Precursor Systems Analyses of Automated Highway Systems

RESOURCE MATERIALS

Automated Check Out

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FOREWORD

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

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

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

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

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

NOTICE

TABLE OF CONTENTS

Figure **Page**

VOLUME IV — AHS SYSTEMS ANALYSIS

CHAPTER 2: AUTOMATED CHECK-OUT (TASK C)

Section **Page**

TABLE OF CONTENTS

Figure **Page**

TABLE OF CONTENTS

Figure **Page**

TABLE OF CONTENTS

Figure **Page**

List of Tables

Table **Page**

TABLE OF CONTENTS

Figure **Page**

TABLE OF CONTENTS

Figure **Page**

List of Figures

Figure **Page**

VOLUME IV — AHS SYSTEMS ANALYSIS

CHAPTER 2: AUTOMATED CHECK-OUT (TASK C)

1.0 EXECUTIVE SUMMARY

The check-out process is a critical component for ensuring AHS safety. It concerns the process of assuring safe transfer of control from the automated driving system to manual driving. Because the driver has been out of the driving loop during AHS operation, there is concern that the driver will not be ready or capable of assuming driving control and responsibility. Check-out is the procedure for transferring vehicle control to manual operation in a way that ensures driver readiness and capability, and tests the integrity of mechanical vehicle components needed for manual driving. The objective of this task is to identify and analyze issues associated with the design and implementation of a check-out process, within the context and structure of the AHS representative system configurations.

In order to complete this task, we have applied engineering analyses and small group brainstorming as the primary technical approaches. In addition, we have conducted a literature review, and have obtained inputs from other PSA tasks, as necessary. Our analysis has identified two distinct forms of the check-out process. The first, normal check-out, occurs at the end of an AHS trip. It is a routine process used to evaluate the driver’s ability to retake manual control, when he/she has indicated a desire to exit the AHS. The second, emergency check-out, occurs during an automated trip, when a malfunction in the system is detected, requiring driver intervention. This type of check-out usually occurs with little forewarning.

1.1 CONCLUSIONS/KEY FINDINGS

The conclusions/key findings from this analysis are listed below. They are described in more detail in the discussion that follows.

- There are two types of check-out that must be considered: normal check-out and emergency check-out.
- There are two parts to check-out: the testing of vehicle components, and testing for the driver’s readiness to retake manual control.
- During the process of transition from automated to manual driving, the driver must take control of the vehicle rather than having the vehicle give control back to the driver.
- The check-out “test” should be an integrated part of the larger check-out process.
- If check-out “tests” are required during the automated portion of the trip (for the purpose of maintaining an adequate level of vigilance), these “tests” should be meaningful and not artificial and extraneous.
- The driver portion of the check-out process must account for the wide variability in capabilities within the driving population.
- The requirements and approach for check-out are interdependent with the requirements for, and design of, AHS features and infrastructure.

1.2 APPROACH

The transfer from automated vehicle control to manual control involves a mode switch. The relationship between the automated and manual systems of the vehicle that are involved in this mode switch are shown in figure 2-1. The objective of the check-out process is to ensure, when making this control transfer, that the linkages between the manual controls and vehicle actuators are functioning properly, and that the driver control logic is fully engaged and integrated within the dynamic driving situation.

