. Engine failure can also affect the full braking capacity of the vehicle, especially in the case of an electric vehicle which may rely partially on regenerative braking.

Most detailed engine inspection will be part of routine vehicle maintenance, as it is today. The oil and water levels must be maintained, the engine controller and spark plugs must be up to the manufacturer’s standards, and engine timing and performance curve must be correct. Any damage to auxiliary parts, such as valve wear, cracked coolant hoses, or a loose head gasket can be determined from routine visual inspection and as part of the electronic tune-up.

Those engine systems which can be measured dynamically probably require no special equipment. Vehicle sensors already exist for engine temperature, oil level, and oil pressure. During check-in these values, resident in the vehicle, will be read off by the dynamic check-in system.

<u>Vehicle / Body Condition</u>

Debris on the automated highway can cause major problems and easily become a hazard. There must be a standard for the condition of the external vehicle components which otherwise are not involved in vehicle operation. Any damage which might cause a part of the vehicle to fall off during routine operation must be detected. This damage is usually related to a collision or to rusting out of some supporting component. Routine inspection will probably be all that is required in the case of body condition. Included in this inspection should be an investigation of the vehicle suspension to verify that there is no serious damage to the suspension which could cause steering or braking difficulties.

If the vehicle has a trailer, then the security of the load must be established. No open loads would be allowed. Also, no overhead (car carrier) external cargo would be allowed. In the case of a commercial carrier, visual inspection at the time the highway is entered and certification from the shipping organization are both required. A mixture of trailers and commercial and private vehicles would only be allowed in RSC 3.

The states of certain vehicle components which are not part of the normal vehicle operating system may be unacceptable for driving on a highway. The hand brake may have failed to completely release, the hood or the trunk may not be fully shut, or the car door may be ajar. Although these are not desirable situations under any driving circumstances, they are occasionally true, and they cannot be allowed on a high speed freeway. The consequences could be brake failure in the case of the unreleased hand brake or large pieces of the vehicle flying off and causing a debris hazard. There must be sensors to detect these conditions (there typically are such sensors in the newer model cars) and the signals must be transmitted (continuous testing) to the check-in facility for evaluation.

<u>Transmission</u>

The transmission and differential are the other major parts of the drivetrain, and typically they do not suffer any instantaneous breakdown. However failures in this equipment do occur, leading to the same sort of hazard and inconvenience that are caused by engine failure. The primary features which must be checked are the transmission fluid level and the differential fluid. These may be checked routinely. In addition the general operation of the drivetrain may need to be tested on the road during the routine inspection to determine current functionality. The constant velocity joint is one of several elements in the drivetrain which would impact performance if damage, resulting for example from a lack of lubricant, occurred. The loss of power to one wheel would cause a steering problem which could result in the vehicle traveling into a parallel lane and causing a collision. Transmission gear ratios are part of the vehicle description. A typical vehicle will have an electronic transmission, so a test of the transmission microprocessor will be an adequate test of proper shift performance.

Steering

In order to have a steering system that can be controlled remotely, the system must be driven electrically. It is possible that the manually operated steering system will also be driven electrically (drive-by-wire) since this would remove the need to have an additional actuator for manual steering which had to be disconnected during check-in.[6] Or the automatic/manual steering system could utilize an actuator in series with the steering wheel. The steering wheel would be locked in place when the vehicle was on the AHS, but the actuator would be able to maneuver the car. It is not clear how the manual/automated steering system will function in the final design because of the many possible system configurations. This could have an impact on the steering functions which must be tested during check-in.

The manual functions which must be tested during check-in are primarily those which are similar to the present steering arrangement. These are the steering linkages, the power steering fluid levels, and the status of vehicle lubrication. All of these are likely to remain routine maintenance systems. During routine maintenance, it may also become necessary to test the manual steering system on the road because steering is extremely critical to the AHS.

Visibility Enhancement And Emergency Equipment

The principal reason for requiring that this equipment be operational at check-in is to insure that the equipment is working when the vehicle checks out. Windshield wipers, headlights, and other equipment of that type should not be necessary when the vehicle is under automatic control. The emergency equipment and the lighting equipment are also required in the event that there is a major catastrophe and the entire AHS system is nonfunctional. In addition, the wipers and headlights provide human factors benefits. Passengers feel more secure if the road is lighted and the human operators no doubt prefer to see the traffic on the highway. Snow chains and/or snow tires will be required if the vehicle will be exiting into conditions which may include snow. Other means to deal with snow will have to be used on the automated highway. The use of snow chains on an AHS would be inconsistent with two major objectives of the highway, to reduce congestion and travel time, and the use of snow tires would not guarantee safety except, again, at an inconsistently low speed.

All of this equipment will no doubt be verified by routine check or the driver will notify the operator that the equipment is available as he enters the AHS. Failure to have this equipment in working condition as the vehicle is checked off of the automated highway may result in a fine, however lack of equipment during check-in would not prohibit entry. It is possible that some separate system will be devised to insure that the equipment is available and operational, however that does not appear to be a high initial priority, furthermore, there is a trend in modern vehicle design to include internal function checks (door open, trunk ajar, etc.) and there will no doubt be simple sensors in place when the first AHS is introduced. In that case, the condition of the headlights and other equipment of that nature will be available for verification during check-in.

Wheel Speed Sensor

The wheel speed sensor is a critical element of the ABS and as such it must be tested for check-in. It is also a sensor which may be used to detect the condition of the road surface. In particular, it may be used to recognize the presence of icy conditions which could cause a system malfunction if the speeds of the vehicles were not reduced.

The wheel speed sensor must be tested dynamically, however that test is typically performed as part of the ABS self check during startup and in combination with routine maintenance of the ABS the two may be adequate for check-in. During check-in a comparison of the wheel speed output signal on dry asphalt with the infrastructure measurement of vehicle speed would provide an adequate dynamic test.

Vehicle Speed Sensor

The vehicle speed estimator, which is the speed of the undriven wheels except when the car is accelerating or decelerating, and is otherwise derived from the wheel speeds using a complex algorithm, is used by the ABS, by the road surface probe, and also by the infrastructure to determine the vehicle speed during automated operation. On dry road, the wheel speed sensor is a very accurate estimator of vehicle speed and it connects to a system bus which can be accessed easily by the internal vehicle controller. However, it may be that the inherent lack of reliability on slippery surfaces will force the use of an on-board radar vehicle speed sensor to detect ground speed under all conditions.

In either circumstance, the vehicle speed must be measured dynamically during check-in. The measurement is the same as for the wheel speed sensor, except that the signal compared with the infrastructure vehicle speed measurement device is extracted from the signal processor port which outputs vehicle speed instead of wheel speed.

Available Quantity Of Fuel

In a typical scenario the driver will notify the check-in facility of his destination and the system will calculate the amount of fuel (gasoline, battery charge, etc.) required and query the vehicle to determine the amount of energy available. Some modern vehicles already have trip computers on-board which perform this function, although their accuracy probably should be improved. Failure to have adequate fuel may only cause the vehicle to be steered on the AHS to a roadside energy supply facility. However, it is critical to know how far the vehicle can proceed in order to avoid breakdown on the roadway. A dynamic measure of fuel supply must be made utilizing a sensor in the energy supply system on the vehicle. In addition, the vehicle specifications must include information that allows an accurate estimate of the distance that the vehicle can travel on the specific AHS with its current supply of fuel. This data should be updated automatically in the vehicle using a processor quite similar to a trip computer, but with a required high precision, that considers vehicle speed, distance traveled, and fuel consumption.

Antilock Brake System

The ABS used as a method of retaining vehicle control during a panic stop is of value only during an emergency situation on the automated highway and should never have to be used. For example, if the lead car of a platoon needs to utilize ABS, it is unlikely that the following vehicles will be able to operate in synchronism with the lead car and there will be a chain collision, although not a serious event if momentum transfer is small. However, it is very likely that the ABS actuator system, coupled with the standard brakes, will serve as the nominal AHS braking system because it is already electronically controlled. Therefore the ABS must be tested at check-in.

The ABS is tested whenever the car is started up, applying a self-test program that exercises both the software and hardware elements of the system. This self-check can be applied dynamically, with only some adjustment, however the maximum speed for a successful test is not known at this time.

Vehicle System Processors / Computers

Each system processor in the vehicle has certain common characteristics which may be tested routinely during maintenance and during continuous operation. The engine and ABS controllers are tested during maintenance and the ABS controller experiences a self-check during vehicle startup. The principal faults that are searched for are electronic elements that are shorted out and open circuits. Intermittent faults are much more difficult to discover than complete circuit failures. The standard way to search for faults in circuits is to send a scheduled electronic signal through the system for a short period of time and observe the results at several nodes within the electronic processor circuitry. Each AHS processor should be tested in this manner during routine maintenance and some may be tested during non-AHS operation and the results should be stored in a retrievable memory for inspection by the automated system during check-in. The built-in redundant circuits that are typically part of each automotive processor should also be tested during this procedure. Testing will become more complex as the number and complexity of the circuits increases, and there will be some additional self-tests which shall be performed during dynamic check-in on the automated system microprocessors.

Communications

The communications system includes the vehicle transmitter and receiver which talk with the roadway communications system and, depending upon the design, with other vehicles, and also the driver keyboard and the interior vehicle display system which allow the driver to input information and requests to the highway controller. A part of this system is similar to any other system processor and can be tested routinely just as the other control computers are tested. The major issues, all of which are critical, are whether or not the system can receive a message without any distortion and transmit that message to the correct control element and also whether or not the vehicle communications system can transmit a message to the highway or to another car on the road. However, failure to respond or failure to transmit a message can be associated with failure of some other part of the vehicle system or with the infrastructure communications network.

Some of the sources of inadequate communications performance can be internal interference, low signal-to-noise ratio, an open circuit, a short circuit in the communications electronics, faulty wiring, a broken antenna circuit, or an integrated circuit with an intermittent flaw. All of these could be detected by routine maintenance checks but any of them could develop in between routine test cycles and if there were no dynamic testing then the vehicle might be allowed on the AHS with a faulty communications system. Therefore both routine and dynamic testing are required. The routine testing must clearly identify what component of the communications system is at fault, whereas the dynamic test need only identify the existence of a serious malfunction in the system. There is no guarantee after the dynamic test that the error is in the communications and not in the particular controller element that was being tested at the time. It is, however, essential that the dynamic testing be accurate in its capability to distinguish between a vehicle failure and an infrastructure failure, so that maintenance of the infrastructure may take place immediately.

The routine tests should focus on the ability of the system to identify in detail any message sent by a fixed transmitter, to communicate that message to the correct controller, and to respond by transmitting a specific reply back to the static communications equipment. Both received and transmitted messages should be faithful reproductions of the expected responses. There should be a minimum acceptable S/N reception and response and system repeatability should also be tested by repeating the test several times.

Although performance of the controller cannot be completely separated from communications reliability, some distinction can be achieved by transmitting a handshake code at the beginning of the check-in testing which is designed only to elicit a specific response from the communications system. A directional, vehicle-to-vehicle communications link, such as an optical communications device installed on each vehicle, is especially difficult to test dynamically. Such a system of two-way communication is not included in any of the RSC's in this study, but it has been suggested in other automated highway examples. The test equipment must be at the position relative to the vehicle requesting entry where another vehicle would normally have its communications antenna. The test equipment, both for routine and dynamic check-in procedures, will be a major addition to the AHS system. The variability of interference on different roadways may require higher quality equipment on some automated highways.

Automatic Brakes And Controller

Unless there are two separate braking systems (a prohibitively costly addition) with separate actuators and brake lines, one for manual operation and one for AHS, the only elements of the automatic braking system which are not tested under the previous topics of ABS and brakes are the controller and its action on the manual actuators. The brake system routine test must include the AHS portion of the system. The controller and special hardware that connect to the brake system would be evaluated routinely. If there is a separate AHS brake actuator (for example, a rear electric brake such as might be used on an electric car), then that system and the coupling hardware which switches the brake system from manual to automatic would be inspected during each routine test. Maintenance testing should also include an equivalent AHS road check to determine full functionality.

Beyond the typical dynamic self-checks that have been referred to above, the additional dynamic testing must be done after control of the brake system has been transferred to the automatic mode. This evaluation could involve any short length of on-ramp where a specific brake application and release could be commanded. This additional automatic brake test is required because the ABS self-tests do not exercise the brake calipers and other actuator components. Also, the self-tests do not test the system when the master cylinder has been separated from the system and fluid is dispensed from an accumulator in the same manner as for traction control.

Automatic Drivetrain Controller

Transfer of the drivetrain to automatic control involves disconnecting the throttle linkage and automatic gearshift lever (it is unlikely that a manual transmission vehicle would be equipped to operate on an AHS), which should be simple in a modern vehicle with sophisticated engine control and electronic transmission already standard equipment. The majority of the testing will be of the vehicle electronics, controlling computer, and associated communications system, all of which are described generically above.

Routine testing would include a demonstration that the engine could follow a preset throttle up, throttle down schedule. In addition, a demonstration of the ability to disconnect the throttle and gearshift would be required. Dynamic testing of the drivetrain controller would utilize the same schedule of deceleration and acceleration inputs that would be used to test the brake controller.

An issue to consider in this dynamic testing is what should be done if manual control of one or more subsystems is not released automatically because of a system malfunction. Management of this malfunction is implicitly a responsibility of the driver, who would be notified of the failure by his vehicle AHS screen and told to drive the vehicle to a secure area or back to the non-AHS roadway. Additional safety is provided if the on-ramp area is designed so that failure to execute all of the test commands correctly would result in the vehicle arriving back in the non-AHS world in most instances. This issue will be covered in more detail in the section on validation alternatives.

Automatic Steering And Controller

Functionality of the automatic steering mechanism, including the controller hardware and software, is essential to automated vehicle safety. The test procedures do not currently exist, nor does a fully steer-by-wire system exist and addition of these will be a major technology program, much larger than programs for either the drivetrain or brake systems which have already been automated. On a fully automated highway, the manual steering system will be locked out or otherwise rendered inaccessible to the driver and the steering system will be powered by the current power steering system augmented by a control system. This control system includes a mechanical simulation of the torque provided by the driver during normal steering in order to operate the power steering system, which currently requires torque provided by the driver. Power steering is required to operate the vehicle in emergency lane change maneuvers and over existing highways (it is not proposed that new highways be constructed for AHS). A separate steering system could be produced in parallel with the current manual system, however it may be unacceptably expensive, so it has not been considered here. In general, the steering system need not be specified for a particular highway, however there may be maneuvers required on certain roadways which could not be performed at AHS speeds by heavy trucks. During the initial phase of check-in, the specification of the individual vehicle will be evaluated by the ramp monitor and if the truck is not qualified for operation on that roadway, it will not be allowed to proceed onto the automated highway.

The basic testing that will take place during the scheduled maintenance checkup will be the tests of the circuitry, interfaces, and communications which have already been described in general terms elsewhere. Specific automated steering tests will have to demonstrate that the control can be transferred easily and reliably between the driver and the control system. At every inspection it must be demonstrated that the vehicle will perform a series of steering instructions accurately and that the automated steering actuator system will function correctly on the roadway.

During actual check-in, the maneuvering capability of the automated system must be demonstrated again and it must be shown that the driver cannot override the steering system when the system is commanding automated steering. Steering capability can be demonstrated with a steering schedule that the system must perform during entry. To demonstrate system control without designing the driver into the test procedure, a positive mechanical test mechanism must be developed that can only signify success if the steering wheel is locked and decoupled. A steering system, or any system, which divides authority between driver and computer in a complex manner will require a complex dynamic test program in order to verify that the proper division of control has been made.

Vehicle Longitudinal Ranging Sensor

Longitudinal ranging (and possibly position and range-rate) sensors are required in RSC 2, but they are also required in general as part of the collision avoidance system which serves as a backup safety device for any system controlled by the infrastructure.[7] The following discussion is intended to address the autonomous vehicle AHS, but a significant part of it may apply to any AHS because of the requirement for a backup safety system. The reliability of the longitudinal sensor is a critical necessity for traveler safety. The sensor must correctly determine and maintain the distance to the preceding vehicle and, as a part of the adaptive cruise control (ACC) and on roadways with mixes of different sized vehicles, must be able to discriminate motorcycles leading by 15 m from trucks leading by 60 m, filter out stationary, non-threatening objects, and perform a variety of other recognition tasks necessary to allow accurate position-keeping under all conditions. Most of this capability may be designed in at the factory, but a portion of the capability must be reevaluated periodically to prevent accidents.

Most of the routine system tests will cover the same factors that the other electronics systems tests investigated. If the ranging equipment is radar equipment, then standard objects of known cross section can be used to establish the amplitude and Doppler sensitivity of the radar system. If communications equipment is used to establish range to leading vehicle, then communications and signal timing tests need to be performed.

Dynamic tests are primarily communications and electronics tests. However, some amplitude sensitivity tests for the radar may be necessary, since weather effects may alter range sensitivity and the antenna system may have been damaged previously by collision or debris. The weather and debris issues are more important if the electromagnetic frequency range is in the infrared or optical band. A standard target in the field-of-view but on the roadside may be adequate for testing both the signal strength detected by the sensor and the radar system determination of vehicle-to-target range and relative vehicle speed.

Vehicle Lateral Position Sensor

There are several possible types of lateral sensors which might be used in an AHS vehicle to guide the vehicle around a turn, keep it in a lane, or cause it to change lanes. These would include accelerometers and yaw sensors as well as magnetic position sensors and optical lane detecting sensors.[8] Electronics and communications systems check-in is required for all systems. Lateral control is a critical characteristic for all three RSC's and both routine maintenance tests and dynamic tests must be performed before a vehicle is allowed to check-in to an automated highway.

If the lateral system relies upon passive detection of lane markers, then routine tests must verify the amplitude of the signal in the presence of a lane marker at a variable position. Semi-active operation with magnetic markers which serve to mark turns and to provide some information about the design of the turn [9] requires the testing of information reception fidelity as well. If an active transceiver system is used which relies upon information from the side of the road, then a duplicate roadside communications system may be required. It may be possible to remove an accelerometer or yaw sensor from its mount and test it separately during routine maintenance.

In real time, two types of tests, other than standard electronics checks, can be envisioned. In the first test, the signal information received by the vehicle when passing a marker system may be compared with the expected data to ascertain whether or not the later system is performing adequately. In the second type of test, the vehicle must first be placed in an automated mode and then it may be steered using the lateral position sensor and the automated steering system. This method tests both steering and position sensing at the same time, but requires that the vehicle be removed from the traffic stream if it failed the test after it had already been placed in the automated mode.

Driver-Vehicle Associated Check-In Functions

All of the associated functions are characterized by the fact that they are stored within the vehicle database or within a public or private agency database when the vehicle begins the check-in procedure and are read by the infrastructure check-in system as the vehicle enters the system. The data were originally generated within the vehicle, by the driver, or by the appropriate agency. The data are also characterized by their association with the privacy of the driver of the vehicle. No special electronics system has to be established to acquire the data, as in the first category, but privacy is a major concern and must be addressed for each function. Although possible privacy issues are raised in this section and the relative importance of privacy in each topic is considered, there is no attempt to resolve the issue. Privacy issues will be covered more thoroughly in another activity. The functions are listed in table 2, along with a summary of their sources and relationship to AHS. Their privacy sensitivity factor and system value factor are also estimated on a scale of zero to ten, with ten being the most critical.

<u>Driver Name Or Identification Number</u>

If the current driver's name is required in order to check-in to the AHS, then it becomes possible to track an individual, to trace any criminal activity, perceived or real, and to initiate a variety of other checks of the driver's background. Therefore this identification is a major privacy issue. However, it is also necessary to identify any properties of the driver which might cause a hazard on the AHS or affect the success of check-out. The identity, in some form, of the actual driver is thus essential to operation of the AHS.

<u>Legal Status Of Driver</u>

If the driver is sought on an outstanding warrant by law enforcement authorities, this can be determined by matching his name with all available criminal records. Therefore this is a critical issue to the driver. On the other hand, this fact itself is of much less importance to the automated system, since the driver's activities will be limited on the AHS. However releasing the driver back onto the public streets creates a legal issue because the system may be liable for any future criminal activity.

<u>Driver's License</u>

An individual's driver's license identification is equivalent to that individual's name in current society, so the license is as much an object of privacy as the name of the driver. Similarly, the license conveys as much information to the automated facility as the driver's name. The existence of a license is proof that the driver possesses some experience operating a motor vehicle, which is critical to any highway system.

Table 2. Driver-Vehicle Associated Check-In Functions

FUNCTION	INFORMATION SOURCE	SPECIFIC TO AHS	PRIVACY SENSITIVE SCALE OF (1-10)	SYSTEM VALUE SCALE OF (1-10)
Name or Identification Number	Driver	No	10	10
Legal Status of Driver	Agency	No	9	5
Driver's License	Driver	No	10	10
Driver's License Validity	Agency	No	5	10
Vehicle Registration	Vehicle	No	0	6
Vehicle Registration Validity	Agency	No	0	6
Driver's Medical Record	Driver	No	8	8
Driver's AHS Certification	Driver	Yes	4	10
Vehicle's AHS Certification	Vehicle	Yes	0	10
Warrant for Vehicle	Agency	No	5	2
Toll Account Status	Agency	No	2	4
Toll Card Number	Driver	No	4	4
Insurance	Driver/Vehicle	No	4	5
Smog Check Certificate	Agency	No	2	7
Business Licenses	Vehicle/Driver	No	0	4
Commercial Cargo Information	Vehicle	No	0	8
Driver Sobriety	Vehicle	Yes	8	6
Driver Alertness	Vehicle	Yes	3	5

Driver's License Validity

The establishment that a driver's license is not valid is usually perceived by the driver as an invasion of privacy. However, if the driver's license has expired and if the AHS agency issues a warning rather than a citation, with a limit on the number of days allowed to correct the deficiency, the government involvement becomes a benefit to the driver. In other cases, if the license has been voided for traffic violations, the driver may be very concerned about loss of privacy. However, if the agency monitoring the AHS knows the license has been invalidated for serious driving violations, because of the liability associated with allowing the driver access to city streets after exiting, or being rejected from, the automated highway, the government agency may be obliged to detain the driver and call for a law enforcement officer. Also there is a risk that the driver may become a hazard if given control during a malfunction.

Vehicle Registration

The existence of a vehicle registration does not affect the privacy of the driver, however the vehicle registration is a part of the proof that the vehicle is certified to operate on an AHS.

Vehicle Registration Validity

Registration validity does not affect the privacy of the driver, but it is another part of the AHS vehicle certification.

Driver's Medical Record

A partial medical record of the driver, listing any possible condition which might require emergency service on the highway, is essential to the safe operation of the AHS. The record should also list any condition which might affect the driver's performance in an emergency situation and any condition which might make the driver a risk if he were released indiscriminately back to the non-automated road. The public is sensitive to any release of medical information, however this data might be accepted as a necessity and privacy would not be an issue. There are several options available which would address this privacy issue. For example, the driver could be offered the opportunity to eliminate the requirement to provide his medical record if he agreed that the highway management was not liable for his safety, as correlated with the medical record, while he was on the AHS. Further exploration of this topic will be covered in Activity O, which is concerned with social issues.

Driver's AHS Certification

This information is critical to the successful operation of the AHS. The certified driver is able to provide assistance to the system in case there is an emergency. She is also aware of her responsibilities on the AHS and especially the operations during check-in and the driver condition requirements at check-out. The certificate may be viewed, from the standpoint of privacy, as equivalent to the driver's license. In this study it is presumed that the certificate is not directly linked to the driver's identity in the agency data bank. However, it can be traced back to the driver's identity if there is a question of ownership. The impact on the individual's privacy is small.

Vehicle's AHS Certification

As was the case with the vehicle registration, this is not a privacy issue, since it is not related to the identity of the driver. Since certification includes the entire off-site maintenance checklist, it is a critical element of AHS check-in.

Warrant For Vehicle

A warrant for the vehicle may have been issued if the vehicle was stolen or it was used in a crime. If the law enforcement policy allows that vehicle to be pursued on the AHS, then that information is critical to AHS check-in. It is assumed that such is not the policy on our hypothetical highway, because of the risk to safety and functionality. Regardless of official policy, information about the vehicle's legal status does impact the privacy of the driver.

Toll Account Status

The impact of this function on the system is, to some extent a function of the manner in which tolls are billed. Tolls are collected electronically at the entrance and either billed to the user on a regular basis (credit method), or debited to an account that has already received money from the user (subway fare method). In the first case, the driver is accepted unless the credit card is invalid. In the second case, the amount of money currently in the account must be compared with the fee charged to go from the entrance to the exit requested by the user and if the amount is not sufficient, then the user must accept a different destination or leave the entranceway and add funds to the account or the system may allow the user to pay the difference at the exit ramp. This debit card system is essentially the same as that used in many modern subway systems. In all of the examples above, some critical information is passed to the agency during check-in which could cause the agency to refuse entry to a particular vehicle. The privacy of the driver is not impacted to a great extent, since denial of entry is the only penalty assessed. This function is not specific to AHS but it is specific to toll roads of any type.

Toll Card Number

It is presumed that the toll card number in the second case given above is completely disassociated with the user's identity. In the first case, the usual connection between credit card and identity applies. The importance of the toll card number to the agency is equal to the importance of the toll account status.

Insurance

It is not clear that being self-insured on an automated highway is relevant. If damage or injury occurs on the AHS it is likely to be covered by some type of institutional insurance, whether provided by a private organization, the state, or by the user as specific insurance required to use the highway. Therefore the privacy of the individual can probably be protected by separating the insurance information from the user's identity. If the agency does not automatically provide insurance on the AHS, then proof of insurance is critical to liability restrictions on the roadway.

Smog Check Certificate

The vehicle is required to have an up-to-date certificate on the automated highway, thus allowing the AHS to provide a social benefit that cannot be derived from a non-automated roadway. Therefore this function is of more importance to the agency than toll information, although not as critical as information that might affect performance on the highway. There is a slight risk to the driver because the system may choose to report non-compliance to authorities and a fine may be issued to the driver.

Business Licenses

Commercial licenses of various sorts, for carriers and for delivery trucks, are routine information that are used for toll information and have no effect on roadway operation. Information on the vehicle size could impact acceptance to the specific roadway but that data is contained in the vehicle AHS certificate (which may include all the necessary business information). There is no privacy issue associated with a commercial vehicle.

Commercial Cargo Information

There is no privacy issue, but there may be a significant system issue. It is critical that the appropriate highway agency know if the truck carries hazardous material. On a mixed vehicle highway (RSC 3) the spacing between vehicles may be adjusted to virtually guarantee that there will not be an accident involving the hazardous material vehicle and any other vehicle. The same approach might also be used on an all-commercial vehicle highway. Hence this information is critical to the check-in function.

Driver Sobriety

A driver who is not sober presents two hazards to the automated system. First, the driver may fail the check-out procedure and affect the exit area storage system. Second, the operator may not be able to perform any required duties during an emergency situation. There are methods for evaluating sobriety while the vehicle is being driven. One method, which is currently being marketed, performs a chemical analysis of the driver's sweat from his hands while they are on the steering wheel. Acquiring information about the driver's sobriety, however, severely impacts his privacy and that conflict is a significant social issue which must be resolved.

Driver Alertness

If the vehicle has an alertness detector, and there are such monitors which have been proposed for general public use, such as a system which follows eye motion or a device which analyzes the movements of the steering wheel, gas pedal, and brake pedal to determine stability, that system will be operating continuously, even if the driver is not on an automated highway. The most recent data will be available to the check-in system for evaluation. Allowing a driver who may fall asleep during his travel on the AHS is a risk that he may not be approved for check-out, especially if the trip is short, or that he may not respond appropriately during an emergency. It could also benefit the driver, as he may be safer on the AHS than he would be off of it. The impact on the driver's privacy is not great, since authorities will presumably not be contacted, but the driver may object to the use of an alertness monitor in his vehicle.

Public Service Vehicle Check-In Functions

Under some circumstances, public service vehicles will travel on the automated highway. In the case of RSC 3, which considers a mix of large and small vehicles, any public service vehicle which is equipped to operate on the AHS may utilize the service any time it chooses. In emergency situations on the highway, emergency vehicles must have access to the emergency, and therefore there must be provisions made for non-equipped oversized vehicles to traverse the roadway whenever they are needed. In addition, if there is an emergency off the AHS and travel on the automated highway would significantly reduce the time for an emergency vehicle to reach the critical area, it is unlikely that the vehicle could be prohibited from using the AHS. Public transit vehicles might not use a narrow lane automated roadway because of size considerations, but any roadway established for large vehicles will certainly be used for transit as well as commercial vehicles. Therefore check-in services for public service vehicles to the automated highway are required, as shown in table 3.

The manner in which the public service vehicle is checked in is a function of the service that the vehicle is in the act of performing. If an emergency is involved, the check-in may allow fast, unimpeded entry to a clear space (open a space between two platoons, e.g.) in a lane, or the system may close down a lane so that the vehicle can travel at any desired speed , or the system may close down the highway to allow response to a major emergency on the AHS. In order to quickly identify the type of vehicle and service required a simple code could be derived (sample shown in table 3) to access the service required. Of course, for major emergencies, notification should be provided immediately to the automated highway control structure to begin the process of generating access to the highway. This will allow the check-in procedure to be completely avoided and thus avoid the delays associated with check-in.

If the vehicle is equipped to operate on the AHS then the basic check-in functions, absent the driver-vehicle verification functions, should be performed. There would be a quick test of current maintenance record and a minimum dynamic test before the vehicle was under full automated control. However, non-automated emergency vehicle would not be prohibited from entering the system and traveling on open lanes if the emergency was judged to be sufficiently grave and access to the AHS was possible.

Table 3. Public Service Vehicle Check-In Functions

VEHICLE CLASS	SERVICE CODE	EMERGENCY DESCRIPTION	CHECK-IN SERVICE PROVIDED
Law Enforcement Vehicle	L0	Routine Travel	Standard Service
	L0	Official Call (Including off-AHS Pursuit)	Standard Service
	L1	Official Call (Life Threatening Emergency)	Immediate Entry (Platoon Adjustment as Required)
	L2	Vehicle Pursuit (on AHS)	Immediate Entry to AHS (May Shut Down One or More Lanes)
Ambulance or Other Medical Emergency Vehicle	A0	Routine Travel	Standard Service (Presuming that the Vehicle is not Oversized)
	A1	Official Business not on the AHS	Immediate Entry (Platoon Adjustment as Required)
	A2	Routine Emergency on the AHS (For Example, a Medical Alert in a Single Vehicle)	Immediate Entry to AHS (May Shut Down One Lane)
	A3	Emergency Requiring Immediate Service on the AHS	Immediate Entry (Shut Down Entire AHS)

Table 3 Public Service Vehicle Check-In Functions (Continued)

VEHICLE CLASS	SERVICE CODE	EMERGENCY DESCRIPTION	CHECK-IN SERVICE PROVIDED
Fire Department Equipment	F0	Routine Travel (For Example, After an Emergency)	Standard Service (If Lanes Are Available for an Oversize Vehicle)
	F1	There is an Emergency Requiring Fire Equipment away from the AHS which can benefit from the AHS service	Clear a Lane to the Length of One Platoon (May Need an Extra Lane to Accommodate Extra Width)
	F2	There is an Emergency Requiring Fire Equipment on the AHS	Shut Down All Lanes (in the Vicinity of the Emergency)
Transit Vehicle	T0	Routine Transit Schedule	Standard Service (Utilize Wide Vehicle Lanes for RSC 1 and RSC 2)
	T1	Peak Demand Transit Schedule	One Transit Lane Set Aside (All RSC’s)

Law Enforcement Vehicle

Except for the absence of driver-vehicle check-in, a law enforcement vehicle would be checked in like any private vehicle whether it was on routine patrol or on official duty. Special vehicle access
to the AHS is certain to be disruptive, causing a hazard and increasing travel times for several kilometers of traffic. The use of an AHS should improve police response sufficiently for most circumstances that the issue of special access would not arise.

In the case of a major police emergency that requires several law enforcement vehicles which would benefit from additional time saved by not having to wait in a check-in line or for a platoon opening, the system can bypass the entire dynamic check-in procedure, allow an opening in the on-ramp, and guarantee a platoon length space when the vehicles arrive so that they can travel at their desired speed, unimpeded, for several kilometers. This operation requires pre-arrangement and verification of the existence of an extreme emergency. If the cruisers are not the correct size, or if the vehicles are not equipped for an AHS, then more than one lane might have to be made available, but this would lead to major disruption of the system.

If there is a problem on the automated highway, for example a pursuit of an unequipped vehicle, then the law enforcement vehicle must have access to the automated highway without any delay caused by check-in, although a quick check of maintenance specifications is possible in the time it takes for the authorized vehicle to transfer control to the automated system if that is appropriate. In most cases of this type, pursuit will have to be done without automatic control, since the AHS is not programmed to conduct pursuit of a vehicle which is controlled manually. Check-in therefore consists of a sequence of delays for all vehicles entering the highway downstream from the start of the chase and the clearing of a lane for the police car and probably also for the pursued vehicle.

Ambulance Or Other Medical Emergency Vehicle

An ambulance that is not on an emergency call will receive the standard service offered by the AHS, and will not enter if it is oversized. The code which establishes the nature of the emergency vehicle’s task and service priority shall be set by the driver of the vehicle. If it develops that the vehicle operators tend to exaggerate their need for priority, then the system would change and the details of the check-in code would be established by the dispatcher.

If a business call is issued to the ambulance from a location off the AHS, then the priority code of the vehicle is increased and the ambulance enters the AHS quickly and receives its own platoon-length space for travel. Again, even a life-threatening emergency may not warrant exaggerated use of the control features of the AHS because of the routine efficiency of the system. This plan will be modified if it develops that speeds on the automated highway are not as high as expected because of congestion. Automatic control allows traffic adjustment to allow single vehicles to travel rapidly even though the bulk of the vehicles is moving rather slowly.

In the case of a routine single vehicle emergency on the automated highway, such as a driver experiencing a heart attack, space must be made for the ambulance at the end of its journey, and the simplest procedure would be to bring the vehicle requiring assistance over to a roadside stop area. The ambulance would receive the A1 code treatment until it reached the location of the other vehicle. However, if it is not possible, to bring the vehicle to the roadside, then the lane in which the vehicle is located should be cleared and the ambulance can travel at any desired speed down that lane. The check-in facility is responsible for much of the logic used in establishing the roadway conditions at the entrance and thus facilitating the access to the highway. If a decision was made that the emergency vehicle needed to enter into a situation in which none of the lanes had been cleared of traffic, then the vehicle inspection data storage, the maintenance information stored within the vehicle's AHS computer system after routine testing of all check-in functions, should be queried during check-in to ascertain whether or not the vehicle was technically able to operate on an AHS.

If a major incident has occurred on the automated highway, then the AHS must be shut down so that multiple emergency vehicle operations can be facilitated. This would only occur if the roadway had been blocked by the event, and shutting the AHS down would probably be the reaction even if ambulance operations did not require it. Again, a check of the inspection data must be made if the roadway has not been cleared so that the ambulance does not create an incident.

Fire Department Equipment

Fire equipment will receive essentially the same check-in service as other emergency equipment. During routine travel, when not speeding to an emergency, the fire equipment must pass the same tests as law enforcement and other public vehicles. Size of the vehicle is particularly important in this case, as the typical automated highway would not be wide enough for a fire engine.

If there is an emergency not on the AHS, then the check-in and highway service received would be determined by the current fire department ranking of emergency levels. Vehicle size is a key issue. In case the oversized equipment requires two lanes, the priority level must be sufficiently high and, in that case, the fire vehicle must wait until space downstream of the on-ramp has been made for the equipment. Check-in of vehicles preceding the emergency equipment may be bypassed and those vehicles may be sent off the entranceway, rather than being admitted to the AHS, because of the need to insert the emergency vehicle into the system as quickly and safely as possible. Check-in of fire equipment requested for an emergency on the AHS is essentially identical to check-in of other emergency equipment.

Public Transit Vehicle

Transit vehicles in this analysis do not include car pools or car pool vans, as their operation is common to other private vehicles, rather than public transit vehicles. Check-in of transit vehicles is typically similar to check-in of private vehicles and is not related to check-in of emergency or law enforcement vehicles. All inspection tests required of a private vehicle are required of a transit vehicle, the functions are the same, and the criteria are the same. However, there are dissimilarities between transit vehicles and passenger cars which will affect methodology and how the functions are considered. A typical transit vehicle, especially a bus that does not operate on a demand schedule, will traverse the AHS ten or more times a day. In addition, it is housed in a facility which includes maintenance technicians. Also, because of its constant use, it will require maintenance more often.

Because of the bus schedule, the transit vehicle should undergo dynamic testing once, at the beginning of each day, and that result should be recorded in the vehicle records so that it is not required to be checked in dynamically again that day. Presumably, the public transit vehicle will have better monitoring equipment than a private vehicle because of government safety standards, however, if the transit vehicle fails the test, the vehicle must be removed from service (it cannot be admitted to the AHS and therefore cannot fulfill its scheduled requirements) and sent back to its storage area for corrective maintenance.

Two additional check-in functions are required of a public transit vehicle. First, it must transmit a coded vehicle security message demonstrating that the passengers and driver are safe. Second, it will transmit either a ‘no interest’ signal or a request to receive a higher priority status in the automated highway system because it is operating in a peak transit condition, as determined by the automated transit system which monitors future loading based on past history and current demand. This request will speed access to the automated lane and gradually transfer from that lane all slower vehicles which would impede the progress of the transit vehicles operating at peak load. The request must be verified by the transit system dispatcher during check-in for it to be honored and it may be denied if traffic will not allow rapid access or a dedicated transit lane.

Infrastructure Check-In Functions

A sophisticated Intelligent Vehicle Highway System will be in existence when the AHS is established. This system will provide traveler information services and traffic management information and service to the user of the automated highway system before the traveler enters the AHS, even during early check-in. All such services, which are traveler information services rather than unique AHS services, must be communicated to the driver during a time when communication will not delay entry to the system. The functions which the infrastructure must perform in addition to evaluating the vehicle and passengers include some of these ITS services as well as functions which alert the driver to the condition of the AHS and the basic approval function which must introduce the vehicle to the AHS. The majority of the infrastructure functions are of an informative nature. The functions may be different for short trips than they are for long trips. The information should be provided before the driver is committed to enter the AHS so that he may leave the entranceway, without interfering with the passage of other vehicles if he decides that the AHS does not provide the best service for his objectives. In fact, a complete, functioning ITS system would probably have the capability to acquire the necessary AHS data base for check-in, except for dynamic test data, and transmit a full comparison of alternative transportation modes while the driver was still traveling to the AHS entrance. The infrastructure check-in functions are listed in table 4.

Table 4. Infrastructure Check-In Functions

FUNCTION	DESCRIPTION OF FUNCTION
Acceptance/Rejection Data	Notification of acceptance to the AHS or notification of rejection including a description of the reasons for rejection–Records to be stored in the vehicle computer
Lane Closure Information	Information on lane closures
Destination Definition	Off-ramps available, public transit options, parking structures
Destination Description	Weather, expected travel time to chosen destination, and traffic status - current transit schedule and parking situation
Automated Roadway Status and Special Requirements	Possible toll charges, snow and other equipment required at destination, types of vehicles on AHS
Travel Alternatives and Itinerary	Transit and parallel street alternatives and time comparisons, the system plan for gas, food and rest stops if necessary, and the availability of other automated highways which might connect with the highway that will be entered

Acceptance / Rejection Data

There are two basic groups of check-in functions performed at the check-in station, one is dynamic and the other is a readout of data, most of it gathered during the routine maintenance inspection, concerning the vehicle and driver. Data readout should be done first and as early as possible in the procedure. Acceptance at this first level precipitates the second level, dynamic, check-in procedure and both the driver and the vehicle computer which stores vehicle condition information are notified. Acceptance at the dynamic level occurs after the vehicle control has been transferred to the automatic system. The driver and the vehicle computer receive notification and automatic control of the vehicle continues as it enters the highway. The driver receives these notices so that he will recognize that the vehicle is no longer controlled manually. The system computer receives these notifications because they verify for future reference that the vehicle condition was acceptable to the AHS and because there is a toll involved which must be paid electronically after the second acceptance (there may also be a fee for entering the check-in procedure).

If the vehicle is rejected, it is important that the vehicle storage computer have a record of rejection and also why the vehicle was rejected. This rejection record must be corrected before the vehicle will be able to enter the AHS again, since the first item that the check-in system will search for in the vehicle record will be an uncorrected previous rejection. This record must specify why the vehicle was rejected and what corrective action must be taken. If possible, it should contain locations of agencies which can help correct the problem. The driver must also receive notice of rejection and some information detailing the circumstances of the rejection. If the disapproval occurs during the first inspection level, the driver must be notified to turn off the entranceway and re-enter the non-AHS roadway. Otherwise, during dynamic testing, the vehicle will be automatically shunted off the roadway and onto a lane leading back to the non-AHS street.

With the information explaining his rejection available, the driver may have a dispute regarding the check-in decision. Therefore, there must be information notifying the driver of a location or a cellular telephone number where he can discuss his concern. The driver should receive sufficient information after rejection so that the failure can be corrected on the basis of that information. If an unsafe condition has been detected, the in-vehicle communication system should alert the driver to the hazard and to any imminent danger.

Lane Closure Information

Operation on the AHS should involve no risk to the passenger, and so the system should not anticipate that safety information would be required. However, if some lanes are closed and others are open (thus affecting travel time), travelers will still be accepted on the roadway. This information should be given early to the driver to allow her to decide whether or not to continue the check-in procedure.

Destination Definition

Although the driver knows where he is going, it is not necessarily true that he knows the name of the off-ramp or the street where he will get off the AHS, especially if he is making a long journey. The check-in system will provide the available choices and descriptions of the street system based on the driver's destination and obtain from the driver a specific off-ramp as the AHS destination. The destination decision must not impact ramp entry time, so it may be necessary to have a transmitter located before the on-ramp where destination information is provided to the driver. The public transit system at the destination, including the locations of transit stations, would also be described in case the traveler intended to use transit at the end of the journey. Parking structures and their locations would also be described in the destination area definition.

Destination Description

Destination conditions such as weather and traffic status should also be communicated after initiation of the first level check-in so that the driver can choose whether or not to continue the procedure or perhaps alter the destination. Conditions such as snow, rain, or fog would alert the driver that special equipment such as snow chains might be required when the destination was reached, or that the travel time off the AHS would be longer than anticipated. Traffic information would also provide information on current travel time to the destination. If the total travel time, including time on the automated highway, was too great, the traveler might prefer to use public transit or an airplane for a long journey. On a long trip, the automated system might vary several times, including long distances of travel in rural areas, where travel time might vary according to the current mix of traffic on the highway.

The amount of current information describing the destination would be too large to transmit during check-in. Therefore the driver would be required to communicate specific questions to the system during check-in. These might include questions about current parking availability, current transit schedules, and route guidance after exiting the AHS.

Automated Roadway Status And Special Requirements

The traveler will need to be informed of general and special conditions on the AHS which is being traversed. This information will include the description of the types of vehicle currently traveling on the road, the number of automated lanes, a special description of any rural road segment that will be included in the trip, and the current road speed. Special fog or night vision equipment might be required, or snow tires or snow chains might be necessary at the destination. The traveler will be interested in the fee for traveling the highway, especially as compared with the cost to travel another roadway.

Travel Alternatives And Itinerary

The automated highway is part of a traffic management program to reduce congestion and travel times and increase traveler safety. Therefore alternative routes should be described to the driver of an AHS vehicle. This would include the other automated highways in the vicinity and AHS intersections which may be part of the complete itinerary. Most of this information can be obtained before the check-in station is reached. This information would include a comparison of public transit and alternative highway (including other automated highways) route travel times with the travel time on the AHS.

If the trip is longer than the distance that the vehicle can travel without being refueled, either because the car’s gas tank was not full initially or simply because the journey is greater than the range of the vehicle, then the traveler needs an itinerary on the AHS which will inform him of the gas stops that are planned and the locations of planned meals and perhaps overnight motel stops if the journey is extremely long. These exits are built into the fully developed AHS system to allow travelers to derive additional system benefits. This information will be provided at the time when the current fuel level is determined and the travel link times are derived.