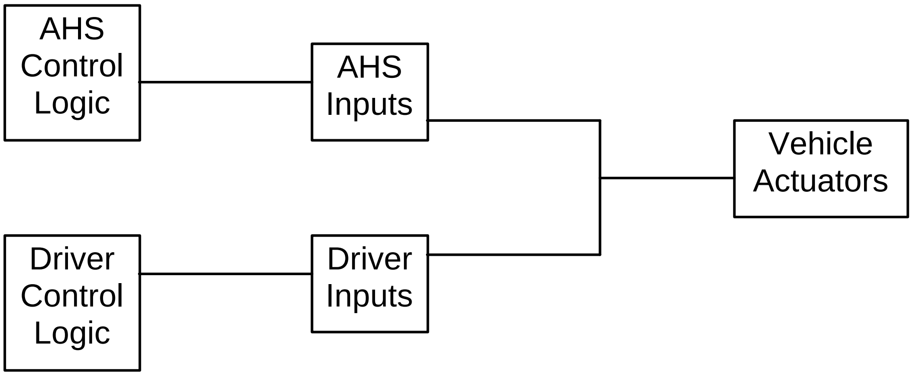

Figure 2-1. AHS Driver Check-Out Model

It can be seen from this model that there are two aspects of the check-out process that must be considered. First, the integrity of the linkages between the vehicle actuators (e.g., the mechanical components that turn the wheels) and the driver's inputs (e.g., steering wheel, pedals) must be verified before the automated control linkages can be safely disengaged. Second, driver readiness to assume control must be verified. Issues for accomplishing these requirements are described in this section and are summarized below.

1.2.1 Assumptions

Several assumptions were made about the design of AHS to provide a common understanding for this analysis. These assumptions do not constrain the issues and conclusions defined, but rather provide a framework for their discussion. In many cases, if these assumptions are not correct, the design of the check-out process will be made easier. The assumptions and their impact on AHS check-out are summarized in table 2-1.

Given the assumption that drivers will have a malfunction management role during AHS operation (at least for initial AHS implementations), there will be a requirement for emergency check-out procedures. These will carry more demanding check-out time constraints than for normal check-out at AHS exits. Special check-out procedures will need to be applied to meet these more demanding requirements. It may be necessary to use less comprehensive tests, perhaps supplemented with an alarm to speed the alerting process.

Table 2-1. AHS Assumptions Applied to Provide Context for the Check-Out Analysis

Assumption	Description	Implication for Check-Out
AHS cannot force drivers to obey all traffic laws.	AHS may help mitigate hazards associated with law breakers (e.g., vehicle inspection verified at check-in, minimal required driver capability verified at check-out). However, some risks from law breakers cannot be totally avoided (e.g., non-AHS-certified drivers using another driver's license). Potentially serious hazards resulting from law breakers will need to be addressed through enforcement or other means.	There are conditions that will reduce drivers' ability to safely exit the AHS that will not be tested directly during check-out (e.g., alcohol consumption). The check-out process will be applied to ensure that drivers have minimal capacity to safely transition to manual driving and drive safely. It will not be applied to ensure that all laws associated with safe driving are complied with.
Drivers will have a role during AHS operation requiring them to remain awake.	Because AHS is most likely to develop in an evolutionary fashion, we assume there will be a driver role during AHS operation (e.g., system monitoring, malfunction management), at least in early AHS implementations. This role will require driver wakefulness.	This assumption makes the check-out process more difficult to manage because there may be a requirement for check-out to be accomplished at any time, not just at exits. Further, since drivers will have a role in malfunction management, check-out under system failure conditions will need to be accomplished very quickly. It will be necessary to deal with sleepy (or sleeping) drivers, if such a situation occurs.
Drivers will not be required to preselect destinations.	Most drivers will have a final destination in mind when entering the AHS. However, intermediate, unplanned stops may be required (especially on long trips) and some drivers may not be willing or able to pre-select exact exits (e.g., when traveling to unfamiliar cities).	In addition to ensuring safe transition to manual driving, the check-out process will need to be concerned with determining when the driver desires to exit the AHS (at least it makes sense to include this within the check-out procedures).
Drivers will be able to override the AHS and retake control (at least in initial AHS implementations, such as RSC I1).	Since during initial AHS implementations we assume the driver will be required to serve in a system monitor role, there may be situations in which the driver determines that the AHS is not working properly and will need to take control.	The check-out design must consider the requirement for a driver initiated check-out process.
Drivers will have a "panic button" available for emergency AHS trip termination.	There may be situations in which the driver needs to immediately stop the vehicle (e.g., medical emergencies). Under these conditions, transition to manual control should not be undertaken. Nevertheless, AHS operation will be ended (e.g., the vehicle may be parked and help summoned).	Check-out design should recognize this manner of ending an AHS trip and consider driver interface issues (e.g., determining reason for ending the AHS operation).