Task 2. Check-In Validation

Check-In Validation Procedure Catalogue

One principal objective of a check-in analysis for an automated highway is to develop a list of the procedures that might be used to validate the vehicle and the driver for entry onto an AHS. These procedures vary with the function to be performed on the AHS and with the configuration of the automated highway.[10] In addition, there can be several alternative methods of validation for a given function and several different check-in systems for a particular highway configuration. The choice of a validation procedure for a given function depends upon the procedure's cost, impact on system safety, reliability, availability, effect on system operation, marketability, compatibility with the current system design, and appeal to those who must choose the validation method. It is also true that these same features will ultimately decide which infrastructure check-in system will be installed at a particular location.

The three check-in station types are the remote vehicle inspection and maintenance station (mandatory in all cases), the on-site (Semi-remote in RSC 3) inspection station, and the dynamic (automated vehicle) inspection station. Also, the vehicle is the equivalent of a major check-in station because of its capability for continuous self-test and communication of the resultant information to stationary check-in sites. None of these check-in installations is entirely unique. There are many common features, and similarity between station types is determined by the data that is acquired at a station. The remote station check-in and the in-vehicle check-in require the existence of an on-site verification station in order to receive the data (ranging from a simple pass/fail notice to a full data dump) that has been stored in the vehicle.

There are at least six different ways of combining these elements to create a local check-in system. The six combinations, and some comments on the implications of the different inspection stations, are presented in table 5:

- **A – Remote Site Inspection And Maintenance Station**
  All testing is done in the static mode at a local, remote station which also services the vehicle and maintains both AHS and non-AHS equipment. Results of the testing are stored in-vehicle and communicated to a check-in stand at the AHS on-ramp which decides which vehicles enter the automated highway and also initiates automated control.

- **B – Remote Site Inspection And Maintenance Station Plus Continuous In-Vehicle Self- Testing**
  The vehicle stores the results of all the self-testing with the electronic inspection sticker from the remote site and relays the information to the check-in verification stand for an entry decision.

Table 5. Inspection Station Description

Check-In Station Design	Static Inspection Station		Continuou s In-Vehicle Testing	On-Ramp Dynamic Testing with Automated Vehicle
	Remote Location	On-Ramp Location		
Station Set A	X			
Station Set B	X		X	
Station Set C	X (Same as others but with Remote Automated Tests)		X	
Station Set D	X			**X**
Station Set E	Routine Maintenance Only	X	X	**X**
Station Set F	X		X	**X**
Automated Component Tests?	Possible, with Remote Track Installation	Incomplet e	Incomplete	Yes
Components Tested at Entry?	No	Possible	Yes	Yes
Detection of Potential Debris?	Sometimes	Possible	No	No
Time Delay at Entry?	No	Yes	No	Possible

- **C – Dynamic Testing Included With Inspection And Maintenance At The Remote Station And Continuous In-Vehicle Self-Testing**
  The testing station must now possess the additional capability to test the AHS equipment in operation, thus making it both a static and dynamic test station. A small section of test roadway would probably be required. In addition, test driving of the vehicle on non-AHS roadways would become part of the routine checkup.

- **D – Remote Site Inspection And Maintenance Station Plus On-Site Dynamic Testing**
  The remote site is responsible for essentially all of the testing that it was required to do in example A, but a dynamic test station has also been constructed at the on-ramp to operate the vehicle automatically and test the AHS-specific features of the car before it may enter the automated roadway (see figure 1).

- **E – On-Site Inspection And Dynamic Testing Plus Continuous In-Vehicle Self-Testing**

All critical testing is done in the immediate vicinity of the on-ramp, so that the vehicle may need to come to a complete stop before it is allowed to enter the automated roadway (see figure 2). This is a slower process, but testing is likely to be extremely reliable. It will be the objective of vehicle and system designers to create AHS vehicles which do not have to stop at the AHS entrance.

- **F – Remote Site Inspection And Maintenance Station Plus Continuous In-Vehicle Self- Testing Plus On-Site Dynamic Testing**
  Adding the dynamic testing to scenario B can potentially improve the ability to detect failures in automated components, but is more costly and can degrade system performance in terms of the time necessary to complete the observations and diagnostics.

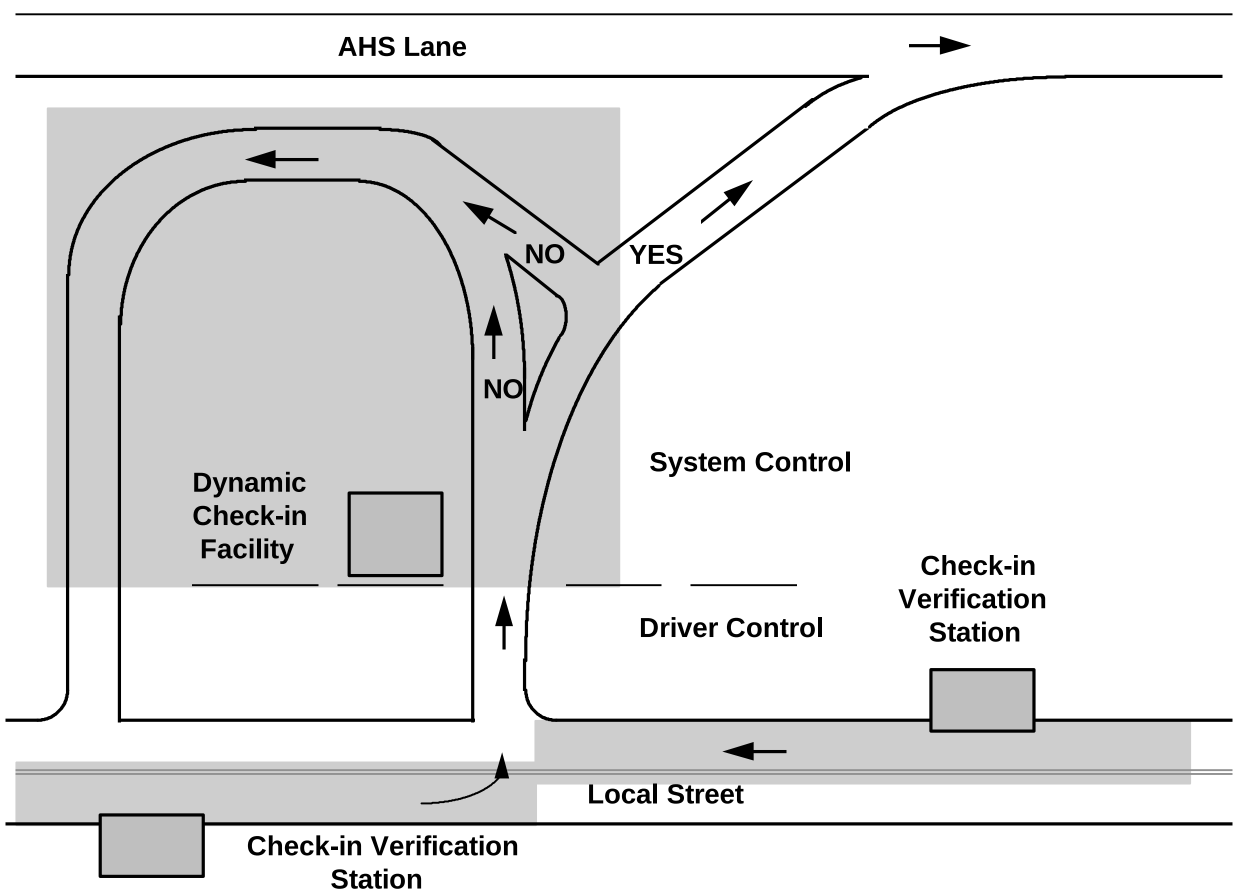

Figure 1. Check-In Facility Locations Station Set D/F
(For RSC's 1 and 2)

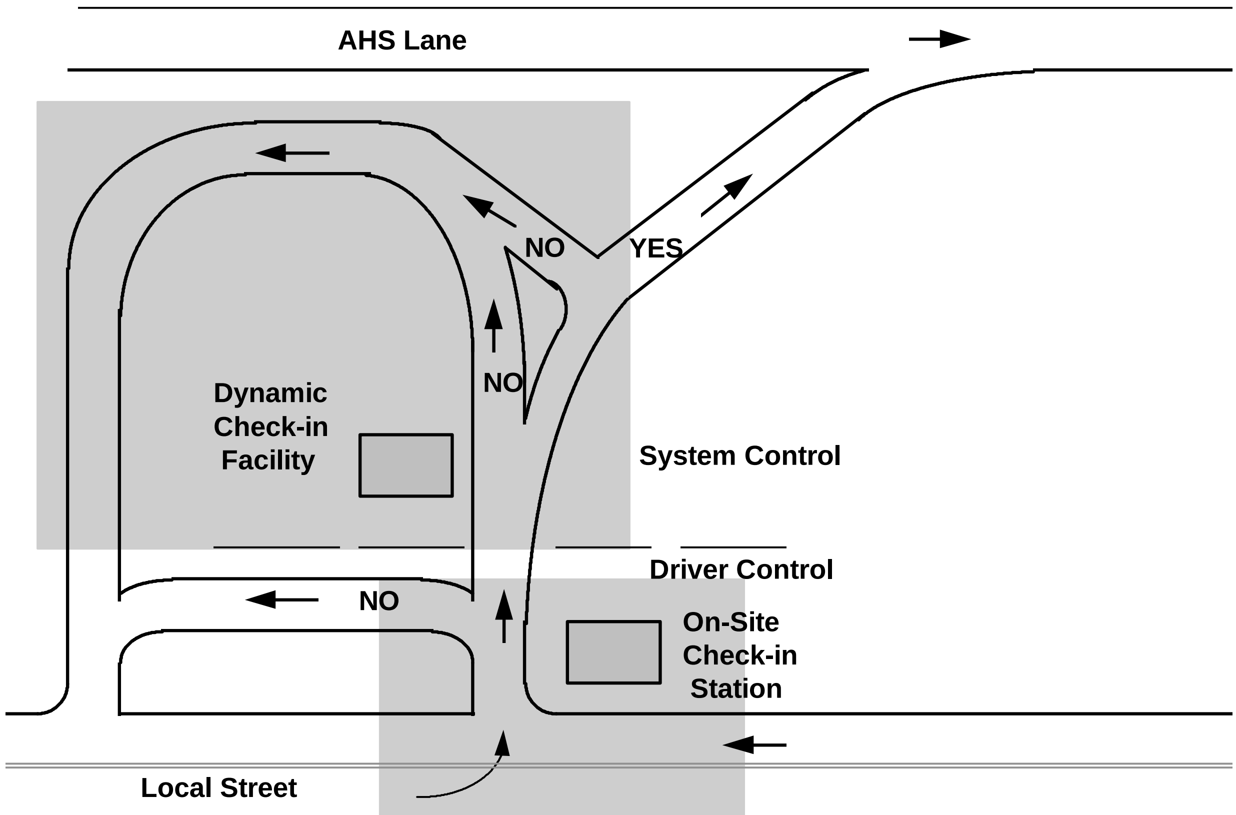

Figure 2. Check-In Facility Locations Station Set E
(For RSC's 1 and 2)

Dynamic testing is defined in this report as the testing of those features of the automated vehicle which are not required in order to operate the vehicle manually. Some elements, especially the computer functionality, may be tested in the background while the vehicle is operated manually, but other automation-specific elements must be tested during automatic control.

The level of testing and the interval of time between full inspection tests is not considered here, however it is clear that these factors will be critical for complete design of an inspection system. The capability of the check-in station to receive inspection data via communication from the car is common to all six designs. At a minimum, the vehicle must be able to store the results of the last check-in in order to reduce the time spent in check-in if the car failed its last entry test and no additional maintenance was performed since that date.

Driver validation [11] is also important during check-in, primarily so that there will be fewer failures during check-out, but also to mitigate the risk of personal emergencies, such as sudden medical problems, during travel on the automated highway. As pointed out in task 1, driver monitoring can introduce privacy issues,[12] since some drivers will object to monitoring, and this will have to be addressed. One could allow all drivers to enter the roadway and filter out the problems at the exit. This transfers more responsibility to the exits, but it will speed up entry and may alleviate some privacy issues.

Validation testing is not concerned explicitly with ramp design. The issue may enter in a discussion of the speed of entry, the number of check-in lanes, or the placement of an exit for a rejected vehicle, but entry design is primarily the responsibility of the Exit/Entry Activity. The major check-in concerns are:

- Impact of a check-in test on entry vehicle flow rate.
- Cost of a check-in test.
- Cost of equipment for a check-in test.
- Damage caused by the check-in test.
- Failure to test a critical component.
- Failure to correctly test a critical component.
- Failure that occurs after the test but before entrance to the automated highway.
- Association with the current vehicle system self-test methodology.
- Other methods of evaluation specific to the equipment.

These concerns may be applied as Methods of Evaluation for the different validation techniques and for the several check-in system designs.

Vehicle Function Validation

The functions in task 1 have been separated into sub functions in order to identify separate validation alternatives. Also, the validation procedures have been divided into those which may be done during inspection, those which may be done during normal vehicle operation (including operations which are not necessarily routine), and those which can only be done during a dynamic test. This evaluation is limited by the fact that some sub functions are either unique to a particular system configuration or are intertwined (and this relationship may also vary with configuration) with other elements in such a way that the sum may require more testing that any of the parts. There is no practical way of covering every possible system in detail. The following discussion is limited to a ‘smart’ vehicle, thus choosing the more complex example, with a radar longitudinal sensor and an optical lane marker lateral sensor. Several options are discussed in the RSC subsection of this task.

The dynamic tests are performed when the vehicle is under automated control, although the parameter being tested may be relevant to both automated and non-automated operation. Neither in-vehicle testing nor dynamic testing are sufficient for entry. Inspection and static testing may be sufficient, provided that the frequency of component failure is low and catastrophic failures are always preceded by readily identifiable warning signs, such as low tire pressure or poor engine performance. The results of the in-vehicle evaluations that are made routinely are retrieved during check-in as part of the total acceptance set.

Braking Functions

This analysis will attempt to evaluate the majority of all braking functions which are necessary and sufficient for a “smart” vehicle on an automated highway.

Emergency Braking

Inspection Tests

The major inspection tests will be the routine tests that are often done during periodic vehicle maintenance, such as brake fluid level verification and wheel removal to check wear on the calipers. These tests shall be required during every inspection test. A road test shall also be required which includes a planned stop with a brake application force that is comparable to that necessary for an emergency stop. The braking torque profile, obtained by an axle torque sensor, and the time history of the velocity shall be measured and compared to profiles which represent standards for operation on an AHS. The assumption in this dynamic test is that the tires are all in good condition and that the stop is made on dry asphalt. If the brake torque is adequate, the primary factors which determine stopping distance are the applied torque rate and the surface friction between the tire and the roadway. Tire pressure and condition shall be monitored during the inspection to insure that failure to meet a standard performance level is not associated with faulty tires.

There may be different required standards for some automated highways. The vehicle shall be rated ‘pass’ or ‘fail’ for each unique class of roadways for which it would nominally be qualified, and the ratings shall be stored in the check-in database in the vehicle’s AHS computer memory.

As an alternative to the road test, a static brake application test utilizing Hardware-in-the-Loop (HIL) technology might be performed. Currently, there is no procedure for measuring any parameter other than brake fluid pressure during such a test, and tests have not been performed with the wheels rotating (car in gear). This alternative, although it might be less costly and is theoretically feasible, is not a demonstrated technology.

Continuous In-Vehicle Testing

The current status of the braking system may also be obtained from data recorded during vehicle operation. If an axle torque sensor is made standard equipment, then the torque and speed profiles may be obtained for every vehicle stop. The most recent value, or a mean of several recent values, of these data will be used to generate ‘pass’ or ‘fail’ codes. Tire information necessary to evaluate these results may be obtained from the tire inflation monitors or from data stored from the last static inspection test. Brake fluid level may be determined with the aid of a fluid level sensor in the fluid container bottle or from previous static data. The condition of the calipers and the tire wear are obtained from static inspection data.

Dynamic On-Site Tests

The dynamic test, if one is required, should be a full braking stop of all wheels on a level, dry asphalt entry section to an automated highway. In order to avoid delays, and since a demonstration of wheel braking is an adequate demonstration of automated braking, the vehicle slowdown should be as little as possible. The brake system would be under automated control and the torque would be such that a normal wheel would stop rotating within 0.5 seconds. The brakes should be released after 0.5 seconds or after the first wheel comes to a complete stop, whichever occurs first. This criteria was chosen because the ABS must begin to release the brakes after the first wheel has ceased spinning in order to minimize the slowdown of the vehicle. Final velocity after the full braking interval would depend upon initial velocity, which may be anywhere from 32 to 64 km/h, but it would not be less than 16 km/h under normal conditions. Failure to meet a given requirement for brake torque and slowdown would automatically result in rejection from the AHS.

Routine (Low g) Automated Braking

Small increment braking will be an essential part of operation on the automated highway, whether in a platoon or in a time slot, because of the need to maintain precise position and to accurately maneuver in and out of a lane. Therefore the brake function must be under accurate control. Every vehicle must demonstrate that it can match the required system slowdown rate imposed on all vehicles on the roadway.

Inspection Tests

The routine tests performed for emergency braking cover this function as well. During the road test, the brake system sensitivity to brake application could be measured. This might be done several times, without actually stopping the car, in order to establish the sensitivity accurately. The desired information is vehicle deceleration vs. brake fluid pressure. At the inspection station, HIL tests can be performed to obtain brake pressure response, fidelity and speed, to AHS control commands. These tests would be limited to the minimum necessary to demonstrate that the vehicle matches the original AHS manufacturers specifications.

Continuous In-Vehicle Testing

Performance recording is applicable here just as it was for the emergency braking function. Brake fluid pressure, rather than torque, is important and the pressure response to controller instructions that was acquired in the inspection station must be combined with this data.

Dynamic On-Site Tests

The relationship between a commanded speed reduction profile and the resultant vehicle performance can be established directly by issuing instructions for one or more slowdowns during the dynamic testing.

Automated Brake, Antilock Brake, And Traction Controllers

These controllers, with the possible exception of the engine controller portion of the traction control system (TCS), will ultimately be located in a single microprocessor and many of their functions will be shared. Because of the high cost of mechanical instrumentation in the vehicle to detect mechanical component failure, it has been the practice in nearly all cases to use the controller as the principle means of testing for mechanical component failure by comparing system performance with anticipated performance. This is certainly true in ABS testing [13] and it will be true in automated brake system testing unless mechanical equipment costs are drastically reduced or the consumer is willing to pay the resultant higher cost of sophisticated test equipment.

Inspection Tests

A single electronic tester shall be constructed that shall access specific terminals on the controller which allow the exercise of critical software functions. For a given input sequence, if the output from the microprocessor corresponds to the anticipated response, within a certain established range, then the controller shall have passed the inspection test. For example, the assembly line data link (ALDL) logic sequence used to test the ABS VI (an electric motor based system) at a dealership is a specific current trace which completely exercises the antilock brake solenoids and motors. The output electronic signal, although it is complicated by the back electromotive force from the motor, is well specified in the inspection manual. The ABS controller resultant is matched to that signal for the purpose of verification. The ABS V (Bosch/industry terminology for the more common system) has a simpler test sequence because it is totally solenoid based, but the operation is essentially the same. Since the automated brake system utilizes the same solenoid system as the ABS/TCS system, the same type of current input/output test will be the methodology for the static AHS test.

Continuous In-Vehicle Testing

The self-test of the ABS can be performed at any speed, it need not be made only when the vehicle ignition is turned on, as is done now. The self-test, however, is not as complete as the tests (which cannot be made at speed because they affect brake operation) that are made during a static inspection. The addition of the more complex test sequence to the self-test and the extension to testing on the road (for example a test every time the vehicle stops at an intersection) is an option.

Dynamic On-Site Tests

The dynamic tests of the vehicle emergency braking, as described above, are a sufficient, possibly more complete than controller inspection testing, evaluation of the controller reliability.

Brake Self-Test

The capability of the self-test circuit to correctly test the performance of the ABS and brake controller functions must itself be tested. The frequency of testing required may be much smaller than for other functions, but the critical nature of the brake system makes such testing imperative. Routine inspection tests should be adequate for determining whether or not the self-test circuitry has developed flaws.

Inspection Tests

A self-test program can be evaluated by comparing the output with the known, correct response. Any deviation from a correct response will require corrective action before the vehicle can be allowed onto an AHS roadway. Each microprocessor which has a self-test program in the software also has terminals which may be used to access the self-test features independently. Automated, electronic testing of the self-test routines will be a part of the methodology for testing the various automobile controllers.

Fail-Soft Capability

The fail soft circuitry is presumed to be a parallel circuit to the controller that operates the AHS brake system. If the primary circuit fails, the backup circuit performs the same functions as the primary circuit until the microprocessor can be replaced or repaired.

Inspection Tests

Test the secondary circuit in the same manner that the primary circuit was tested. Transmit a test signal to the first circuit that indicates that a part of the primary circuit has malfunctioned and the controller should transfer operations to the backup circuit. Correct switching and performance of the secondary circuit indicates that the fail-soft capability remains intact.

Continuous In-Vehicle Testing

Occasionally switching from the primary to the secondary circuit for additional testing during non-AHS driving may be of value. There is a tradeoff here between the design cost for additional testing and the safety value.

Dynamic On-Site Tests

Unnecessary switching between circuits during AHS operation is a practice which might introduce more risk than it removes. Routine inspection tests should be an adequate guarantee that the fail-soft system is functioning.

Antilock Brake Wheel Speed Sensor

Inspection Tests

These tests will consist of inspection of the toothed gear and the Hall detector used to measure the passage of a tooth during normal driving for road damage. If the system relies on some other sensor attached to the wheel, the same visual type of inspection will no doubt be required. In addition, the controller electronics which converts the sensor data into wheel speed estimates will be tested as described above. This sensor test will also be required as a test of the vehicle speed sensor if the wheel speed sensor is used to estimate vehicle speed.

Continuous In-Vehicle Testing

There will be a connector link to the wheel speed measurement which can be attached to the vehicle diagnostic system. However, since there is not necessarily an independent reference speed available, wheel speed sensor tests during vehicle operation may not be possible.