It may also be necessary to accept less certainty about full driver engagement in order to avoid a potentially more serious system failure condition. Both emergency and normal check-out procedures will need to be developed for AHS and both will need to be accomplished within available time budgets. The design of emergency check-out will require consideration of the underlying causal conditions and trade-off between time available and the potential consequences if check-out is not accomplished quickly.

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1.2.2 Automation Guidelines/Implementations

Automated systems are becoming more and more commonplace today, and research into design approaches for optimal human oversight and intervention is being undertaken. Guidelines for the design of user interfaces to automated systems are emerging. These can provide guidance for the design of AHS, and particularly for AHS check-out related operations (e.g., maintaining awareness level to allow successful emergency check-out) . A few examples of these guidelines that may be applicable to AHS are given in table 2-2.

1.2.3 Driver Readiness Issues

There is a large body of research dealing with how humans process information that can be applied to the design of an effective (driver) check-out procedure. This research deals with the way humans detect and discriminate stimuli, recognize and comprehend information and situations, make decisions, and select and execute responses. Knowledge of human strengths and limitations, within these activities, is necessary to design an effective check-out process. For example, a check-out process that focuses the driver's attention on the most critical information will help avoid selective attention and distraction problems. In addition, redundant cues can shorten and improve the process of developing driving situation awareness, (e.g., alert the driver about special road conditions). By careful human factors design, the driver readiness portion of the check-out process can be fine-tuned to perform in the most optimal fashion.

Table 2-2. Sample Automation Guidelines and Example AHS Implementations

General Automation Guideline	Example AHS Design Approaches
If automation reduces task demands to low levels, provide meaningful duties to maintain operator involvement and resistance to distraction.	• Remind drivers about approaching exits and request desires for continuing or exiting. • Provide information about system and trip status for driver review. • Provide access to on-line AHS training material.
If alarms have more than one mode or more than one condition that can cause the alarm, clearly indicate the mode or condition.	• Clearly indicate nature of AHS failure condition (especially if driver must respond).
When response time is not critical provide information to allow the validity of alarms to be established quickly and accurately.	• Present AHS status information in addition to alarm condition.
Provide training for operators working with automated equipment not only to ensure proper set-up and use, but to impart knowledge of operational concepts, malfunction procedures, and monitoring requirements.	• Make AHS operation extremely simple and/or provide training. Consider special licensing requirements.

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Human monitoring performance and associated vigilance decrement problems (reduction in level of alertness) have also been extensively studied. This research base can also be applied to AHS design of level of alertness and monitoring performance features. For example, knowledge of task duration has been found to affect the vigilance decrement. This can be applied to develop different approaches for maintaining vigilance on rural and urban AHS segments. One approach to ensure that the driver remains vigilant and alert is to test the driver periodically throughout the trip. However, these tests should be meaningful and related to the trip on the AHS. People generally do not respond well to meaningless tasks, and may perform poorly if they do not believe the test is important. For example, AHS could alert the driver that an exit is approaching, and could ask whether the driver desires to check-out. The act of responding to the system is an indication that the driver is awake and alert.

The driver check-out process must be designed to ensure that the driver is capable and engaged with respect to each important aspect of driving performance. Figure 2-2 shows a generalized model of the driving task including each important cognitive and control subtask.

The check-out process must address each of these subtasks to keep the driver in-the-loop, ready, and capable of assuming driving responsibility.