Dynamic On-Site Tests

There will be a vehicle speed reference measurement system available during a dynamic test, and it will be used to measure the vehicle speed on dry asphalt and to convert that to wheel speed, using the wheel radius as supplied by the in-vehicle database. The internally sensed speed and the externally measured speed shall be compared and the result used either to adjust the internal system calibration or to deny access to the vehicle if the two results are not within an established tolerance.

Brake Apply And Release Cycles

A typical ABS command interval is 8 milliseconds. Presumably this will also be adequate for brake and release cycles in platoon operation. The hardware must respond to the instructions in a precise, anticipated manner in order to achieve stable braking and to achieve accurate spacing between vehicles in a platoon.

Inspection Tests

There are already in place test programs for determining whether or not the ABS is responding correctly to specific commands. These programs are routinely exercised during a regularly scheduled inspection at a qualified repair shop (see previous discussion).

Continuous In-Vehicle Testing

This test methodology shall be contained in the testing for the ABS and automated brake system controller.

Dynamic On-Site Tests

The test of the vehicle automated braking operation, as described above, is a sufficient, in fact possibly more complete than the inspection test, test of the controller.

Antilock Brake Lateral Control

The ABS/TCS can provide lateral stability during maneuvers and hard braking which may be necessary in emergency situations on the automated highway.

Inspection Tests

These shall be the standard tests described above for the controller, with additional testing done in the controller computer if necessary.

Continuous In-Vehicle Testing

In addition to the self-testing that has been described above, the results of the last application of the ABS/TCS/yaw control system shall be stored in the on-board computer and made available to the ALDL or other bus architecture for analysis during check-in and during routine inspection checks.

Dynamic On-Site Tests

In addition to the nominal full braking test described above, an additional test of braking in a turn on dry asphalt may also be performed, however this test could impact system safety and therefore its implementation is an issue for further study. Whereas the controller and ABS have already been tested on dry asphalt, the primary feature that will be tested is the lateral friction characteristic of the tires.

Transfer From Manual To Automated Braking

There is an obvious requirement to test the capability of the braking system to switch to the automatic function and back to the manual function. This feature is quite similar, but not identical, to the ABS function.

Inspection Tests

An off-board controller/transmitter shall be used to send signals to the brake controller requesting either manual or automated brake operation. In the manual mode, the response to pressure on the foot pedal shall be measured electrically and compared with the expected response. In the automated mode, the received signal shall also trigger the application of brake-by-wire at a certain level and that response shall be measured and compared with a known requirement.

Continuous In-Vehicle Testing

The current routine in-vehicle ABS controller tests described above can be used to verify that the automated brake function is operational and can be switched on by the in-vehicle AHS. This does not, however, demonstrate the performance of the communications link which is part of the startup operation at the on-ramp. The instructions to operate the automated brakes shall be used only when the vehicle is at a full stop (stop sign or stop light).

Dynamic On-Site Tests

During the dynamic brake test on asphalt (which can only be performed if the automatic brake switch has correctly functioned) the brake release portion, the terminal stage of the brake test, shall serve as a demonstration of the system ability to return the brakes to manual operation. A full manual test shall only occur during the check-out procedure.

Engine Functions

There are several engine functions which must be evaluated as part of the check-in process before the vehicle can be allowed onto the automated highway. Some functions are easy to evaluate or are already evaluated during normal operation, some functions are costly to test, and some functions typically change very slowly with time.

Engine Parameters

The standard parameters are engine temperature, oil pressure, coolant level, and tune-up parameters such as spark plug timing. The standard AHS vehicle will operate with an electronic engine controller that is more sophisticated than current systems that are on the market, but it will still require periodic adjustment to avoid performance loss.

Inspection Tests

Engine oil level, oil condition, coolant level, and engine controller properties will be measured in the same manner that they are now during routine service and maintenance. The inspection frequency will be impacted by the additional AHS requirements and by the type of additional check-in operations that occur at the on-ramp and in the vehicle. The engine temperature can only be inferred from the status of the measured quantities, but that has traditionally been an adequate inspection. Additional testing, for example running the engine until the nominal engine temperature is reached and it has been demonstrated that the engine will not overheat under normal circumstances, will increase the cost and possibly the risk, with time, that unacceptable engine wear has occurred.

Continuous In-Vehicle Testing

Temperature and oil pressure sensors are standard equipment in all vehicles, and connection to the in-vehicle check-in data base should be a simple procedure. Additional engine properties, supplied by the On-Board Data system (OBD),[14] which would probably be a part of the check-in data base, are also available for transfer to a verification station at the on-ramp.

Dynamic On-Site Tests

No additional equipment would be installed as part of dynamic testing to measure the engine parameters.

Engine Controller

The engine controller, now expanded to include automated control functions such as throttle control, would be a single microprocessor coupled through the latest bus to the body control module and the on-board data base system. Most of the controller functions would be associated with engine management and would not be specific to an AHS operation.

Inspection Tests

Current engine controller tests are nearly identical in nature to the ABS controller test, except that a different service computer module is installed in the electronic test module to interrogate the engine control electronics. A general, but not complete, list of tests available through the Powertrain Control Module (PCM) is presented in table 6.[15] The PCM monitors a variety of data such as that shown in the table and in addition performs diagnostic tests which can detect failed sensors. A list of such diagnostics would include:

- Response / switching times.

- Commanded vs. measured states.
- Open/short/intermittent tests.
- Out of range test.
- Rationality / input signal consistency check.
- Circuit continuity check.
- Time in state.
- Time to activate.
- Periodic dynamic tests.
- Illegal switch combinations.

Additional tests, such as tests for trends that might warn of impending failure, could be devised, although there would be a cost for the service. In addition, sophisticated operational algorithms could be included which would prompt the electronics to walk through several control scenarios to demonstrate that the system would function properly even if a system malfunction occurred. The rationale for adding these new types of tests would have to come from a complex trade-off study balancing cost and lost time against added safety and improved travel time.

Table 6. Data Monitored By The PCM

Powertrain component	**Data monitored**
Engine	Engine misfire, identification of the misfiring cylinder Engine coolant level and temperature Engine speed Engine load Spark timing Battery voltage Vehicle speed Manifold pressure Oil level and pressure
Transmission	Transmission fluid temperature Torque converter clutch state Torque converter control solenoid Shift solenoids Turbine input speed Transmission output speed
Fuel Flow	Throttle position Fuel flow / Air flow

Continuous In-Vehicle Testing

With some exceptions, the same self-test diagnostics could be used during vehicle operation to insure that no degradation occurred since the last visit to the remote inspection station. Tests including operational scenarios would not be practical during vehicle operation, however tests performed during manual operation would exercise almost every processor element that would be activated by an artificial scenario. Excluded would be such tests as those which actually exercised an automated throttle, unless such an instrument were already part of manual operation.

Dynamic On-Site Tests

These tests are the vehicle performance (acceleration, deceleration) tests described in the next three sections.

Transfer From Manual To Automated Control

It will be necessary, unless there is a dynamic test facility, to test the capability to initiate automatic engine operation. The ability to switch back from automatic operation to manual control will be important in a certain class of malfunctions.

Inspection Tests

An off-board controller/transmitter shall be used to send signals to the engine controller requesting either manual or automated engine operation. This operation will begin after the engine is turned on and with the vehicle in a position such that the wheels can spin without the car moving (this can be done, within limits on a service hoist). In the manual mode, a driver is required to operate the throttle and automatic transmission. The response to pressure on the throttle pedal does not generate the same engine speed or other vehicle performance characteristics that would be observed if there were tire/road resistance, but there is a predictable response that can be compared with the expected response. In the automated mode, the received signal can also trigger the application of automatic engine operation at a certain level and that response shall be measured and compared with a known requirement. The amount of information gathered about the engine performance from this test is limited, but it is primarily a method for demonstrating that the drivetrain can successfully be commanded to operate in either the automatic or manual mode.

Continuous In-Vehicle Testing

Currently there is no practical way of testing the capability for switching between the driving and the automated engine mode while the vehicle is being manually operated. However, the advent of adaptive cruise control will provide in-vehicle testing of a switching process which is quite similar to the automated switching process. In fact, there may be only one engine switching operation for both modes. In the adaptive cruise mode, the engine switching is initiated manually, but further switching in and out of automated control will be performed by a complex algorithm connected to the vehicle sensors and the vehicle speedometer. certain functions will be different for each mode, so that there must be an additional switch which distinguishes between the request for initiation of each mode.

Dynamic On-Site Tests

Initiation of the dynamic engine test demonstrates that the automatic engine switch has correctly functioned. Demonstration that the switch will perform correctly with any initial manual conditions is done during static testing. Demonstration that the automatic-to-manual switch is functioning can only be done thoroughly with the cooperation of the driver. There is risk associated with the routine reliance on the driver to function as part of the dynamic check-in test. At an average speed of 20 meters/second on the ramp, the dynamic test time would be 5 seconds on a 100 meter test length. One second of time would be a maximum amount of time that could be allowed for a switch out of automatic, into manual, and back to automatic, and there are very few drivers who could respond routinely and reliably to a command in less than a second. If it is concluded, as a part of malfunction management, that this capability must be demonstrate during entry, then it would be more appropriate to conduct the switching test at the nearby check-in verification station. There is adequate time, and a failure to revert back to manual engine control could be resolved by parking the vehicle at a location beyond the on-ramp and out of the traffic, especially those awaiting admittance to the AHS. Of course, a full switch-to-manual test will occur during the check-out procedure.

Fail-Soft Capability

Again, it is assumed that the fail soft circuitry is a parallel circuit to the primary engine controller that operates the automated engine system. If the primary circuit fails, the backup circuit performs the same functions as the primary circuit until the microprocessor can be replaced or repaired.

Inspection Tests

The secondary circuit test is the same as the test for the brake fail-soft system. Transmit a test signal to the first circuit that indicates to the electronic system that a part of the primary engine control circuit has malfunctioned and the controller should transfer operations to the backup circuit. Correct switching and performance of the secondary circuit demonstrates that the fail-soft capability is intact.

Continuous In-Vehicle Testing

Occasionally switching from the primary to the secondary circuit, if it can be done without affecting the performance of the engine controller, will provide additional testing during manual operation. There is a risk that the switching may affect the manual engine controller operation, especially if the secondary circuit has an intermittent flaw that affects general engine controller operation When the microprocessor controller is constructed, a series of tests must be performed to determine the probability of failure and to allow a proper tradeoff study between the several safety issues and cost issues.

Dynamic On-Site Tests

As was stated above and in the section on brake fail-soft tests, unnecessary switching between circuits during AHS operation is a practice which might introduce more risk than it removes. Routine inspection tests should be an adequate guarantee that the fail-soft system is functioning. If those tests are not sufficient, then additional dynamic testing will be necessary.

Automated Acceleration And Deceleration

Typical inspection and maintenance of a modern automobile requires some testing of the engine during operation to determine engine timing accuracy and other characteristics such as valve operation. For a vehicle to be qualified on an automated highway, the engine control requirements are so broad and critical that additional testing is necessary.

Inspection Tests

It is assumed, as it has been throughout this discussion of engine testing, that the remote testing facility does not include a test track of any sort. In station set C, a remote track is available. In that case, all of the inspection tests can be significantly improved be operating the automobile and performing dynamic tests of the engine performance.

Without a track, the static test methodology described in the discussion of the transfer from manual to automated control can be used to test engine acceleration and deceleration characteristics. As was pointed out in that discussion, the amount of information that can be gained about the current engine Map is quite limited because of the absence of true road friction to limit wheel speed.

Continuous In-Vehicle Testing

Engine performance during routine manual operation can be monitored for a variety of running properties. Displays of the engine speed are available on many current vehicle models. Throttle angle will, of necessity, be accessible for evaluation on any AHS vehicle. The system torques may be inferred from these three variables, or the torques can be measured, at a significant cost, by torque measuring solid state devices. The on-board computer storage unit shall have access to this information and shall store enough data to adequately describe the engine operating condition to a check-in verification station.

Additional demonstration of the capability of the system to follow automated instructions is derived from performance during operation of the adaptive cruise control system. As described above, this system is similar to the AHS and the acceleration and deceleration commands required to maintain constant spacing should emanate from the same controller with little alteration in their nature. In the case that AHS vehicle spacing is derived from the infrastructure, the communications link will be disconnected during adaptive cruise control (ACC) operation, but this has very little impact on the testing of automated engine operation.

Dynamic On-Site Tests

There is little additional testing that is required to supplement the continuous in-vehicle testing. The driving scenario that is dictated during dynamic testing should not be required to unduly stress engine performance, as the resultant data will serve principally as a demonstration that the engine is correctly responding to commands given by the automated vehicle/infrastructure system.

Functions Associated With Tires And Wheels

The principal concern regarding tires is the risk that a blowout will occur on the automated highway. Tire failure can be related either to tire pressure or to tire damage, and these can be detected, respectively, by measuring the tire pressure and by inspecting the tire. Wheel damage can result in rapid tire wear or in loss of a wheel bolt or, in some cases, in the loss of the wheel during travel on the highway.

Tire Pressure

Inspection Tests

Both the tire pressure and the functionality of the tire inflation monitor (TIM) [16] must be inspected. The condition of the TIM may be readily tested by reading the monitor output from the expanded functionality PCM and comparing with the pressure gauge reading. On-site testing would require a special device that could quickly remove and replace the valve cover and measure air pressure, or else the check-in would have to rely on the TIM completely.

Continuous In-Vehicle Testing

Data from the TIM shall be stored in the automated vehicle database for readout when the check-in verification station requests the output.

Dynamic On-Site Tests

Unless there is a blowout on the ramp, there is no reason to separate TIM pressure data during dynamic tests from pressure data gathered before entry.

Tire and Wheel Condition

Inspection Tests

Inspection shall include testing bolt tightness, measuring tread wear and checking the tire sidewalls. Because of the added risk on an AHS, there will be strict standards that must be met which would not apply to a non-AHS vehicle. Inspection testing on-site would require either a human observer at the site or cameras located in spots where the necessary tire data could be quickly obtained.

Continuous In-Vehicle Testing

Currently there is no methodology for automatically evaluating tire and wheel condition.

Dynamic On-Site Tests

No tests.

Wheel Alignment

Alignment of wheels is unlikely to create an immediate hazard on an automated highway. However bad alignment can wear tires quickly and detection of severe misalignment could a justification for denying access to the AHS.

Inspection Tests

A current certificate attesting to an alignment inspection within a specified time previous to highway entry and recorded in the vehicle computer is required.

Continuous In-Vehicle Testing

Currently there is no methodology for automatically evaluating wheel alignment.

Dynamic On-Site Tests

No tests.

Steering Functions

Currently, there is no link between the body control module (BCM) or the PCM and the steering system, since there is no capability for steer-by-wire. In the future, there will likely be automated steering, and the system performance will be monitored just as the ABS and the powertrain controller are monitored.[17] If there is no manual steer-by-wire system, the inspection tests become more complex because the mechanical portion of the automated steering system is not in use during manual operation. On the other hand, there may be automated, non-AHS steering available if electronic steering is in use, and continuous in-vehicle testing of the automated steering system may be a very reliable system test.

Mechanical Components

Included in the list of mechanical components are the steering linkage, the rack and pinion mechanism, and the bushings and tie rods which attach to the wheels.

Inspection Tests

The typical visual inspection shall be expanded to include a well defined list of components and a check off of each item will be stored in the vehicle database. If there are load sensors that are used to detect steering motions, those will be included on the inspection list. If inspection testing is done at slow speed at the on-ramp, then cameras that can observe under the vehicle may be required.

Continuous In-Vehicle Testing

The condition of the steering components will not be tested during routine driving conditions.

Dynamic On-Site Tests

No tests.

Hydraulic Fluid Pressure And Level

The condition of the power steering fluid is critically important to the automatic steering system because there is unlikely to be an alternative force such as the driver to accept authority for maneuvering if the fluid is lost from the system. However, it should be noted that the modern experimental steer-by-wire systems use electric motors for their power source, thus obviating the requirement to test steering fluid pressure and level.

Inspection Tests

A fluid pressure sensor shall be inserted into the steering fluid system and a fluid level transducer shall be used in the steering fluid reservoir. These shall be read out and compared with independent measurements made at the inspection station to verify the accuracy of the equipment and to record the current pressure and fluid level.

Continuous In-Vehicle Testing

The pressure and level sensors shall be interrogated at routine intervals to determine fluid conditions and the current value shall be stored in the vehicle data base.

Dynamic On-Site Tests

No unique tests.

Transfer From Manual To Automated Steering

This transfer is critically dependent on the type of hardware that will be in the automobile when the first AHS vehicles are available. If the manual steering system is hydraulic, then there must be some major hand over of mechanical control in order to maintain steering control. Also, the exact design of such a system has not been specified, but it will be assumed to be a mechanical force applied at the steering wheel shaft. This implies that the power steering system functions whether control is manual or automatic. If, however, the manual system is already electronic steering, then the steering may quickly shift from commands generated by the driver's hand motions on the steering wheel to commands produced by a steering algorithm which receives inputs from vehicle position sensors and off-road intelligence. Both systems will be considered in this report.

Inspection Tests

In a manner similar to the engine switching tests, an off-board controller/transmitter will be used to send signals to the steering controller requesting either manual or automated steering operation. This operation will begin after the engine is turned on and with the vehicle in a position such that the wheels can be turned without the car moving (e.g. a service hoist). In the manual mode, a driver is required to operate the steering wheel. If the automated system is a mechanical alternative to the manual steering system, then the driver might also be required to exert some steering force when the vehicle was controlled automatically in order to establish the relative force necessary to reacquire manual control. The response to such a steering torque on the wheel yaw angle would not be the same as that which would be observed if there were tire/road resistance, but there is a predictable response that can be compared with the expected response. In the automated mode, the correlation between the predicted and measured response to the received signal can be measured and compared with a known requirement. The amount of information gathered about the steering system performance from this test is limited, but it is primarily a method for demonstrating that the system can successfully be commanded to operate in either the automatic or manual mode.

Continuous In-Vehicle Testing

It would not be practical or safe to switch to automated steering if there were no built-in automated system that was designed to operate autonomously on highways which were not automated. If such a system (probably based on an electric steer-by-wire system with lane sensing) were installed in the vehicle, then it could be tested if the vehicle were in a location where an automated system would be normally applied. For example, an advanced vehicle control system (AVCS) steering design would allow the driver to rest during long distance traveling on a non-automated highway (perhaps a precursor to an automated highway), but automated steering on city streets would demand more of a steering system than the AHS and would probably not be allowed. That is not to say that such an intricate system might not be available one day, but it would probably be developed after the AHS was well established.

Testing of such a steering system would not be continuous, since the steering system would only be used on some occasions. Therefore the test results must be accompanied by the date of test and the verification station would utilize a reliability algorithm to determine whether the test was a recent test or was too old to be a valid check of automated steering.

Dynamic On-Site Tests

Initiation of the dynamic steering test demonstrates that the automatic steering switch has correctly functioned. Demonstration that the automatic-to-manual switch is functioning can only be done thoroughly with the cooperation of the driver. There is risk associated with the routine reliance on the driver to function as part of the dynamic check-in test (see discussion of engine switching in that section).

Steering Controller

The relative merit of different tests is sensitive to the type of automated steering system (steer-by-wire or separate mechanical device) in the vehicle. If there is also a non-AHS capability, then further changes in testing are probable.

Inspection Tests

The tests described in the discussion of the engine controller are similar to the tests which would be performed for a steering controller (regardless of the type of automated steering system), provided that the controller were part of the BCM.

Continuous In-Vehicle Testing

With some exceptions, the same self-test diagnostics could be used during vehicle operation to insure that no degradation occurred since the last visit to the remote inspection station. Tests that included operational scenarios would be practical only during automated steering operation (provided the non-AHS capability existed). Tests that did not affect steering actions performed during manual operation would exercise almost every processor element that would be activated by an artificial scenario.

Dynamic On-Site Tests

These are the vehicle performance tests described in the next section.

Steering With Automatic Control

Inspection Tests

Without a track, the static test methodology described in the discussion of switching from manual to automated control can be used to test automated steering characteristics. As was pointed out in that discussion, the amount of information that can be gained about the automated steering is limited because of the absence of true road friction to limit wheel speed.

In station set C, a remote track is available. In that case, all of the inspection tests can be significantly improved be operating the automobile and performing dynamic steering tests.

Continuous In-Vehicle Testing

Steering performance during routine manual operation will yield little information about automated steering if the automated steering is operated by a mechanical system which applies torque independently of the driver's actions. If the driver operates the steering system through an electronic system, then the operation is quite similar to automated steering, and steering performance may be monitored and the results stored for readout to the verification station. If the vehicle is also operated in the automatic mode during non-AHS driving, then a full experimental data set will be acquired.

Dynamic On-Site Tests

These tests are extremely critical if the automated system must be actuated by mechanically transferring control of the steering from the driver to the automated control mechanism and there is no test track associated with the inspection station. The dynamic test section is designed to fully test the steering system under electronic control. If the AHS is controlled by the infrastructure (RSC 1 or 3) commands are transmitted from the ramp control station to the vehicle to make both right and left turns and to modify speed during the turns. Otherwise the vehicle must follow the guidance of a set of magnetic markers which illicit the same internal commands. During continuous in-vehicle testing, if the vehicle is controlled manually through an electronic steering control, the manual operation may have tested all of the important control functions except the communication link. The necessity for the dynamic site will therefore not be as great.

Fail-Soft Capability

It is assumed (see discussions for engine and brakes) that the fail soft circuitry is a parallel circuit to the primary steering controller that operates the automated steering system.

Inspection Tests

The secondary circuit test is the same as the test for the brake and engine fail-soft systems.

Continuous In-Vehicle Testing

Occasionally switching from the primary to the secondary circuit can only be done if the automated system is operating. This will only be true if the vehicle possesses the capability to allow the driver to switch on an automatic steering and lane sensing system during non-AHS operation. There is a risk that the switching may affect the steering controller operation, especially if the secondary circuit has an intermittent flaw that affects general steering controller operation (see discussion in the engine and brakes sections).

Dynamic On-Site Tests

See the sections on brake and engine fail-soft testing.

Vehicle Transmission And Differential

The vehicle drivetrain, except for the engine, is relatively unaffected by the transfer of control from the driver to the automated system. The electronic controller operation and shift commands are unchanged.

Automatic Transmission Performance

The most important transmission check-in operation is the accurate keeping of maintenance records so that the transmission does not fail because of abusive wear or thorough disrepair.

Inspection Tests

Inspection consists of visual examination of the individual transmission elements for wear or damage and proper maintenance of the transmission fluid. Also the part of the drivetrain controller which is associated with the shift mechanism and the torque converter must be tested as part of the engine controller tests.

Continuous In-Vehicle Testing

In-vehicle testing, primarily verification that the shifting is smooth and occurs at the proper engine speed, is part of the engine continuous in-vehicle testing.

Dynamic On-Site Tests

Dynamic tests are the same as continuous in-vehicle tests.

Differential And Constant Velocity Joint Condition

Proper maintenance and good record keeping are also the most important part of the check-in procedure for the differential and constant velocity (CV) joint.

Inspection Tests

Inspection consists of visual examination of the differential and the other elements connecting the transmission to the wheels plus lubricant replacement at the proper times.

Continuous In-Vehicle Testing

No tests.

Dynamic On-Site Tests

No tests.

Fuel Quantity

For the internal combustion engine (ICE) the fuel level is related only to the remaining stored energy compared to the standard capacity of the fuel tank and the amount of energy required to get either to the vehicle destination or the next fuel supply depot. In the case of the electric powered automobile, this also refers to the condition of the storage medium.

Fuel Supply (Gasoline)

The requirement at check-in is that the supply of gasoline be greater than the minimum amount. This minimum is determined by the check-in (or verification) station, which matches the vehicle fuel efficiency as recorded in the vehicle and the number of kilometers to reach the traveler destination or the next gas station (on or off the AHS).

Inspection Tests

The driver is expected to maintain sufficient fuel to meet check-in requirements, however a record of the last addition of gasoline is not necessary or sufficient for check-in.

Continuous In-Vehicle Testing

The typical fuel gauge has an accuracy of a few liters. The check-in system accounts for this as it detects the current vehicle fuel supply by reviewing the current fuel gauge reading.

Dynamic On-Site Tests

No tests.

Fuel Supply (Stored Charge)

This requirement is essentially the same as it is for gasoline supply, except that the fuel efficiency is the range of the vehicle, accounting for the nominal speed on the automated highway and the next fuel station must be a location where the battery can be replaced with a fresh battery of equal age and reliability.

Inspection Tests

The date, time, and distance traveled for the last battery recharge are recorded internally. If the battery is a replacement, the information on the new battery is the data recorded on the vehicle computer.

Continuous In-Vehicle Testing

By subtracting the kilometers traveled since the last recharge from the kilometers expected from the battery and adjusting slightly by a time factor related to the time since the battery was last charged, the available range can be calculated. Currently, there is no method for determining the true lifetime of the battery or the likelihood that it will not hold its charge.

Dynamic On-Site Tests

No tests.

Battery Capacity To Hold A Charge

Although there is no sure method of predicting the lifetime of a given battery, it is possible to bound the lifetime of almost all batteries by means of conservative estimates. This requires that up-to-date records of the age, number of charges, kilometers traveled, and nature of the kilometers traveled be kept. In addition, any abusive use or previous damage of the battery should be recorded. This record must accompany the battery and be inserted into the computer record of each vehicle in which it is installed. This data shall be examined before check-in of any electric vehicle to an automated highway.

Electrical System Condition

The analysis will include both the design and age of the battery and the wiring plus the condition of the battery cooling/heating system (if needed by the electric car), the fan belt, and other unique features of the electric car electrical system.

Battery, Fan Belt, Voltage Regulator, And Wiring Damage

Inspection Tests

Most of the inspection tests will be visual examinations of the individual components. In addition, the battery will be checked off-line to determine its capacity to hold a charge. In order to do so, a replacement battery which is shown to be reliable and is no older than the previous battery shall be installed. With the replacement battery installed, the voltage of the electrical system and the delivered current to a known load shall be measured with the engine running.

Continuous In-Vehicle Testing

System voltage shall be monitored continuously during vehicle operation. If there are any substantial deviations from normal behavior they shall be recorded in the vehicle computer and reported on an exception basis to the check-in verification station.

Dynamic On-Site Tests

No tests.

Electric Car Battery Peripheral System

Besides the thermal management system that would be required by certain types of batteries, other systems might include regenerative braking (assumption that the battery has been somewhat recharged during braking), or a propane supply (for a fuel cell in order to generate hydrogen). This validation discussion is a brief summary of some tests that might be performed.

Inspection Tests

The thermal management system can be tested by operating the system separately and measuring the thermal output for a known commanded input. The propane supply is similar to a gasoline supply and will be treated in a similar manner. The operations required to test the regenerative braking must be performed on a roadway where road friction will affect the amount of energy returned to the battery.

Continuous In-Vehicle Testing

The voltage-current characteristic observed when the vehicle is stopped or slowed significantly may be measured and compared with a standard profile to determine any loss of capacity for resupply of battery capacity during braking. This is a feature used in evaluating the battery range, but not necessarily a characteristic of AHS operation, where hard braking is not expected.

Dynamic On-Site Tests

No tests.

Vehicle Longitudinal Position/Distance Sensor

The position of the vehicle will be determined either by means of wayside sensing (RSC 1 and RSC 3 and RSC 2, lead vehicle only) or by means of range determination to the nearest vehicles in the platoon using vehicle-to-vehicle communications (RSC 2). Both of these methods are based on communications and will be covered in that section. This section will deal solely with the system used for collision avoidance. It will be assumed, based on current communications from GM, that such a system will utilize a radar to detect threatening objects.[16, 18] The system consists of a processor/controller and radar sensors with internal processors to convert received energy to a conditioned signal for the microprocessor and to convert the controller signal to a tailored microwave transmitted output.

Longitudinal Range Measurement

The object of these tests is to demonstrate that the system has maintained a standard range, range rate, and angular accuracy.

Inspection Tests

The remote tests can all be performed with the vehicle at rest, but a simple target radar range is required Move a target at an angle to the radar line of sight across the field of view and record from the output of the vehicle radar the apparent range and range rate and angle to the target. The comparison with the true values will determine the reliability of the vehicle system and whether or not the vehicle may be allowed to operate on the automated highway.

Continuous In-Vehicle Testing

The collision avoidance system is operated on the non-AHS roadway system just as it is on the AHS, therefore it is tested whenever a collision might be possible. Since there is no reference target data, however, the routine operation of the collision system does not constitute a proof that it correctly measures ranging parameters.

Dynamic On-Site Tests

This test is the inverse of the static inspection test. The vehicle moves past a fixed, known target at a surveyed location and the measured range, range rate, and angle as a function of time are compared with the expected values. The expected values are determined by establishing the vehicle coordinates exactly at the dynamic test station and correlating the vehicle clock and the infrastructure clock and relating the data stored in the infrastructure according to these coordinates.

Longitudinal Object Detection

The radar system must be capable of distinguishing with sufficient accuracy, multiple returns from objects of various sizes and at various distances.

Inspection Tests

The remote tests can all be performed at the same time that the ranging tests are performed (see above). Record the amplitude of the target as a function of location and compare with the known value. Only a few samples at different ranges are required for an adequate demonstration of the accuracy of the amplitude measurement system.

Continuous In-Vehicle Testing

The discussion that was presented in the previous section on continuous testing of range accuracy also applies to the testing of target amplitude measurement accuracy.

Dynamic On-Site Tests

The same target used to determine radar ranging accuracy shall be used to determine the ability of the radar system to measure target amplitude. This may be done by comparing the target amplitude as measured in the vehicle with the known value of the target backscattered signal strength.

Longitudinal Collision Avoidance Controller Performance

The collision avoidance controller[19] will take the sensor information and identify threatening situations. If there is a threat, it will first send a warning signal to the driver and then, if necessary, take evasive action involving the engine, the brakes, and the steering system. Controller check-in tests are intended to demonstrate that the controller will operate in a specified manner if appropriate signals are received from the sensor system.

Inspection Tests

The collision avoidance controller tests are nearly identical in nature to the engine controller tests, except that a different service computer module is installed in the electronic test module to interrogate the collision avoidance control electronics. A general, but not complete, list of tests is presented in the discussion of engine controller tests in table 6. In addition to these controller tests, the signals generated by the controller during the ranging and object detection tests will be monitored. Those signals operate the engine, steering, and brake controllers and provide a warning to the driver of a potential hazard. There will be terminals on the output side of the controller that will allow monitoring of the output signals when the vehicle is stationary and in test mode.

Continuous In-Vehicle Testing

The same self-test diagnostics could be used during vehicle operation and could be stored for readout at a verification station, however the output signals would not be accessible except during a real collision avoidance scenario

Dynamic On-Site Tests

An actual collision avoidance scenario cannot be reproduced during check-in because of the space and time required for such a demonstration and because the test might create a safety problem if the vehicle failed to operate correctly. However, a possible solution to this problem which would allow measurement of control signals that would normally cause a response in the vehicle actuators would be to disable the connection to the actuator controllers during a collision avoidance controller check-in test scenario. In that case, the object used for radar sensor tests could appear as a threat and the avoidance system would generate control signals that would be intercepted by the check-in analysis system and sent to the dynamic check-in station for validation.

Vehicle Lateral Position/Distance Sensor

Lateral position determination will be determined by wayside sensing (RSC 1), by magnetic markers in the roadway (RSC 2), or by optical detection of the lane edge (RSC 3). The first method is a communications function and will be discussed in the communications section. The latter two will be discussed in this section, and they will be separated in the validation analysis.

Lateral Position Magnetic Marker Detection

The objective of this test is to determine if the vehicle magnetic detection system,[20] mounted under the vehicle, can, within the specifications of the marker system, accurately detect the presence, the relative location, and the value of a marker as it passes under the vehicle.

Inspection Tests

As the detector is installed under the vehicle, it is important to visually inspect the detector for road damage. It may prove to be necessary to demount the device for detailed testing in a separate system at the inspection station, however that depends on the evolution of the detector hardware design. Magnets similar to those used in the roadway should be passed by the detector to determine the signal detection capability. Output may be read from connectors hooked up directly to the device terminals or from the electronic controller, depending on hardware design. The field test should be done at several locations in angle and range to verify that there are no unexpected blind spots. The system should also be tested to determine that the detector can determine the polarity (bit value) of the magnet.

Continuous In-Vehicle Testing

There is no test for the magnetic marker detector during operation on a non-AHS road unless the markers are installed as a safety guide for equipped vehicles.

Dynamic On-Site Tests

A full operational test will be performed in the dynamic test section in order to evaluate the lateral detection system as well as the automated steering system, which was described previously. The markers will be installed in the on-ramp surface in such a manner that they simulate both a vehicle following a lane and a vehicle changing lanes. This will be coordinated with the steering system test to optimize the amount of diagnostic information obtained within a relatively confined space. The controller will have connection points which will allow direct readout of the measured lane position, current marker polarity, and predicted lane curvature based on the information from previous magnetic markers.

Lateral Position Optical Lane Marker Detection

The optical lane marker detection system[21] is an alternative to the magnetic marker system. It possesses the capability of viewing the line separating two lanes ahead of the vehicle and estimating the lateral vehicle position with respect to the lane line. It will operate in conjunction with several vehicle motion sensors such as the vehicle speed and vehicle longitudinal position sensors, and there may be two cameras, rather than one, used to detect lane positions separately and provide some three dimensional capability. Lane marking on the AHS may include reflective markers which are coded to provide information similar to that encoded in the magnetic marker polarity.

The optimum camera imaging system has not been developed. Therefore it is not clear whether the camera system will be mounted high up on the vehicle to provide vehicle as well as lane detection, or will be mounted lower down to reduce weather effects and shorten the range to the lane markers. In either case, no solution to the visibility loss resulting from fog or rain has been found as yet.

Inspection Tests

The condition of the camera and its mount must be visually inspected during static testing. A target similar to a lane marker shall be moved past the active lane detection camera and the output will be recorded and compared with the nominal result for the detection and tracking test. If the camera is also responsible for vehicle detection, a target resembling a vehicle will also be used to test the operational capability of the optical detector. Output may be read from connectors hooked up directly to the device terminals or from the electronic controller, depending on hardware design. The optical test should be done in such a manner as to verify that there are no blind spots. The system should also be tested to determine that the detector can determine the coded information in reflective markers if that system is utilized.

Continuous In-Vehicle Testing

Unlike the magnetic detector, the optical detector can operate without special adjustments to the highway. However, the system may be designed for use only on an automated roadway or with special reflectors or with special reflecting paint, so that it is not necessarily true that continuous testing will always be possible. The controller will have connection points which will allow direct recording of the measured lane position, current reflector code, and predicted lane curvature based on the information from previous coded reflectors.

Dynamic On-Site Tests

The dynamic check-in testing of optical lane sensors will resemble very closely the testing proposed for lateral magnetic marker guidance testing. The lane marker design will allow check-in verification that the vehicle can successfully change lanes as well as follow a lane on the AHS and the tests will be coordinated with steering tests. The same terminals as those described in the continuous tests will be used to output data to the check-in station.

Lateral Position Magnetic Controller Performance

The lateral position controller must convert the bit information from the markers and the sensed lateral position of the vehicle relative to the marker closest to the magnetic sensor into estimates of current lateral position relative to the edges of the lane and future road curvature and steering, braking, and engine requirements.

Inspection Tests

The lateral position magnetic sensor controller tests are nearly identical in nature to the collision avoidance controller tests, except that a different service computer module is installed in the electronic test module to interrogate the lateral control electronics. The same list of tests is relevant. In addition to these controller tests, the signals generated by the controller during the marker detection tests will be monitored. Those signals feed the steering controller and provide a warning to the driver of a potential lateral collision hazard. There will be terminals on the output side of the controller that will allow monitoring of the output signals when the vehicle is stationary and in test mode.

Continuous In-Vehicle Testing

The same self-test diagnostics could be used during vehicle operation and could be stored for readout at a verification station.

Dynamic On-Site Tests

The magnetic marker sensor tests, and the automated steering tests, will be combined with these tests of the lateral position computer into a single set of tests on a single stretch of on-ramp. The results of these tests, the inputs to the steering, brake, and engine controllers, will be compared with expected results as part of check-in.

Lateral Position Optical Controller Performance

The optical lateral position controller must perform almost the same tasks as the magnetic lateral position controller. The outputs to the steering, braking, and engine controllers will be quite similar. However, processing of the data will be quite different because the preview information is based on visual observations of the changing roadway curvature and the current relative lateral position is always known by the sensor system since, unlike the magnetic system, the integrated system has no blind zone.

Inspection Tests

The lateral position optical sensor controller tests are essentially identical to the lateral position magnetic sensor controller tests, except for slight differences in the algorithms used in the controller to process signals and to recognize lane edges and vehicles which might malfunction. The same list of internal tests and the same data obtained during sensor performance checks are necessary.

Continuous In-Vehicle Testing

The same self-test diagnostics could be used during vehicle operation and could be stored for readout at a verification station.

Dynamic On-Site Tests

The optical sensor tests, and the automated steering tests, will be combined with these tests of the lateral position computer into a single set of tests on a single stretch of on-ramp. The results of these tests, the inputs to the steering, brake, and engine controllers, will be compared with expected results as part of check-in.

Visibility Enhancement And Emergency Equipment

Visibility enhancement and emergency equipment are not required during normal AHS operations, however they may be required as a response to a malfunction or at the time of check-out because of the need to have the hardware for operation on a non-AHS roadway. The equipment includes the windshield wipers, the headlights, tail lights, and brake lights, the rear window defogger, snow chains and emergency flares, a spare tire or equivalent tire inflation equipment, and other equipment which is not currently required but may be required in the future. This equipment may also be characterized by the fact that virtually none of it can be inspected automatically. Tests of lighting and windshield wiper functionality are not currently available and the cost for development and deployment may not be justified by their limited utility on the automated roadway.

Headlight, Tail Light, And Brake Light Operation

Inspection Tests

Routine maintenance and inspection will be redefined to include a test of all lighting systems by visual observation that the lights may be turned off and on. In addition, it may be considered necessary to inspect the lighting bulbs for flaws or to maintain a record that would cause automatic replacement after a certain period of time.

Continuous In-Vehicle Testing

Use of these lights during night time operation demonstrates to the driver that the equipment remains functional.

Dynamic On-Site Tests

No tests are directly connected with dynamic check-in, however the action of turning the lights on and off as the check-in station (or the verification station) is approached may be the most reliable method of demonstrating the functionality of the equipment.

Condition Of Windshield Wipers And Defogger

Inspection Tests

The wipers are easily checked visually by turning them on. Their condition should also be visually inspected to determine if there is excessive wear. The defogger requires that some moisture be on the rear window before its operation can be demonstrated. Moisture can be applied with a spray bottle.

Continuous In-Vehicle Testing

Use of the wipers and defogger when the equipment is needed will demonstrate their effectiveness during vehicle operation.

Dynamic On-Site Tests

No tests are directly connected with dynamic check-in, however the action of turning the wipers on and off as the check-in station (or the verification station) is approached is again an adequate test for the wipers, whereas there is no practical method of testing defogger operation at the site.

Presence Of Emergency Equipment In Good Condition

Emergency equipment can only be inspected during a static check-in, using a check list that covers all requirements for the automated highway systems that are accessible in the vicinity of the remote station. Testing or merely determining that the equipment is present is not considered in RSC 2, it is not sufficiently high priority to warrant action during check-in to RSC 1, but it might be done as part of the RSC 3 check-in if time is available. Therefore the determination that the supplies exist and are in good condition must be made visually at the remote site inspection station.

The demonstration that good equipment did exist in the vehicle is not the same as a demonstration that functional equipment is available in the vehicle at the time that it enters the highway. Presence of the full list of equipment depends on the attitude of the driver, unless there is an individual at the inspection station who is enabled to peer into the vehicle and note the existence of the safety equipment. This does not seem to be practical. Cameras at the on-ramp would not be very effective either, since some equipment would naturally be stored in the closed storage compartments.

Communications Equipment

A properly functioning communications system is critical to the performance of AHS. The reliability and testability of the communications system depends on the availability of a built-in test function. This function should both detect and isolate faults within the system. The degree to which the communications subsystem contributes to the lateral and longitudinal control of the vehicle will determine the level of testing required and the timing necessary to ensure safe operation. Some functions may be compatible with inspection site testing, while others may require testing at the initiation of check-in, but most will only require continuous monitoring to maintain a high level of confidence.

Vehicle Transceiver Unit

Vehicle communications are an integral part of the longitudinal control loop. Safe headway maintenance depends on continuous communication between each of the vehicles in the platoon for RSC 1 and between each vehicle and the roadside for RSC 2 and 3. The continuous operation of the vehicle transceiver is considered critical to safe operation of the AHS, and tests are described which can verify correct operation of required functions.

Inspection Test

No inspection tests are envisioned as necessary at periodic inspection stations with the possible exception of routine manual inspection of the wiring harness and connectors to the transceiver. However, some of the tests described as continuous in-vehicle tests could also be performed at fixed sites. By performing these tests at an inspection site, the functionality of the in-vehicle test equipment itself could be verified. Improper coding of signals by a transmitter in the vehicle can be detected as bit errors or bit erasures by the test equipment. Therefore it is proposed that, in a manner similar to that used to test engine electronics at an auto dealer repair shop, the communication electronics be tested independently with test equipment that includes remote transceivers as a backup to the in-vehicle testing.

Continuous In-Vehicle Test

The reliability of the vehicle electronics is expected to be extremely high, yet continuous monitoring of the vehicle communications equipment may be required due to its safety critical involvement with the longitudinal control loop. Continuous monitoring of vehicle transceiver performance may be especially appropriate during the early stages of AHS deployment to increase agency and public levels of confidence in the reliability of the system. There are two general approaches to achieving continuous test capability, over the air test messages, and self-contained loopback tests. Periodic test transmissions can be specified as a portion of the message protocol and sent over the air at pre-determined intervals. Test transmissions over the air have the advantage of testing end-to-end functionality without additional hardware. This approach does require that some of the system bandwidth be set aside for test messages, and additional software is required to provide the capability.

The other common continuous test technique is referred to as a loopback test. The loopback test is accomplished by using a small amount of signal energy from the transmit path to excite the unit’s receive path. A comparison can be made between the original transmitted message and the loopback reception. Any change in the data will indicate a problem in the communications hardware. The advantage of a loopback is that no radio frequency (RF) bandwidth is consumed. This approach requires a small amount of additional hardware to allow the signal to be fed back from the transmitter to the receiver in a benign manner, as well as loopback firmware. The firmware performs the processing necessary to compare the transmitted and received test message.

Self-test functions of the memory and processing units associated with the vehicle communications system can also be performed automatically, during the power-on sequence, by a program that is part of the system controller software. An error message can be generated to indicate failure of the test. This information can be displayed to the driver prior to an attempt to enter the AHS, and can be stored in a status register for verification during the check-in process to prevent access to the AHS by a vehicle with faulty communications equipment.

Dynamic On-Site Test

In the case of the communications system, dynamic testing refers to interactive testing that occurs as the vehicle enters the check-in facility, and does not require a complete dynamic test area. Dynamic testing must be performed prior to entry to the AHS, in the absence of continuous monitoring, to provide a rigorous check of proper communications system operation. At the check-in facility, a fixed message could be sent from the roadside transceiver to the vehicle transceiver. The received message would then be compared to the fixed message stored in memory. Similarly, a fixed message could be sent from the vehicle transceiver to the roadside transceiver and compared to the fixed message in memory. An error in either direction would prevent the vehicle from passing check-in. This process is similar to the test transmissions described for the continuous test case, but is performed only at check-in rather than being repeated periodically at a set rate.

Vehicle-Vehicle Ranging System

Two basic types of vehicle-vehicle ranging have been discussed in Activity D: Lateral and Longitudinal Control. The first type is radar, which can include infra-red or laser, microwave or Doppler. Radar relies on measuring the time or angle of arrival of reflected energy transmitted and received by the same unit. The second technique exploits the vehicle-vehicle communications link and involves two active units, and is accomplished by measuring relative phase relationships in signals, given known propagation delays in message transfers between the units. The above discussion on vehicle transceivers covers the testing of the communications link and will not be repeated here. The focus of this discussion will be testing of radar devices.

Inspection Test

The remote tests can all be performed with the vehicle at rest, but a second transceiver is required Move the test equipment transceiver at an angle to the vehicle transceiver line of sight across the field of view and record from the output of the vehicle transceiver the apparent range and range rate and angle to the test electronics. The comparison with the true values will determine the reliability of the vehicle system and whether or not the vehicle may be allowed to operate on the automated highway. Also, routine inspection of the wiring harness and equipment connectors may be done at the inspection site..