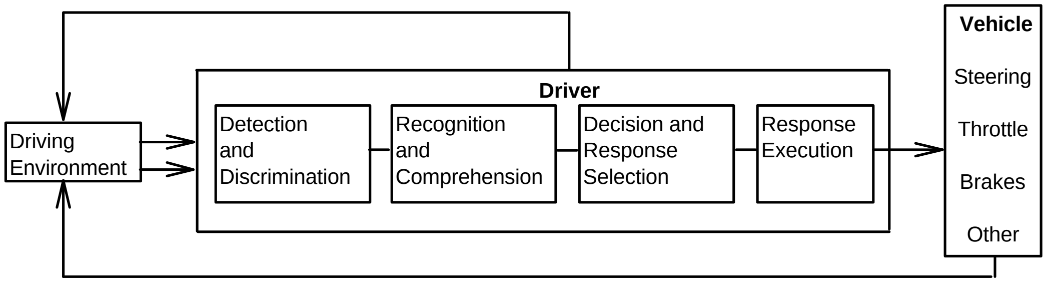

Figure 2-2. Information Processing Model

Given enough time, testing for driver capability and engagement with respect to the driving subtasks, shown in the information processing model (figure 2-2), would be straightforward. There are substantial research and tools available to support the measuring of human performance with respect to each of these activities. However, the practicality of implementing a driver assessment procedure within the check-out process must be considered. Drivers will not tolerate a system that requires a battery of tests each time the AHS is exited. Additionally, AHS flow requirements and infrastructure limitations dictate that the tests be accomplished quickly. The AHS check-out challenge is to accomplish the goal of a comprehensive driver assessment within the worst-case time available. Further, this must be accomplished for AHS drivers varying in age, experience, and capability.

It would be most advantageous if the driver assessment procedure is accomplished within the process of transferring control from the automated driving system to manual driving. That is, the control transfer procedure should be designed to include steps that accomplish both transferring control to the driver, and assessing the driver's readiness to accept control. Table 2-3 shows each component of the driving task, as illustrated in figure 2-2, and identifies a general approach for assessing driver capability with respect to each. This is a very general model that needs to be further developed and tested during the next AHS program phase.

Table 2-3. A Generic Model of Driver Assessment within the Driving Control Transfer Process

Driving Subtask	Example Driver Assessment Approach
Detect and discriminate roadway stimuli	• The process of assuming vehicle control must ensure that the driver is attending to the roadway ahead. By placing the signal that the vehicle is ready to relinquish control in the forward field of view, the driver's focus can be properly directed. • The timing of vehicle ready signals should be determined on the basis of the time needed for worst-case drivers to gain a sufficient sense of dynamic roadway cues for an adequate level of situation awareness and pursuit-tracking performance (i.e., lane keeping).
Recognize and comprehend the driving situation	• The response to the vehicle ready signal can be simple yet one that requires recognition and comprehension. For example, require drivers to hit a button on the steering wheel that relates to correct vehicle speed or to a road sign ahead (could be a variable message sign showing a random number). • Special roadway condition information can be provided verbally during process (verbally so as not to compete with ongoing visual processes).
Demonstrate adequate decision and response capability	• Correct response to vehicle ready signal above provides evidence of adequate decision and response functioning.
Demonstrate correct response execution	• Driver must have hands on the wheel and feet on the pedal(s) (or the appropriate pedal). Driver may be required to initiate an appropriate steering wheel input (as determined by AHS sensors or just turn the wheel back and forth once) and tap the brake (as currently done for disengaging cruise control).

It must be emphasized that this is a very skeletal description of a possible driver readiness assessment process. The specifics of this procedure need to be determined and validated on the basis of further analysis and test. This generic example of a possible approach to meeting the requirement for testing driver readiness serves to demonstrate how the steps of driver readiness assessment can be embedded within the vehicle control transfer process in a way that is practical for AHS implementation.

One critical aspect of the driver readiness assessment process is that it never fails in determining that the driver is controlling the vehicle when automated control is relinquished. Our recommendation for meeting this important requirement is that the driver be required to **take control** rather than have the vehicle give up control. The driver should be required to initiate a positive action using the vehicle's manual controls to complete the control transfer process. This is very similar to the way drivers currently take control from today's cruise control. The check-out process must ensure continuous active control of the vehicle, and has important liability implications. This is an important conclusion of this task.

1.2.4 Vehicle Check-Out Issues

In addition to verifying that the driver is ready and actively controlling the vehicle, the integrity and proper functioning of the critical vehicle control mechanisms must be ensured. Most vehicle control functions operate under both automated and manual driving conditions, and, therefore can be assumed to be working. However, the manual links to safety-critical actuators must be verified. These include actuators for steering, braking, and throttle. Three possible approaches to AHS design relevant to these tests have been identified.

In the first design approach, either the manual vehicle control system or the automated vehicle system can be connected at a time. One can be connected only when the other is disconnected. The approach to verifying manual control integrity with this design may be mechanical; e.g., a mechanical switch can be engaged when manual controls are "locked-in." Automated control links can only be allowed to disengage when the mechanical engage switch is engaged.

The second approach requires software logic and control response testing. In this approach, both control modes remain connected to the vehicle actuators at all times. An electrical switch is used to control which mode is to be recognized by the actuators at any one time. The verification of control integrity must be done through control response testing, and the switch to manual control can only occur after the automated system has been disengaged.

In the third approach, manual control is always engaged. All that is needed to disengage the automated system is to provide an input to the manual system. Thus, the vehicle actuators can accept commands from both control modes simultaneously. We do not recommend this approach, since a driver who accidentally provides an input to the manual control system (e.g., bumping the steering wheel) will interfere with the automated control system. This could lead to a potentially dangerous situation.

1.2.5 AHS/Highway Design Issues

There are also issues of AHS infrastructure design that have been identified during this task. It is assumed that the check-out process will be performed while the vehicle is traveling at regular highway speed (as determined by the automated system). It may occur on the AHS or in the transition lane. Thus, during the time required to perform the check-out tests, the vehicle will cover quite a distance. In addition, it will be necessary to allow the driver to retake the check-out test upon failure on the first attempt. This further increases the distance traveled by the vehicle. For example, a vehicle traveling at 60 mph will travel 1/4 mile in the time necessary to conduct a 15-second test, and 1/2 mile in the time necessary to conduct two 15-second tests. It is necessary to initiate the check-out process far enough in advance for all of the check-out tests, and retesting if necessary, to be conducted prior to reaching the driver’s desired exit. The point where check-out must begin is determined by the speed of travel, the duration of the check-out test, and the maximum number of allowable retests. Roadway conditions may also affect where (and when) check-out is initiated. When the roadway is in less than optimal condition (e.g., rain, ice, or snow), vehicles require a greater distance to decelerate, and may require additional time to perform the check-out process. Also, the check-out process may need to be modified in these situations, to reflect the increased difficulty of the driving task during non-optimal conditions.

The design of the check-out process may also affect the design of the entry/exit infrastructure, and may depend on how a check-out failure is handled by the system. Upon a check-out failure, AHS may either keep a driver on the system past the desired exit for further testing, or may park the vehicle at the desired exit. If a vehicle is allowed to continue to the next exit, it may be necessary to merge that vehicle back into AHS traffic (if the vehicle had been pulled into the transition lane for check-out testing.) If a vehicle is to be parked, it may be necessary to construct parking lots at exits, or to merge the vehicle back into traffic until a breakdown lane can be reached. Obviously, it is undesirable for vehicles that fail the check-out process to interfere with the AHS traffic.

1.3 RECOMMENDATIONS FOR FUTURE WORK

Based on our analysis, it is not possible to specifically design an appropriate check-out process. Check-out is dependent on the design of many other AHS components, as well as the representative system configuration. However, based on our knowledge of what issues must be addressed during the check-out process, we can make the following recommendations for future work. First, additional study on the ability of a driver to retake manual control of his/her vehicle at high speeds and close headways is warranted. In addition, we recommend an experimental approach to the determination of the passing criteria for the check-out process. Individual variability, as well as the level of participation in the eventual AHS design, must both be taken into account. Finally, we stress the importance of designing the check-out process based on human factors considerations (e.g., information processing, vigilance, and interaction with automation), and in cooperation with other AHS design tasks (e.g., entry/exit, malfunction management, and lateral/longitudinal control).