Continuous In-Vehicle Test

The image processing circuitry can be designed to include built in test functionality, providing fault isolation of this subsystem. The RF portion can incorporate power sensors in the receiver path to detect correct signal levels, and the transmit path can include detection of local oscillator frequencies to verify functionality.

Dynamic On-Site Test

One method available for measuring ranging capability during dynamic tests is to place a source above the path of the vehicle and recording the range and range-rate in the vehicle and transmitting the results to the check-in station for comparison with the correct results. This method would be effective for any RSC ranging sensor.

Fixed Vehicle Specifications

These are the vehicle specifications listed in task 1. These specifications will be communicated to the verification station or the on-site inspection station every time that the vehicle attempts to enter an automated highway. Acceptance or rejection will depend upon the specific highway design as well as an obvious failure to comply to the requirements of an AHS. For example, since mixed platoons (not mixed highways) of commercial trucks and private motor cars are unsafe, the check-in station will manage entry to synchronize commercial trucking convoy assembly. There is no inspection associated with this data. The communications protocol design will attempt to convey the maximum amount of specification data to the AHS with the minimum amount of transmitted words.

Variable Vehicle Specifications

Some properties of the vehicle vary with time. Specifically, a driver may need to bring a trailer on the highway in order to transport a boat, or other cargo or as a housing facility for a vacation trip. Or the driver may wish to transport cargo in a small truck,[22] otherwise completely compatible with the other vehicles on the automated highway. Check-in is required for these situations and there are several methods for performing the accompanying tests.

Trailer Description

The trailer will be allowed to enter only certain automated highways, because it will tend to degrade vehicle performance and because it will tend to move into the adjacent lane and affect traffic in a parallel AHS lane. The trailer must have its own identification electronic tag to show that it has been tested with the present vehicle.

Inspection Tests

A visual inspection of the trailer will establish its principal characteristics. The trailer brakes must be checked to insure that they have sufficient brake fluid and that the calipers are not worn. If the vehicle is tested dynamically, to check brake performance, for example, the trailer will accompany the vehicle and the tests will be performed with the two together. It is possible that the check-in data storage computer on-board the vehicle will retain information on vehicle AHS-worthiness with and without the trailer.

Continuous In-Vehicle Testing

There are no current in-vehicle tests for trailer operation, however the braking system for a trailer may, on larger trailers, be fitted with an ABS someday, in which case there would be data available on brake performance on non-AHS roadways.

Dynamic On-Site Tests

If the trailer is allowed on the particular automated highway, then it will be a part of the vehicle during the dynamic tests. This will mean that the vehicle, with trailer, must meet standards of handling, acceleration, and braking that match the expected conditions on the highway for all vehicles. In addition, it must be established that the trailer will not drift into the path of a vehicle in another lane. Either an overhead camera will be used to establish that the trailer meets those maneuverability standards, or there must be a lane detector or lateral and yaw motion sensors which can be used to establish the trailer performance that may be expected on the highway.

Cargo Description And Weight

The cargo carried by a vehicle may be either attached externally to the vehicle, carried inside the vehicle, or carried in a separate trailer. It will be quite difficult to develop proof that external cargo can be transported safely on an AHS. Unless an overhead camera is located on-site, the nature of the cargo may be left up to the discretion of the driver. This is not an acceptable condition, therefore it seems likely that there will either be overhead cameras at each check-in site or there will be visual inspection at the site.

Inspection Tests

Remote inspection of cargo is not practical unless the vehicle will enter the automated highway soon after the inspection. This is only considered in RSC 3. There will be a requirement for remote inspection that limits the time between inspection and entry so that the cargo cannot be altered in any way.

Continuous In-Vehicle Testing

For a commercial vehicle, it might be possible to install a measurement device that would allow cargo weight to be determined during vehicle operation. In general, only Weigh-In-Motion would be effective in determining commercial cargo weight before the truck approached an on-ramp, and this method is likely to only be used at specific weigh stations for taxation purposes.

Dynamic On-Site Tests

The dynamic test of a loaded vehicle will be the same as the test of an unloaded vehicle, thus the vehicle must be capable of similar maneuvering, slowing, and accelerating.

Application Of Validation Criteria

Each function has some strong dependencies which may affect the cost, safety, or other criteria of validation. These validation criteria, which were discussed briefly in the Check-In Validation Procedure Catalogue, vary in significance depending on the subfunction and on the type of test station that is used to perform the check-in test. In table 7, the critical validation criteria are matched with those subfunctions which are considered to possess critical validation criteria and with the specific test station type. Subfunctions are not listed unless a critical issue is identified.

Table 7. Application Of Validation Criteria

FUNCTION/ SUBFUNCTION	INSPECTION TEST	CONTINUOUS IN-VEHICLE TEST	DYNAMIC ON-SITE TEST
AUTOMATED BRAKING			
Emergency Braking (Any Braking Stop Greater than 0.25 g's)	Demonstration Test Could be Expensive, Other Tests Low Cost	Critical Components are all Tested While Driving	Check-in Test Damage Could Occur, Could be an Impact on Flow Rate
Fail-Soft Capability	Test of Equipment has High Reliability	May Have Damage to the Brakes and Safety Risk if Backup Circuit is Tested	Risks are Possible if Backup Circuit is Tested
ABS Wheel Speed Sensor	Demonstration Test Could be Expensive, Other Tests Low Cost	This Test may not be Possible if There is no Baseline Speed Sensor	This is an Adequate Critical Component Test
ABS Lateral Control	These Tests Would be Part of the Controller Tests	There is Low Additional Cost to Record the Lateral Braking Performance During Routine Operation	Braking in a Turn Could Cause Damage, Introduce a Safety Risk, and Impact Flow Rate
Transfer from Manual to Automatic Control	Expensive Test and Critical Component Test	Addition to Current Vehicle Test	Part of Emergency Braking Test
ENGINE FUNCTIONS			
Engine Parameters and Controller	Use Standard Tests	Standard Tests	Part of Other Tests
Transfer from Manual to Automatic Control	Potentially Very Expensive Test of Critical Components	This Action is Tested with Adaptive Cruise Control	Check-in Test Damage Could Occur, Could be an Impact on Flow Rate

Fail-Soft Capability	Test of Equipment has High Reliability	Slight Damage to the Brakes and Safety Risk if Backup Circuit is Tested	May Have Damage to the Brakes and Safety Risk if Backup Circuit is Tested
Automated Acceleration and Deceleration	Potentially Very Expensive Test of Critical Components	Adaptive Cruise Control Test, High Cost for Direct Torque Measurements	Same Test as Continuous In-Vehicle Tests

Table 7. Application Of Validation Criteria (Continued)

FUNCTION/ SUBFUNCTION	INSPECTION TEST	CONTINUOUS IN-VEHICLE TEST	DYNAMIC ON-SITE TEST
TIRES AND WHEELS			
All Tire and Wheel Functions	Inspection Tests are the Most Reliable	Only Tire Pressure can be Measured (TIM)	Recent Tire Damage Cannot be Measured
STEERING FUNCTIONS			
Hydraulic Fluid Pressure and Level	Steering Fluid Sensors Will be	High Cost Equipment, But Used for Critical Data	The Same as the Continuous Tests
Transfer from Manual to Automatic Steering	Potentially Very Expensive Test of Critical Components	No Current Non-AHS Equipment is Available	Check-in Test Damage Could Occur, Could be an Impact on Flow Rate
Steering Controller and Steering with Automatic Control	Self-Tests are Built-in, But Other Tests are Potentially Very Expensive	Built-in Self-Tests, Unless Non-AHS Automatic Steering is Available, Full Testing is not Possible	These are the Critical Tests That Demonstrate Functionality of the Controller
Fail-Soft Capability	(See Engine Fail-Soft Discussion)	No Current Non-AHS Equipment is Available	(See Engine Fail-Soft Discussion)
VEHICLE DIFFERENTIAL AND TRANSMISSION			
All Functions	Inspection Tests All Critical Equipment		
FUEL QUANTITY			
Fuel Supply (Gasoline or Electricity)		Voltage or Fuel Level Plus Range Are the Critical Data	
Battery Capacity (Lifetime)	This is the Critical Electric Fuel	Parameter and It Is Not Clear That It Can Be	Obtained, But it May Be Bounded
ELECTRICAL SYSTEM CONDITION			
Electric Car Battery Peripheral System	Separate Thermal Testing, If Required, Could Be Costly		

Table 7. Application Of Validation Criteria (Continued)

FUNCTION/ SUBFUNCTION	INSPECTION TEST	CONTINUOUS IN-VEHICLE TEST	DYNAMIC ON-SITE TEST
LONGITUDINAL POSITION/DISTANCE SENSOR			
Range Measurement and Object Detection	The Initial Cost for the Test Equipment Is High, But the Data is Critical	Nominal Data from Non-AHS Operation of the Collision Avoidance Equipment Will be Obtained	Careful Target Design Is Required To Obtain All Necessary Critical Data
Collision Avoidance Controller	Routine Self-Test	Routine Self-Test	Internal Modifications Will be Low Cost and Provide Check-in Data
VEHICLE LATERAL POSITION/DISTANCE SENSOR			
Lateral Position Magnetic Marker Detection	Correct Testing of Critical Equipment May Be Difficult	No Testing, Unless Non-AHS Marker System is Installed	These are the Critical Tests That Demonstrate Sensor and Steering System Performance
Lateral Position Optical Lane Marker Detection	Correct Testing of Critical Equipment May Be Difficult	This is a Non-AHS System, and Therefore Cost Will Be Low and Data Rate Will Be High	These are the Critical Tests That Demonstrate Sensor and Steering System Performance
Lateral Position Controller Performance	Piggyback on Sensor Detection Tests, Routine Self-Tests	Routine Self-Tests	Part of the Steering System Test
VISIBILITY ENHANCEMENT AND EMERGENCY EQUIPMENT			
All Equipment	High Cost to Determine Equipment Functionality Automatically		

Table 7. Application Of Validation Criteria (Continued)

FUNCTION/ SUBFUNCTION	INSPECTION TEST	CONTINUOUS IN-VEHICLE TEST	DYNAMIC ON-SITE TEST
COMMUNICATIONS EQUIPMENT			
Vehicle-to-Vehicle Transmitter and Receiver	Wiring Harness and Connector Inspection.	Test Messages and Loopback Tests are Adequate	A Single Fixed Message Test at Entry
Vehicle-to-Roadside Transmitter and Receiver	Same as Vehicle-to-Vehicle	Same as Vehicle-to-Vehicle	Same as Vehicle-to-Vehicle
Vehicle-to-Vehicle Ranging System	See Above	See Above	See Above
Communications Message Accuracy	Thorough Test Message Comparison Can be Done Here	Evaluate Test Message	Use a Bit-by-Bit Comparison Check of Test Message

Validation Scenarios

<u>Normal Vehicle Access To The Automated Highway</u>

RSC 1 – Check-in begins immediately before entering the on-ramp with the driver transmitting destination and intent information to the manned check-in booth. An attendant is assigned responsibility for the vehicle as it progresses at a reduced speed (16 – 48 km/h) through the test range. The station employee looks for illegal loads, downloads information from the vehicle about its current performance capability, verifies that the single digit code that represents all details such as vehicle and driver registration is correct, and initiates the dynamic check-in procedure, which places the vehicle under full automatic control. During dynamic operation the attendant looks at the output from the sophisticated computer system, which is matching vehicle performance to the expected standard on the roadway, for any failure light which would require that the vehicle be directed off the on-ramp. Upon successful completion of the dynamic testing, during which the vehicle has increased speed to a value which allows entry to the automated roadway, the driver is notified that he is approved.

RSC 2 – Check-in begins when the vehicle is within range of the verification station preceding the desired on-ramp. The driver transmits an entry request code and awaits the response from the station, which may be occupied with communication to another vehicle. Verification is a relatively brief procedure, usually complete within 10 seconds, and requires no alteration in driving pattern. The operation communications are conducted between the automated vehicle system and the automated verification system and the driver is notified that he has been approved for entrance to the on-ramp but is otherwise out of the loop.

The driver enters the on-ramp and begins to accelerate to AHS speed when the vehicle enters the dynamic check-in area and the vehicle comes under automatic control. All testing is done automatically and any decisions are made by the computer system. At the end of the dynamic test, the vehicle is at AHS speed and the driver is notified of system approval.

RSC 3 – The driver proceeds to a large, off-road facility which is authorized to check-in AHS vehicles entering any one of several highway on-ramps in the vicinity. The vehicle stops or slows down as it passes through the station so that all functions may be checked and loads may be inspected. The tests may include some dynamic operation on a short test track at the facility. At the end of the test, the driver is notified that she has been approved to utilize a specific automated roadway or set of roadways and the vehicle has had an approval code, dated and combined with the test station number, inserted into its AHS computer storage.

The driver then proceeds to a nearby on-ramp and enters the non-automated highway and drives into the lane adjacent to the merging lane of the automated roadway. The driver initiates the request and approval cycle by pressing a button and the vehicle transmits the request and the approval code in a single message to one of many beacons spread along the roadway which serve the dual purpose of check-in stations and automated highway managers. When entry is approved, the vehicle is placed under automated control and enters the AHS merging lane and the driver is simultaneously notified that she is no longer in control of the vehicle.

Procedure For A Vehicle That Failed At The Previous Check-In

In the case of RSC 1 or RSC 2, the vehicle is expected to drive to an inspection and maintenance station, which could be any vehicle service department or service station or independent repair shop, if it fails at an AHS check-in station. However, there is no time limit on when the vehicle must go in for repairs. The decision is left up to the driver. A failure signature has been installed in the vehicle AHS storage computer, so that, if it were to attempt to enter without first correcting the flaw, the vehicle would be immediately notified that it was not approved for AHS entry, thus avoiding interference at the on-ramp or other entry location. At some remote site inspection stations designed for RSC 3, there is a limited capability to immediately repair the non-functioning component, so that the driver need not wait to drive to a separate repair facility. This repair shop is adjacent to the main check-in station, thus avoiding any reduction in efficiency of the primary test facility.

After the problem is corrected, the vehicle may again attempt to enter an automated highway. There is no special check-in for a vehicle which failed the previous check-in. The only record of the previous failure is the record stored in the vehicle computer which maintains a long term maintenance history to facilitate repairs. For example, should the vehicle fail check-in a second time for the same reason, the prior record might assist the maintenance facility in fixing the problem. The driver enters the facility and is approved, if the previous flaw has been corrected, to drive onto the automated roadway.

Occasionally, the driver will disagree with the decision to disapprove entry, or the requirement for successful entry will be the re-registration of the driver or the vehicle. If the driver plans to take a long trip on the AHS, possibly several hundred kilometers, she might prefer to correct the failure immediately, rather than lose several hours traveling on a non-automated highway. A separate facility, similar to a Department of Motor Vehicles building, will be in the region and the driver may take the vehicle there for further action. For corrections such as updating registration, the driver will communicate with an automated registration teller which will debit her toll card through her transceiver tag. It will be possible for the driver to take the vehicle through a second, very thorough inspection at this facility if she disagrees with the initial check-in verdict. It may be possible to make minor repairs at the station, such as replacing a tire or adjusting some communications element. Charges for these services will be high and will be debited through the tag. If the vehicle passes the detailed inspection, it will receive a special code which it will communicate to the on-site inspection station to avoid check-in at the on-ramp.

Communications Failure At The Verification/Check-In Station

The driver has lost all communications with the check-in station, probably because the vehicle communications system has failed. In the case of RSC 1 or 2, a changeable message sign (CMS) located at the entrance to the on-ramp, will notify the driver that the communications failure has occurred, although failure to receive a response from the check-in station should also serve as a warning of failure. If the vehicle enters the on-ramp in spite of the warning, the vehicle will enter the dynamic test zone, where it will remain under manual control and miss the turn that allows entry to the automated highway. The driver will note that he is on the manual roadway leading back to the street and will continue to operate the vehicle. The vehicle will be driven onto the street and the driver will plan how he will correct the problem with his communications system. If the problem lies with the infrastructure communications system, then the CMS will notify all drivers of the problem and the on-ramp will be closed.

Communications failure at the off-site RSC 3 station is not a problem because the vehicle will be stopped, or can be stopped without affecting traffic, and the error can either be corrected at the adjacent repair facility or the driver can be notified by an attendant and can go to his preferred maintenance station. If communications fails at entry to the AHS merge lane, then the lack of response plus the use of a CMS should alert the driver that he cannot enter the automated system. Should he choose to enter the roadway under manual control, then the entry will be handled as in a following scenario for an unqualified vehicle ignoring check-in failure warning.

Attempted Entry By A Vehicle With An External Load

If the vehicle enters via an on-ramp, as in RSC 1 and RSC 2, the load must be detected by either automated, optical means, or by visual inspection by a station attendant. In either case, the vehicle is prohibited from entering the automated roadway according to AHS policy. The driver must first be notified that he will not be allowed to enter the highway because of the external load. This will be done using the roadway-to-vehicle communications. In addition, the information will be flashed on the changeable message sign above the on-ramp so that other drivers behind and adjacent to the vehicle will be alerted to the fact that the vehicle is leaving the ramp. The vehicle will not enter the dynamic test area, but will be directed to exit by driving straight past the second portion of the on-ramp. There will be a small parking, rest, and storage area to the side of the exit portion of the on-ramp where the vehicle may be temporarily parked and the load may be removed and stored for a fee large enough to discourage use as a routine storage facility.

The presence of an illegal load implies, for all RSC's either a disregard for the law or extreme carelessness. In the case of RSC 3, however, since the external load was not present when the vehicle went through off-site check-in before entering the non-AHS roadway, pursuant to entering the automated road, an attempt to avoid detection is much more strongly implied. The driver adds the load to the vehicle after check-in testing has occurred. She then drives onto the freeway and when she requests entry to the AHS lane, transmitting both the request and the approval code installed by the check-in station, the optical detector at the roadside which is designed to identify illegal or hazardous vehicle conditions such as external loads, entry is denied and the reason for exclusion is provided. If she persists, and attempts to enter the roadway, the highway patrol is notified and the malfunction strategy for apprehending illegal drivers is followed.

Failure During Dynamic Check-In

This failure is associated with RSC 1 and 2 and excludes communications failures, which have been discussed above. Therefore communications with the vehicle is possible, however automated control may be only partial or nonexistent and the number of possible scenarios is large, as the scenario depends upon the particular element which failed. All scenarios begin with the attempt by the check-in control system to gain control of the vehicle and direct it through the dynamic testing. If control has been established and the failure is not in the engine, steering, or brakes, then the vehicle will be automatically maneuvered out of the on-ramp to the manual control zone. Other drivers will be notified by CMS and the driver of the rejected vehicle will be notified in-vehicle of the problem (in detail) and allowed the option of parking in the rest area or resuming manual control and leaving the on-ramp.

If control of braking or the engine is not established, but steering can be controlled, then the vehicle will be automatically steered out of the on-ramp and the driver will be notified that he has retained control of the brakes and/or the throttle. The rest of the procedure is the same as described above.

If the steering cannot be controlled, then the vehicle will miss the turn into the automated on-ramp. This procedure can only be accomplished if there is a single on-ramp lane. The difficulty involved in manually managing a failed vehicle if there are other, automated vehicles on both sides suggests that no more than two on-ramp lanes will be allowed (exits could be built on both sides). The driver must follow the other vehicles, must be prepared to continue driving manually, and must be notified of the failure immediately. Therefore, upon learning that the vehicle steering cannot be controlled automatically, the system will notify the driver that the vehicle is still under manual steering control and the vehicle speed will be reduced to minimize the possibility of accidents while the driver directs the vehicle off the on-ramp. If the speed cannot be controlled either, then the driver will be provided that information also and he will retain manual control while driving to the exit. Sometimes the vehicle will be in such a forward position when the problem is detected, that it cannot reach the exit. In those cases, the driver will be directed to steer the vehicle onto the shoulder (breakdown lane) of the AHS. The remaining procedure was described above.

The final scenario describes a situation in which attempt to gain automatic control locks the brakes, the throttle, or the steering into some dangerous position. The on-ramp will be shut down immediately, with the vehicles coming to a safe, rapid stop. If the brakes on the vehicle are working, that vehicle will also come to a safe stop. If a barrier is in the correct position (RSC 1), then it will be deployed. The likelihood that the steering controller will lock in a dangerous position is much greater at the time of switching, therefore it is recommended that, if there is more than one on-ramp lane, vehicles never enter side-by-side, but rather in a staggered fashion such that the swerving of the adjacent vehicle would not cause an accident. If the vehicle brakes have failed and the vehicle is locked in a swerve maneuver, Then damage can be minimized by spreading apart the other vehicles on the ramp and on the automated roadway. If possible, the engine should be shut down, either automatically or by the driver (who is unlikely to be able to respond to such a rapid series of events).

<u>An Unqualified Vehicle Ignores Check-In Failure Warnings</u>

RSC 1 – The vehicle ignores warnings and does not divert to the exit lane. The driver is given warning in-vehicle and with the CMS and then the barrier is automatically deployed. Other traffic on the ramp is notified and either stopped or maneuvered around the barrier, if such maneuvers are possible.

RSC 2 – If the vehicle possesses an electronic device which allows the system to shut down or maneuver it, then, after appropriate warnings have been given, that device is activated. Maneuvering scenarios may be found in previous discussions. If the vehicle is shut down, then the traffic around it will first be spread apart so that the disabling of the offending vehicle does not impact system safety.

If the vehicle cannot be controlled in any way, and that seems more likely, then the traffic is spread out in the on-ramp and platoons on the automated roadway are diverted around the entranceway as the vehicle enters the highway. At this point, an appropriate malfunction strategy is applied to halt the vehicle and protect other vehicles.

RSC 3 – If control of the vehicle can be taken from the driver, then a maneuvering scenario applies. Otherwise, the traffic is spread out in the on-ramp and vehicles on the automated roadway are diverted around the lane entrance point as the vehicle enters the highway from the non-automated roadway. At this point, an appropriate malfunction strategy is applied to halt the vehicle and protect other vehicles.