2.0 INTRODUCTION

2.1 WHAT IS CHECK-OUT?

In the general context of vehicle control, the transition from automatic to manual control is a mode switch involving both the vehicle and the driver. Mode switching is quite common, but check-out tests prior to this kind of mode switch are not. The need to reliably test the driver in a short period of time is especially challenging. The need to perform vehicle check-out tests is minimal since most vehicle systems are presumably operating reliably, as evidenced by the safe arrival at the check-out position. This section discusses the definition of the check-out process as well as its importance in ensuring safe transitions to the manual mode. This analysis has addressed both normal and emergency check-out processes.

2.1.1 Normal Check-Out

The normal check-out procedure occurs at the end of an AHS trip when the driver has indicated that he or she wants to exit the system. Before control can be returned to the driver, it is necessary to ensure that the vehicle will operate correctly in manual mode, and that the driver is ready to take control. Therefore, during the normal check-out process, tests of the driver and vehicle must be conducted. The AHS system must begin the process early enough: 1) for all tests to be completed by the time the vehicle arrives at the point where control must be returned to the driver, 2) to provide for the retesting of the driver, and/or 3) to allow the safe parking of the vehicle if any test is failed. After successful completion of the normal check-out process, the driver manually drives the vehicle.

2.1.2 Emergency Check-Out

Under normal operating conditions, the AHS is expected to perform without error, and without any driver intervention. However, it is possible (although unlikely) that a malfunction in the system may occur. Many emergencies will be adequately handled by the AHS, without driver intervention, but there may be situations necessitating the driver to initiate, or participate in, an override of the AHS system. An emergency check-out process is required in these situations. The emergency check-out process must be initiated and completed quickly, in order to minimize the time until manual driving can begin. Since the driver and system will have less time to prepare for this transition, the driver testing must include only the minimum tests to ensure vehicle and passenger safety.

2.2 APPROACH

This task has applied engineering analyses and small group brainstorming as primary technical approaches. In addition, a literature review was conducted.

Driver tasks and system functions which constitute the check-out process were analyzed relative to the various RSCs to identify timing, technology, and infrastructure- based check-out issues. Inputs from other tasks were obtained, as needed, to support the analysis. For example, check-out flow requirements/estimates were obtained from the Entry/Exit task, the design alternatives for malfunction management were obtained from the Malfunction Management Task, and the safety implications associated with transition to manual at various potential design speeds were obtained from a study conducted by Honeywell.

2.3 HIGH LEVEL ASSUMPTIONS

The following assumptions have been made and applied within the check-out analysis:

- Drivers will not disobey existing traffic laws
- Drivers will be required to remain awake and perform a monitoring role during AHS operation
- Drivers will not be required to preselect destinations
- Drivers will be able to override the AHS and retake manual control
- Drivers will have a “panic button”

Each of these assumptions are discussed below.

2.3.1 Drivers Will Not Disobey Traffic Laws

In this analysis, it has been assumed that drivers on the AHS will obey all existing traffic laws. Some of these include: having a licensed driver operate the vehicle; not driving while intoxicated (or on drugs); having an inspected, well-maintained, and safe vehicle; and following all traffic signs and instructions. While AHS may help to avoid problems posed by law-breakers (e.g., currency of vehicle inspection may be verified at check-in, and minimal levels of driver competency assessed at check-out), those who break the law can still pose danger to others. AHS will be an integrated part of the existing highway system and drivers will be required to follow the same rules that exist for all other roads. It is not the role of the AHS or the check-out process to be an enforcing mechanism for existing laws (e.g., drivers will not be tested for intoxication during the check-out process.) The check-out process is intended to ensure that drivers are ready to assume safe control of the vehicle at the check-out point and that the transition to manual driving is accomplished safely.