<u>Failure Occurs While Driving To The On-Ramp (After Verification)</u>

This is an RSC 1 failure. The driver is under the impression that the vehicle is qualified to enter the on-ramp. If there is a malfunction which can be detected by the internal diagnostics, she is alerted and does not attempt to enter the rampway. Instead she may choose to have the problem serviced at the service facility in the area, or she may choose another highway for the day. If the problem is not detected in-vehicle, then it may be detected by one of the optical on-ramp scanners that are situated along the on-ramp or by the early dynamic testing done in the dynamic check-in region. Before dynamic testing has resulted in automatic control, she is notified of the problem and proceeds to the exit area. Failure detection procedures during dynamic check-in are described above. The problems which will escape detection after verification has been obtained are those which can only be detected during static testing at an inspection station. There is, therefore a real value to a system which does not rely solely on a static inspection station for any critical testing, since those errors will propagate onto the AHS.

On-Site Check-In Station Inspection Delays

One possible method of check-in is by static inspection at the on-ramp or wherever traffic flows from a non-AHS roadway to an AHS roadway. In this section, the consequences and achievements of such an inspection methodology shall be explored and results from the analysis shall be derived.

This analysis shall not include the check-in process associated with RSC 3. That check-in is done at a fixed off-line station and cannot impact the time required to actually enter an AHS lane. Although the accompanying delay may not be palatable to the general public, it will not create a traffic problem associated with vehicle entry. Passage from a non-AHS highway to an automated highway is also not a major issue. Because of the heavy volume of traffic moving at high speed that will be on the interchange, it is inconceivable that any system would require each vehicle which wished to enter the automated highway to stop at a wayside station on the link. It is obvious that check-in must either be done remotely or that a validation station plus the physical act of handing control over to an automatic system (similar to dynamic check-in but with fewer options for exit if there is a failure) will check-in all vehicles to the automated lanes.

The specific design topic is the installation of a station which every vehicle must pass through as it enters the AHS from a city street. Each vehicle will either stop in the station area in order to be inspected or drive slowly through the area while check-in occurs. For the sake of analytical simplicity, the slow drive-through will be replaced by the sum of a normal speed entry plus a delay that is equivalent, in principal, to the delay associated with stopping in the check-in area. The arrival rate of vehicles at the station is somewhat random, although a stop sign or street light at the intersection could create a reasonably predictable flow. For the sake of the analysis, it will be assumed that vehicles arrive at a steady rate of one every 10 seconds (t). This is a little slower than the entry rate onto a freeway from a busy on-ramp, but it will serve to illustrate several points.

To begin, consider a single inspection bay, at which each vehicle must stop in turn. It may be shown, mathematically, that, if the delay (T) is greater that ten seconds, a queue will build up. This queue will continue to grow indefinitely. Only an increase in arrival time such that the delay is less than or equal to arrival time will terminate the queue buildup. If a second inspection bay is added, the delay requirement to avoid buildup will change. The delay must be less than twice the arrival time if there are two inspection areas, regardless of whether the two areas are in series or in parallel (however, vehicles will form a fixed length queue if the sites are in series). This simple rule can be extended to any number (n) of bays. In general, $T < n*t$ is the condition to avoid the creation of an undesirable queue.

There are three ways, then, to avoid a long line of cars. First, the number of inspection bays can be made large enough to manage the traffic. This number may be as large as ten, which could be a severe demand on land use and unacceptable to the community. Second, the arrival time may be increased to satisfy the requirement. This implies that an effort has been made to discourage use of the on ramp, which is contrary to the program objective to serve the maximum number of cars in order to achieve significant reduction in traffic congestion. However, during early deployment, this time might be quite large because of the small number of properly equipped vehicles, and stationary vehicle inspection might be important because of early concerns about reliability. Therefore there is a synergy between early deployment and on-site testing which would not exist at a later time. Finally, the inspection time could be reduced, in this case below ten seconds, so that there is no backup of traffic. This raises some interesting questions about the objectives of a static test site and also implicitly sets constraints on the entry area design.

Thus far, the objectives of a static on ramp inspection station, as distinct from a validation station, have not been discussed. First, non-electronic components of the vehicle may be inspected at the time of entry to insure compliance with AHS regulations. Existence of an improperly secured rooftop load would be detected, causing vehicle rejection. Vehicle damage that might result in a part of the vehicle dropping on the roadway would be observed. Energy storage in an electric vehicle storage cell could be directly measured. Second, during the early development phase some of the built-in self tests of electronic equipment might not be reliable, or even present, and an electronic tester could be attached to the electronic system and used to test all of the electronic systems. Third, there may be some uncertainty in the communications link which would require separate testing which could not be done remotely. It is important to observe that none of the above tests can be done in a few seconds. If all of those tests and more need to be done, the delay at the static station could be far greater than one minute. With the exception of the reason of early deployment, none of the above objectives seems to be sufficient to warrant erection of on-site inspection stations causing major delays that would inhibit traffic density on the automated highway and/or occupy large urban areas.

There does not appear to be any reason to drive a vehicle slowly through a static inspection station. A visual inspection of apparent damage can be done at the nominal entry speed. Visual inspection of subtle mechanical damage can only be safely done when the vehicle is at rest. Electronic attachments are difficult to make with the vehicle in motion. A full data set of self-check information can be transmitted in a few seconds at urban speeds on a city street.

The conclusion, then, from this simple analysis, is that check-in delays on the automated highway entry ramps should be avoided. The only exception is early deployment, when the entry rate is expected to be slow and some questions about vehicle self-examination remain. However, even in the early stages there are limits to how few vehicles should be on the AHS. If there are only a few entry points, a severe reduction in entry rate may inhibit the demonstration that the highway can accommodate high traffic volumes.

Communication And Data Processing Analysis

This section consists of a brief evaluation of maximum communications requirements and the description of some test procedures that might be applied to the data processing system.

<u>Check-In Communications Requirements</u>

During the check-in process there will be a need to transfer information between the vehicle and the roadside check-in station. The amount of information which must be transferred, the need for one-way or two-way communications, the time allowed to transfer the data and the number of vehicles which must communicate concurrently with the roadside check-in station will vary with the different check-in schemes. The AHS communications system must satisfy the communications needs at check-in as well as the operational needs.

The operational needs of the AHS communications system require a worst case design which allows each vehicle in a platoon to transmit his velocity and acceleration information twenty times per second. With a 20 vehicle platoon (more traffic than is expected at any one time through a check-in station), 400 to 500 transmit opportunities occur each second. Assuming that each transmit opportunity allows a transfer of 400 bits, a data rate of up to 200,000 bits per second is possible.

Static and dynamic check-in have different communications requirements. In the case of a static check-in, the vehicle will perform diagnostics and self-test functions[23] either prior to check-in or at the check-in station. The results of these tests will be sent to the roadside check-in station, which will make a decision to either allow the vehicle to enter the AHS roadway or deny access to the vehicle. This exchange of information may require thousands of bits of data transfer and can be easily accommodated by the worst case operational design.

Dynamic check-in will involve moving the vehicle through a prescribed set of actions including steering , throttle, and braking. These actions must then be monitored to determine if the vehicle is responding properly. Since the actions requested during check-in are similar to, and occur at a similar rate as the actions of an operational vehicle, the operational communications system should adequately support dynamic check-in. That is to say, the platoon communications example given above is much more demanding than even the worst case check-in scenario. Monitoring of the vehicle actions will be performed either by existing on-board equipment or by roadside monitoring equipment. The communications system should have adequate capacity to report responses to actions that are sensed by an-board equipment.

If the operational AHS design does not require real time transfer of information between a vehicle and the roadside or other vehicles, then the requirements for check-in communications will exceed the operational highway requirements. If the inter-vehicle spacing is sufficiently large, each vehicle will be managed separately and only one vehicle requires communication to the dynamic check-in station at a time. In this case, a simple communications system such as a tag/beacon may meet the communications needs for AHS. The communications requirements for check-in must then be designed to fit the communications rate of the tag/beacon. At the validation station, more of the check-in would be performed by the vehicle with only the results of self tests reported.

<u>Check-In Site Computing Resources</u>

Each check-in site will access computing resources in order to process vehicle check-in data. The computing resource requirements can vary from one type of check-in site to another, based on such considerations as type of check-in algorithms to be performed or expected workload (e.g., number of vehicles serviced concurrently or over a predefined time interval). The computer resources can be physically distributed and shared across a network by multiple check-in sites, centralized and dedicated to a particular site, or consist of some combination of these to information processing paradigms.

Since the check-in site performs a safety-critical AHS function—detecting and assessing vehicle malfunctions and alerting drivers and other components of an AHS that one or more vehicle malfunctions exist—some minimal level of periodic testing of the "tester" (i.e., check-in site) is required. Without such testing, a hardware error, latent software error, or inadequate amount of computing resources can potentially result in misdetections and false alarms with regard to vehicle malfunctions.

Discrete Testing – The status of the check-in site computing resources can be thoroughly checked on a periodic basis. Thorough testing on too frequent a basis can potentially degrade the performance of a check-in site functions. Discrete testing could, for instance, be performed during time intervals characterized by off-peak AHS traffic usage.

Continuous Testing – A built-in test can be performed on a continuous basis to test for a set of predefined pathological computer resource behaviors. This type of testing can be performed during free machine cycles, that is, when a computer or peripheral device is idle. If an anomalous behavior is detected, then the check-in site can alert a traffic management center that the site has experienced a fault of some kind, and, if possible, the nature of the fault. However, the identification of run-time errors will require the use of such aids as fault signatures and system performance profiles.

Vehicle Computers And Peripheral (Input/Output) Devices

Testing of on-board vehicle microprocessors, sensors, and other hardware devices is addressed in Vehicle Function Validation section of task 2. However, a potentially safety-critical aspect of testing vehicle computer and peripheral devices is omitted in that section.

Inspection Tests

Inspection tests of hardware devices will necessitate checking for evidence of damage or modification to the devices. However, such checking can be difficult to implement since such devices will likely be a manufactured as a sealed, hardened unit; thus, it may not be possible to inspect the contents visually. One solution is to perform the checking using a logic analyzer, although the analyzer can be fooled. Thus, there is a need to authenticate the input received by the logic analyzer from these devices. One way to perform authentication of the device output is to require that the device produce encrypted data; if a device provides incorrectly encrypted data, then the testing procedure can infer that the device is either modified or faulty.

Vehicle Software

In contrast to hardware, software does not "wear out." However, software can potentially exhibit anomalous behavior when, for instance, a hardware malfunction occurs, the software processes an input value which is outside the domain or range of the data type or is not covered by an exception handler, or when one or more infrequently executed software instructions contains one or more errors and those instructions are exercised by the vehicle computer. Therefore, it is necessary to test that vehicle software does not exhibit anomalous behavior resulting in erroneous processing of check-in algorithms.[24]

Inspection Tests

Inspection tests will involve computer hardware for evidence of damage or modification; difficult to do since the computer system will probably be a sealed unit; need some way of authenticating that the on-board computer is the correct computer for that vehicle.

Continuous In-Vehicle Testing

Latent errors can be difficult or impossible to detect. However, certain types of errors or patterns of anomalous software behavior can be characterized, with the resulting set of error signatures being incorporated into the testing procedure. Patterns of observed anomalous software system behavior, including the results from comparing actual software system outputs with expected software system outputs, can be stored for readout at a verification station.

Dynamic On-Site Tests

Dynamic on-site testing, as defined above in Vehicle Function Validation of task 2, can potentially be a complex or impossible task to perform on vehicle software. The complexity of this task can be high, for instance, if the vehicle software is structured such that there is an overlap in the software functions required for automated and manual vehicle control. Similarly, if a vehicle manufacturer modifies a vehicle’s software to so that an previously manually performed vehicle control function is automated, or vice versa, then the change in automation boundary (and consequently the system functionality) will need to be reflected in the check-in testing procedures.

Driver Function Validation

The operator issues related to qualifying for entry to the AHS are divided into three areas of discussion. The functions the driver may be required to perform in preparation for check-in are addressed. Potential scenarios and their associated driver interactions are analyzed. Second, a list of physical characteristics which may be used to qualify the driver for entry to the AHS are identified. Finally a summary of legal and financial criteria are presented which may be used to determine qualification for AHS licensing. The implications of the physical and legal/financial characteristics are discussed in terms of their potential impact to the system design.

<u>Driver Functions–Pre Entry</u>

During check-in, prior to entry to the AHS, either the driver will be required to activate the on-board AHS-specific vehicle equipment, or, more likely, the equipment will self-actuate following the driver's notification of intent to check-in and the interim approval of the infrastructure to enter the on-ramp. Driver action could occur off-line, prior to arriving at the AHS check-in portal. Activation of the vehicle systems would prompt execution of an internal vehicle status and fault detection routine. The fault detection sequence can be used to verify functionality of the AHS system components, as discussed in Vehicle Function Validation of task 2. The test may be designed to monitor built-in self-check equipment and AHS-specific components and acquire the results of previous tests. System checks which result in a test failure can be used in order to notify the driver of to the nature of the failure. The driver could be required to correct identified failures such as insufficient fuel or poor tires before approval for entry to the AHS check-in area. Sub-system checks which reveal no problems can result in notification to the driver that the vehicle has been accepted to pass into the AHS check-in region and then onto the automated roadway.

The next process will verify that the individual is certified to enter the AHS system via operator interaction with the on-board system.[26] The user interface with the in-vehicle AHS equipment might range from a simple voice recognition system, to insertion of a "smart" card, to a more complex unit requiring touch screen entries. The driver will initiate the identification/validation process upon passing the validation station and receiving vehicle clearance to enter the on-ramp. A smart card can be configured to contain driver related information including valid AHS license, adequate liability insurance, sufficient funds in a toll account, and any physical handicaps or restrictions. A touch-screen or keypad can be used for entry of a unique personnel identification number (PIN) by the driver. False access to the AHS is possible using PIN or smart card technology because of the risk of loss or theft. Voice recognition may provide the most secure method for identifying and validating the driver.

Information regarding the driver may be stored within a local or regional AHS database. The information may be checked on-line to verify that the driver has a valid AHS license and is certified to operate within the AHS. Information regarding medical records, driver's health and any physical handicaps or driving restrictions can be determined when an AHS license is issued, and need not be verified each time AHS is used. The frequency of AHS licensing may be significantly different and more complex that today's normal licensing procedure. The driver's physical condition may be of more importance in obtaining an AHS license as compared to its current status in obtaining passenger-vehicle licenses. The age bracket of today's driver ranges from 14 years of age (with an adult licensed driver) to "X" years of age based on the physical and mental capability of the driver to pass a licensing test. The stringency of criteria for obtaining an AHS certificate may be significantly influenced by driver age, physical condition and abilities, and the complexity of the vehicle and driver AHS equipment interface. One of the goals of AHS is to increase the availability of highway travel to older and handicapped drivers. This objective must be taken into careful consideration when the user interface is designed to avoid excessive restrictions in user population. Demonstrated ability to operate in an automated/non-automated environment may supersede age and physical condition as the primary physical criterion.

The broad range in ages and physical capabilities of potential AHS travelers will impact the design of the operator interface. To ensure ease of use to the greatest number of drivers, the design of the driver vehicle/system interface must consider the following factors:

- The design and integration of the driver display/control suite must be easy to use with minimal attention demand.
- Display conventions and display symbolism should be standardized.
- The driver workload should be minimized by simplifying interaction with on-board equipment.
- Voice information systems may provide an optimized AHS driver/operator interface.
- The design of the driver interface must consider the knowledge, skills, attitudes and physical capabilities of the targeted user groups, including older and impaired drivers.

A wide range of information may exist which can be made available to the operator. Data that could be made available for display to the driver might include navigation and routing, details concerning the driver monitoring system, and displays associated with the collision warning and avoidance system. The method of data delivery to the driver might include a control/display suite consisting of a CRT display, with push buttons and/or a keypad. The level of complexity of the driver information system must take into account the workload placed on the driver both in the pre-entry phase and during travel on the AHS. Studies have determined that increased information input can adversely affect stress levels even when the number of tasks being performed are reduced.

Driver Physical Capabilities

The typical process for issuance or renewal of a driving license includes periodic testing of the driver’s visual acuity to determine if glasses are required for normal driving, and assessment of the driver’s knowledge and understanding of state/local driving laws. Some states require evidence of current liability insurance, certificate of annual vehicle registration, and smog certification. Prior to issuing a license, the state Department of Motor Vehicles (DMV) reviews the previous driving record for violations and notes the medical record in which some driving restrictions may be placed on the individual’s license. These data are stored at the DMV and are available to local, state and federal law officials. Obtaining a driver’s license is a standard and simple procedure. Tests and exams are designed to accommodate all ages, education levels, non-English speaking applicants, and the handicapped. Additional information may be required regarding the driver’s physical capabilities, health and ability to operate on the automated highway. Special licensing criteria established for the AHS may require revamping of the licensing process to accommodate additional proof of qualification.

Driver performance research has revealed significant response and reaction time differences between age groups in many driving situations, ranging from the simple act of locating and operating a control, to responding to stimuli external to the vehicle. The older driver typically reacts more slowly than the younger driver to events around him, glance times generally increase and visual re-accommodation from inside to outside the vehicle and vice versa are more frequent and longer in duration. Color perception also degrades, and brightness and contrast sensitivity decrease with age.

Other driver qualifying issues deal with the education level and basic reading skills of the candidate driver. Research has shown that users with poor reading skills have difficulty interacting with computer equipment and most new technologies. On-board AHS equipment which requires the driver to provide route/trip information, interact with menus, retrieve information, and request data and vehicle status information, may be considerably more difficult for the poor reader to use. Accident statistics also reveal that less educated drivers have more accidents. The operator interface may be designed to accommodate less educated and non-English speaking drivers by simplifying the input/output requirements and reducing the level of interaction to minimize differences in ability and reduce potential for errors.

Other issues deal with the physically challenged driver. Special hand controls are often included in the handicapped driver's modified vehicle. These special controls facilitate braking and acceleration, operation of the radio, heating, ventilating, and air conditioning system (HVAC), and lights. AHS-specific equipment that can be operated by the handicapped driver must be carefully designed and easily accessible. Response time for using the AHS operator interface is expected to be longer for the handicapped driver in comparison to the non-handicapped driver, however little research is available about reaction and response times of the handicapped driver. Research is needed to clarify this issue, particularly under emergency and high workload conditions. AHS configurations such as RSC 2 use barriers to separate vehicles within AHS lanes from manually controlled traffic. Designs for emergency situations in which the handicapped driver may need to be removed from the vehicle must take into consideration lane width, barrier height and separation to accommodate a vehicle for the handicapped that may have special lifts which are usually located on the passenger side of the vehicle.

Special licensing requirements to use the automated highway and specific data on driver performance and physical capability needed for licensing may raise legal issues resulting from the failure of a driver to obtain authorization to use the AHS. The reasons for failing licensing might be due to driver reaction and response standards associated with age or physical handicaps. Visual acuity requirements may be more stringent for AHS than normal licensing, and since education level relates to the ease-of-use and learning of new technologies and to accident statistics, reading requirements may also be more stringent. Non-English speaking drivers and handicapped drivers with degraded ability to interact with special AHS equipment may have a severe impact on system operation and deployment.

Training and testing of qualified users is an issue regarding AHS operator interface equipment. The TRAVTEK studies conducted in Orlando, Florida in 1992-93, provided users of the system with an hour or more of system training. TRAVTEK is a simple navigation/route guidance system, with only a few controls that are used while the vehicle is in a stationary position, and even fewer when the vehicle is in motion. (See Activity G – Comparable Systems Analysis.) Frequent re-testing or training as new and improved AHS equipment is implemented is not a viable option for large user populations. Special training requirements must be avoided to allow the widest possible user population, including, for example, such users as foreign, non-English speaking visitors in rental cars. AHS instrumentation in vehicles must be designed to simplify the user interaction required while the vehicle is moving.

Legal/Financial Considerations

Legal, financial and privacy issues arise based on the amount of information that AHS might require regarding the driver using AHS.[27] General information required when applying for a standard driver's license includes name, age, special vision requirements, class of vehicle allowed to operate, vehicle registration, proof of insurance and appropriate smog certificate. A driver applying for an AHS license may also be required to undergo special testing and training and provide more background data than required for conventional licensing. These data may include evidence that insurance is current, credited toll accounts for debiting purposes, evidence that the vehicle meets AHS operating standards and criteria, medical information related to any physical limitations and identification of conditions (use of medication/drugs) or handicaps, which may impact the driver's ability to resume control of a vehicle.

Providing this information might be considered an invasion of privacy; however, most of this type of personal and background information currently resides in existing databases. A common example of this precedence is the military, where personnel and medical records are kept and are available to certain government agencies. The trend in employment applications is toward increased proof that certain standards are met, including the requirement for drug and substance abuse testing. Another example is the voter registration process, which requires that the individual reveal any felony convictions and certain citizenship information. Obtaining a passport requires proof of citizenship, often based on an individual's birth certificate which reveals the applicants age. Finger printing is often a requirement for employment and driver licensing. Airlines have denied travel to passengers with known health problems or conditions. As society tends toward higher degrees of information maintained in common data bases, sensitivity to this issue may substantially decrease.

Task 3. Issues And Risks Associated With Vehicle Check-In

Vehicle System Degradation

If there is a sufficient time lag between the last validation of a piece of equipment and the entry of a vehicle onto an automated highway, the failure probability assigned to that piece of equipment will be assigned a higher value than it had been assigned previously. On the other hand, constant evaluation at every entry may be prohibitively expensive. Educated guesses can be made at this time based on experience with existing vehicles and manual highways. However, direct extrapolation from such experience will not portray a realistic picture of an AHS paradigm. Instead, the time interval between validations will need to be tuned after the AHS is operational. Data collected about failure sequences and frequencies can be analyzed via hazard and operational (HAZOP) analyses and probabilistic risk assessments (PRA), providing firm evidence on which to base conclusions and recommendations concerning the setting of time intervals between equipment validation and to differentiate these requirements for various classes of equipment or specific parts.

Intermittent Electronic Failures

Such failures are commonplace in the everyday world. Often they are associated with overvoltage damage to a sensitive electronic circuit. These faults are not easily detected during inspection or operation, but they can occur during routine travel on an AHS. Intermittent electronic failures highlight the fact that no system is totally safe, no matter how well it is engineered. In a broader sense, we cannot control the environment in which the AHS operates; accidents are the culmination of a combination of system hazards and environment conditions (e.g., an intermittent electronic failure will result in an accident under certain environmental conditions and not others). There is always some level of risk associated with the operation of a system. In the context of AHS, the interested parties need to come to a consensus on what constitutes an acceptable level of risk.

Alternative Automatic Brake Designs

Suppose that two vehicle manufacturers develop unique, effective AHS brake systems which yield acceptable performance but cannot be actively inspected in the same manner.

Mixed Vehicle Power Systems

If the automated highway can accept either electric or ICE powered vehicles, what are the necessary requirements for a check-in system?

Alternative Automatic Steering Designs

Suppose that two vehicle manufacturers develop unique, effective AHS steering systems which yield acceptable performance but cannot be actively inspected in the same manner.

Software Errors

Suppose that two manufacturers develop different software for the same controller design, or a vehicle has an older and a newer version of the same controller software, both yielding acceptable controller performance. Testing for software errors in these programs is outside the purview of the check-in function for two reasons: (1) unlike hardware, software does not wear out (i.e., the software code is not self-modifying and always givens the same result given the same input and instruction execution sequence) and (2) software developers and maintainers are responsible for detecting all but the latent software errors (i.e., those errors that become observable only after many years of system operation time).

Management of a software errors falls in the categories of Malfunction Management (i.e., taking corrective action once a software error is detected) and in Vehicle Operational Analysis (i.e., performing software testing, program verification, software reliability analysis, etc.). Also note that some level of equipment validation and check-in procedures in general can be implemented in software. Therefore, software errors embedded in the check-in system, whether the check-in system resides in the vehicle or the infrastructure, can have an effect on AHS safety.

Returning to the original example in which multiple versions of software exist which perform the same functions, including vehicle control. Software configuration management and control can be seen as a key factor in helping to minimize the use and maintenance of software. Being able to trace a software error back to a particular version of software and to which vehicles that particular version is installed is of obvious value. Also, as the vehicle and check-in technology advances, not all existing vehicle software systems can be upgraded, due in part to differences in functional capabilities (e.g., the types and version of hardware in the vehicle or infrastructure). Thus, a blind “upgrade everything at once” approach can lead to software running in environments in which it was not meant or tested to be run.

Automatic Monitoring And Evaluation Of Equipment Not Directly Related To Automatic Vehicle Control

Should techniques be implemented for automatically monitoring and evaluating the status of equipment that is not integral to automatic vehicle control, such as parking brakes, windshield wipers, or headlights? Implementation of such monitoring and evaluation techniques can increase the manufacturing cost of a vehicle.

On the other hand, can such equipment play an integral role to automatic vehicle control? Consider the following two scenarios: (1) one or more vehicle sensors are place on the inside of the front windshield and (2) vehicle marker lights are one type of visual input received by a vehicle passenger acting as an “additional sensor.” In both of these scenarios the windshield wipers play an integral role in keeping the area in front of the sensors (including the “human sensor”) free of debris (e.g., water and dirt landing on the windshield as a result of roadway splash). The benefits accruing to system safety are obvious for both of these scenarios. Moreover, the marker lights can serve as a redundant means (i.e., in addition to electronic beacon or other device) for locating and removing disabled vehicles from the automated highway.

Alternative AHS Designs

The vehicle check-in analysis described in this report is based on assumptions about automated vehicle design features which may not be applicable or may not hold in alternative AHS designs. For example, we assume that the longitudinal control sensor will operate either at microwave or radio wave frequencies, whereas in an alternative AHS design a relative distance sensor operating in the infrared band will require some mechanism (e.g., a functioning wiper) to remove the accretion of snow, ice, or rain over the protective cover. Follow-on studies will need to address equipment requirements peculiar to a specific AHS design.

Use Of Non-Original Equipment Manufacturer Parts

Non-original equipment manufacturer (OEM) vehicle parts can be introduced into a vehicle system during, for example, vehicle repair. What criterion, at time of vehicle check-in, is to be used in determining whether non-OEM equipment is acceptable? The performance and behavior (i.e., functionality) of non-OEM equipment can vary dramatically from that of OEM equipment, for example, in terms of the quality of the raw material used in the manufacture of a piece of hardware (e.g., throttle linkage) or quality of the algorithm used in the software (e.g., computation of the adjustment of the steering angle for lane following).

From a safety vantage, non-OEM equipment needs to be certified prior to its use as a replacement part in vehicles, and a complete list of certified non-OEM parts needs to be accessible to the check-in site vehicle validation logic. Also, information about acceptable combinations of OEM and non-OEM parts, and for specific vehicle makes and models, may need to be compiled and made accessible to the check-in sites.

Moreover, replacement parts must provide the same performance and behavior (i.e., functionality) as the OEM equipment: nothing more and nothing less. Even a change to a piece of equipment from that of the OEM specification, resulting in an improvement in equipment performance or behavior, can have a detrimental effect on overall system performance or behavior. For example, an non-OEM brake actuation device providing for greatly reduced latency time in activation (e.g., via the use of more responsive calipers) over that of OEM equipment can result in a crash between the two vehicles, one equipped with the OEM device and the equipped with the non-OEM device, all other things being unchanged.

However, the former considerations are moot if we are unable to detect the presence of non-OEM or non-certified equipment. Reliance on the measurement of equipment performance or behavior (e.g., strength of a radio signal or response time in actuating the brakes or throttle) is not adequate from a detection perspective, since the non-OEM parts can be engineered to provide equivalent performance characteristics to those of OEM equipment under check-in test conditions. Instead, some form of equipment labeling is required such that the equipment can be traced back to its manufacturer, date of manufacture, and so on; this information can then be compared with the unique vehicle identification number in order to assess whether the OEM or non-OEM equipment matches the predetermined list of “allowable” equipment for use on the particular vehicle in question. Even with part labeling, consideration must be given to the issues of how to authenticate the label (e.g., has the label on a piece of equipment been altered or forged) and what standard labeling convention is to be used.

It is very likely that the introduction of AHS will require new standards against which both OEM and non-OEM equipment and parts will be certified before sale and installation.

Unauthorized Modification Of Vehicle-Based Hardware Or Software

A person may have one or more motivations for altering vehicle-based hardware and software, such as to avoid the payment of roadway tolls, elude component failure detection by check-in inspections, “improve” some aspect of vehicle performance (e.g., modification of the throttle or pollution-control equipment to obtain higher fuel economy), and so on.

A starting point for formulating a strategy to detect or prevent certain types of unauthorized modification of vehicle-based hardware and software components is to order the set of components according to a measure of both the likelihood that someone will attempt to modify the component and the severity of the outcome of the component’s modification on the operation of the AHS. For example, the modification of emissions control hardware may be well within the technical ability of a “shade tree mechanic.” Some possible outcomes from such a modification include a change in the performance of the fuel injection vacuum level and an increase in the amount of pollutant be emitted per unit of vehicle operation time. Similarly, the modification of a braking control software, stored in EPROM, can alter the behavior of the vehicle’s automatic braking system. However, the alteration of an EPROM program is probably a less likely event than the modification of the emissions control hardware because modification of an EPROM requires the availability of an EPROM programming device and a knowledge, on the part of the user, as to how to read and write EPROM programs.

Suppose the unauthorized modification of braking system software, stored in an EPROM, is ranked high on the likelihood and severity-of-outcome scale. Two types of strategies can then be devised to address this particular type of unauthorized modification. For instance, a detection strategy can be based on the use of encryption: a vehicle-based computer or a check-in station can authenticate that the code has not changed by comparing the encrypted key to, for example, the byte count or some other signature of the code. A prevention strategy can consist of encasing the EPROM and peripheral board on which it is mounted such that the unit will be disabled if the seal unit is tampered with.

Detection and prevention strategies will also be needed for use with infrastructure based hardware and software. AHS users and operators may both have some motivation for disabling or modifying in some other way infrastructure based components, especially if these components are more readily altered than vehicle-based hardware and software.

Methods Of Evaluation

What are the criteria which might be used to evaluate the validation alternatives? Are these criteria equally important? For instance, consider cost and safety criteria. The AHS user, vehicle manufacturer, AHS operator, and other interested parties may all assign a different level of importance to the cost and safety criterion. The AHS user is primarily interested in safety, with the cost associated with the validation alternatives (e.g., roadway usage fees, taxes, and added cost to the vehicle price) considered to be secondary or tertiary in importance. The vehicle manufacture has a vested interest in minimizing the cost associated with providing for vehicle check-in. The AHS operator, on the other hand, is interested in minimizing both capital investment to implement a check-in approach and the variable and fixed costs associated with maintaining the check-in equipment and facilities. One thing all of these parties share is a desire to strike a balance given a set of criteria, for example, to not be overly cost conscious at the expense of AHS user safety.

Implied Effect Of Physical Barrier On Entry Flow Rate

Although the barrier used to prevent illegal entry is not used often, it does have an impact on the maximum entry rate of vehicles. For example, space must be retained between vehicles in case it is determined that one of the vehicles in the ramp queue cannot be permitted onto the automated highway. The criticality of such a scenario is heightened when provision is made for passenger vehicles and heavy motor vehicles [22] (e.g., tractor-trailers and transit buses) to travel on the same lane (as discussed in Activity F it may not be an economically viable option to segregate different classes of vehicles into separate lanes in urban areas). The criticality here arises from the differences in vehicle mass and performance characteristics (e.g., rate of acceleration of a heavy vehicle on an entry ramp can be much less than that of a passenger vehicle) when accounted for in a crash; in general, the higher the change in velocity, the greater the level of severity of the accident. The mismatch in performance attributes, such as in acceleration and braking, increases the risk of frontal or rear-end collisions due to inadequate vehicle response to the actions of other vehicles.

Effectiveness Of An Electronic Barrier

Assume that the electronic barrier is completely effective with correctly equipped vehicles. How will the system deal with unequipped or electronically modified vehicles? Will the failure rate be too large for the system to be effective?

Law Enforcement Fleet Deployment

If a disqualified vehicle enters the automated highway or the on-ramp illegally, how will patrol vehicles be optimally located and alerted so that apprehension is swift and safe? How will the vehicle be stopped without affecting safety?

Illegal Entry Prevention Trade-Off

In light of the above issues and risks, what can be said about prevention of illegal entries?

Attacks On Computer Resources Used In Vehicle Check-In

What are the threats to the availability and integrity of vehicle check-in computer resources, both those on-board the vehicle and those computer resources located at an inspection site (remote, on-site, and dynamic)? What are the vulnerabilities of these resources to attacks resulting in denial of service (e.g., an inspection site being unable to perform the check-in functions), corruption of data or software (e.g., an unauthorized modification of an algorithm resulting in misdetection of vehicle malfunctions), and so on?

Saturation Of Computing Resources

What is the minimum amount of computing resources that is necessary for maintaining an acceptable level of risk associated with saturation of computing resources. For example, how much computation, storage, and communication support is required in order to guarantee that continuous in-vehicle testing will not interfere with the correct and timely execution of emergency braking procedures?

Task 4. Applications To Representative System Configurations

Some aspects of automated check-in, as discussed in the preceding tasks, vary across the RSC's. Those variations are summarized in table 8.

Table 8. System Configuration Check-In Variation

Check-In Design Features That Vary With RSC	RSC 1	RSC 2	RSC 3
Location of Check-In Station(s)	Check-In Station at On-Ramp and Variable Amount of Continuous In-Vehicle Testing	Off-Site Static Check-In Dynamic Check-In at On-Ramp	All Check-In at Off-Site Which May be Remote or May be at a Nearby General Vehicle On-Ramp
Check-In Station Design	Station Set E	Station Set F	Station Set B
Number of Highway Entries Allowed for a Single Check-In Procedure	One	One (But Dynamic Check-In Could be Considered a Non-Delay Procedure)	Several (Unless Off-Site Check-In is Required for Every Entry)
Method for Preventing Unqualified Vehicle Entry	<u>Physical Barrier</u> A Barrier Will be Implemented to Stop the Entry of an Uncleared Vehicle	<u>Electronic Barrier</u> Automatic Diversion if the Vehicle is on the Ramp, Illegal Ramp Entry Results in Electronic Disablement, Patrol Car Must Stop Illegal Ramp or Highway Entry if the Electronic Barrier Fails	<u>Unrestricted Access</u> Patrol Car Must Intercept Unauthorized Vehicle on the Automated Highway
Impact of Unqualified Vehicle Entry	Considered Impossible	Traffic Entering On-Ramp May Need to be Diverted	Traffic on Automated Highway May Need to be Diverted
Operation of Check-in Station	Inspection Staff With Some Automation	Automated Static Check-In Station, Possibly Automated Dynamic Station	Could Combine Maintenance and Inspection
Typical Time Delay During Check-In	10-30 Seconds on Ramp	None	15-90 Seconds at Off-Site, None at On-Ramp
The Variation in Check-In Validation Procedure Which Will be Analyzed	Vary the In-Vehicle Storage from Descriptive Data to a Complete Inspection Data Set	Consider a Range of Dynamic Tests, from a Simple Entry Demonstration to a Complete Inspection	Vary the Number of Entries for a Single Off-Site Check-In

Task 5. Component And System Failure Questionnaire

In the previous sections of this activity report the items which may require validation at check-in and the methods for evaluating these items were discussed. The critical nature of certain vehicle components was identified. There was no analysis of the likelihood that a component would fail. That issue has been considered by other contractors, but the available statistical data does not appear to be adequate to reach a conclusion.[28] In this section the type of data needed to identify accurately the critical vehicle components which fail often enough to be of concern will be discussed and some general rules for acquiring that data through a combination of questions and inspections will be developed. The proposed program would identify a group of vehicle owner/operators of relatively new cars and ask them questions about their cars and also inspect their cars for potential failures.

The principal objective of this interactive questionnaire is to identify critical equipment which does fail often enough to justify check-in. This requires that several questions about the component failure be answered.

- What is the definition of a failure? During discussion with the vehicle owner the questions that are asked must be comprehensive enough to identify an event which may not be perceived by the driver as a failure, but would cause an incident on an AHS.

- Is the failure unavoidable? Was human error involved in the failure, and therefore it may not count as a failure which would affect an AHS?

- Could the imminent failure have been predicted or detected in advance? Can the failure be predicted from electronic information, that is, can a self-check be developed to monitor the equipment? These are important questions, because detection at check-in must occur in order to avoid malfunctions.

- If the flaw is detected in advance, can it be fixed? After so many kilometers, the oil in the engine should be changed to avoid engine damage. Are there other AHS-critical features which are not currently maintained because the likelihood of failure and/or the consequences of failure are too small?

- Is the failure associated with the age of the vehicle, the model, the price, or the vintage? Perhaps the easiest method for avoiding the failure would be to avoid equipping certain types or models of a given vehicle for use on an AHS.

- Can the vehicle be designed so that the failure does not occur, and how much would such a vehicle cost?

- Was the failure associated with an error made during inspection or routine maintenance? The incidence of such events appears to be high, and adding more inspections to the vehicle record may increase the likelihood that a failure will occur.

The questionnaire should be designed to filter out dishonest responses. Occasionally an individual will report that an accident or a breakdown was the fault of the vehicle when, in fact, it was caused by poor maintenance or operator error.

Some failures are gradual, but the consequences of partial failure may be as destructive as those of a complete failure. For example, brake stopping distance must meet certain standards. With time, the distance will increase, until the brakes ultimately fail if there is a lack of maintenance. Therefore, there will have to be inspections on at least some of the vehicles in the test group in order to track gradual deterioration.

The following is a sample set of questions on brake failures which illustrates the type of information that would be needed from the questionnaire. It is assumed that a large group of recent owner/operators has agreed to answer these questions and participate in a no-cost vehicle inspection.

- Obtain brake specification data from the manufacturer. Also acquire any available data on past failures which might be obtained from the manufacturer.

- Determine how many accidents have occurred that are associated with the brakes. Determine if the brakes failed completely or only partially. Obtain a complete description of the incident. Get the official accident report.

- Determine how much unscheduled maintenance was required by the brake systems. Did brake components require repair or did a component or the ABS computer require replacement? Get the maintenance record and also a description from the driver of the type of failure that necessitated the maintenance.

- Ask for any additional description from the owner which might indicate that the brakes are not operating properly.

- Inspect the entire brake system for damage. This would include a visual inspection for mechanical damage and brake fluid level and an electronic checkout of the brake controller. A further test of the vehicle stopping distance, which would be a test of both the brakes and the tires, would involve an additional cost to the organization and loss of time which may not be acceptable to the owner or the organization in charge of gathering the data.

CONCLUSIONS

The check-in operation is central to a successful Automated Highway System. The phrase 'Pay me now or pay me later' is appropriate to the importance of the activity. If a sensible check-in system is installed, the sum of the costs of all AHS malfunctions and the check-in system will be far less than the cost of AHS malfunctions without check-in. The number of vehicle functions which might fail, if not tracked, on the AHS is indicative of the fact that the check-in system must be comprehensive and reliable. In this report a critical analysis of system functions and the development of methods for validating those functions have been the two principal means of describing the automated highway check-in system.

The system functions that require validation were divided into vehicle and driver functions and the vehicle functions were further divided into critical and less-than-critical functions. In addition, public service vehicle check-in activities that would require check-in operations were catalogued and infrastructure tasks that would be conducted at check-in were listed.

Among the standard vehicle functions that require inspection were engine, brake, and steering operations. These are critical functions, as are the specific AHS control functions, which include lateral and longitudinal sensors, automatic controllers for brakes, engine and steering, and the communications and data processing system which supports automated operations and relays instructions between vehicles and between vehicles and the roadside.

Windshield wipers, headlights, and other equipment which assist a driver but which would provide little benefit to an automated system were considered less critical. Vehicles that were carrying external loads, vehicles with loose or damaged equipment, and the current energy supply and available range of the vehicle are functions which were considered to be in an intermediate critical range. It should be noted that, since the energy supply might be found to be insufficient to take the vehicle to the first off-ramp, there was a variable criticality associated with the available range.

Licensing functions associated with the driver or the vehicle were also catalogued. These properties were correlated with their potential impact on driver privacy and with their importance to the AHS.

Public service vehicle entry to an automated highway often requires different service that a private vehicle entry. This service is provided at the check-in station. During routine operation, the public vehicle should be inspected in the same manner as any other vehicle, however, for example, public safety vehicles should not be deterred from entering the AHS when there is an emergency. Therefore the vehicle type and the nature of the mission of the vehicle was correlated with the type of service that the check-in station would provide.

Infrastructure check-in functions include notification of approval or rejection and also a description of the reason for rejection or any information which might cause deterioration and rejection in the future. Other information must also be provided to the driver regarding highway safety and travel time compared to other transportation modes.

Validation of these functions is performed either at a special check-in station or during routine inspection or while the vehicle is under manual control (continuous in-vehicle test). Each function described in the catalogue, and its subfunctions in many cases, was analyzed with respect to the three types of validation and a description of the validation procedure and its relative merit was presented.

The special inspection stations were categorized according to their functionality. At a validation station, information is communicated from the vehicle to the station and the vehicle is notified that it has either passed or failed the check-in evaluation. No delay is involved with this test. The data communicated from the vehicle includes all information from the built-in-testing equipment and from the last routine inspection.

At a remote special check-in facility, the vehicle undergoes several minutes of rigorous inspection and is then certified to enter the automated highway. This type of station is associated principally with a highway which is divided into automated and non-automated lanes. Since both equipped and unequipped vehicles can enter the highway, testing must be done before the automated vehicle enters the roadway and the results would be transmitted to a verification station before the transition to the automated lane took place.

The check-in station that is located at the on-ramp to a dedicated automated highway and is designed to evaluate vehicle functionality while the vehicle is at rest is similar to the remote facility except that the inspection must be of shorter duration in order to prevent the buildup of queues. Visual inspection is routine at such a station.

The final type of facility is a dynamic test area which compares vehicle performance after control has been transferred to the automated system with a standard for acceptable automated vehicle performance. The test is done while the vehicle is gaining speed to enter the automated highway and includes some on ramp curvature to demonstrate automated steering. If the vehicle fails the test, it is automatically steered off the ramp and into a lot for rejected vehicles.

After the test facilities were defined, function validation tests were defined. High force (emergency) braking, for example, would be tested during routine inspection, during the manual driving cycle, and as part of the dynamic testing done at the on-ramp. This procedure was followed for every vehicle function or subfunction unless one or more tests was not applicable. In the case of vehicle functions such as carrying an external load, which cannot be determined from built-in-tests, the condition was detected by an observer at a static check-in station or by an optical detector at the on-ramp and connected to a validation station. Included in this validation methodology catalogue were vehicle communications, vehicle specifications, data processing, and the less critical functions.

The validation techniques described for each function were demonstrated in a set of scenarios which attempted to illustrate how successful vehicle check-in would be operated. These scenarios are separately done for all three representative system configurations. Both

successful entries and failures are covered, as are situations in which the failed vehicle attempts to enter the automated highway.
The effect of a delay associated with a check-in facility at an on-ramp which required that vehicles come to a full stop and be inspected while at rest was investigated. It was found that a significant delay at such a station when entering traffic was heavy would create a long queue that could only be reduced by a reduction in entry traffic. The objectives of such a facility are also unclear in comparison to a combination of a validation station and a dynamic check-in facility.

A special analysis of communications and data loading feasibility determined that, for a properly equipped vehicle compatible with the automated highway, the communications and data requirements of a check-in facility would be met. Concerns about falsifying data in the vehicle computer or adjusting a critical piece of electronic equipment may be met by encrypting the information in the vehicle computer to prevent tampering.

Driver functional validation may be required because of health considerations or because of a concern that the same driver, when released into the non-automated traffic stream, may cause an accident for which the automated system would be liable. Privacy is a major concern, although equivalent privacy is yielded in everyday life. Liability and privacy remain major unresolved issues.

Many additional issues and risks were identified but were not addressed in detail. There are many issues related to non-standard equipment or multiple versions of the same hardware or software. Another general area of concern is the control and interception of vehicles which fail check-in but attempt to enter the automated highway illegally.

After reviewing the available literature regarding vehicle systems failure it was concluded that a survey of vehicle system failure modes and frequency of failures was needed. This survey would relate only to loss of functionality which could be associated directly to failure on an automated highway. The result of this survey would be a comprehensive list of component details which fail and the likelihood that they would fail if they were not detected at check-in.

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