2.3.2 Drivers Will Be Required to Remain Awake and Perform a Monitoring Role During AHS Operation

It is expected that AHS will be implemented using an evolutionary approach, with refinements and improvements taking place over many years. Eventually, long distance travel where drivers can safely sleep may be possible. However, during the early stages of AHS, an alert driver serving as a system monitor for the new AHS technology will be an important requirement until experience and reliability data are obtained. Allowing the driver to participate as a system monitor may increase confidence and overall acceptance of the new AHS technology. In addition, it is expected that most trips on the early AHS will be of relatively short duration, and may use a mixed-traffic approach, in which automated vehicles share the roadway with manual traffic. These conditions add further requirements for high driver vigilance and awareness during AHS trips.

Even an improved, more mature AHS, with dedicated lanes for automated vehicles, may require drivers to remain awake. Drivers may be required to intervene in certain emergency situations, and therefore must be prepared to do so at any time. Over time, the AHS system may be expanded to handle many of these emergency situations, removing the need for driver intervention and alertness. However, this analysis assumes a near-term AHS requiring all drivers to remain awake to handle emergencies.

2.3.3 Drivers Will Not Be Required to Preselect Destinations

Although most drivers will have a final destination in mind when entering the AHS, we do not believe it will be practical to require this information to be entered during the check-in process. Intermediate, unplanned stops may be required, especially on long trips, and drivers may not be willing or able to preselect exact destinations. In addition, originally planned destinations may be general in nature (e.g., the Washington D.C. area) and may change in route. This analysis assumes that drivers will not be required to enter a destination during check-in, and that exit selection will be incorporated into the check-out process.

2.3.4 Drivers Will Be Able to Override AHS and Retake Manual Control

Although malfunctions in AHS are expected to be extremely rare, it is possible (especially in the early stages) that they may occur. Most malfunctions will be adequately handled by the AHS, though there may be situations in which driver intervention is necessary. It is also possible that the human driver may be better able to detect system or vehicle problems that require immediate human intervention. In these situations, it is important that the driver be able to retake manual control of the vehicle.

If the driver decides to take control, or if the AHS instructs the driver to take control, the driver will undergo an emergency check-out process. This process will verify the driver’s intention to override the AHS, and will quickly verify the driver’s capabilities to drive manually.

2.3.5 Drivers Will Have a “Panic Button”

There may be situations in which the driver needs to immediately stop the vehicle in the median or breakdown lane. For example, if a passenger in the car has a heart attack, the driver may want to stop the vehicle to administer CPR. Since drivers on the AHS may be traveling at high speeds and at close headway, the driver may be unable to manually drive the vehicle off the AHS. In these situations, it is important that the driver be able to exit the automated lane without retaking manual control of the vehicle. The driver should have a “panic button”, which results in the vehicle being automatically parked along the roadway. The use of the panic button could even invoke an emergency response from police and fire crews.

Obviously, the panic button response should be utilized only in extreme emergencies. Drivers should be encouraged to exit AHS at designated exits, if at all possible. To discourage frivolous use of the panic response, it may be necessary to impose severe penalties for non-emergency stops.

3.0 TECHNICAL DISCUSSION

3.1 AHS CHECK-OUT MODEL

The check-out model (see figure 2-3) describes the relationship between the automated and manual systems within a vehicle. In an AHS-equipped vehicle, there are two distinct systems that affect one set of vehicle actuators. The automated system, driven by AHS control logic, provides inputs to the vehicle actuators. The manual system, controlled by the driver, provides inputs to these same vehicle actuators. Only one of these systems can be operational at a time, although it is possible for the automated system to be overridden by the manual system. The process of check-in involves the transfer of control from the driver to the AHS, and the process of check-out involves the transfer of control from the AHS back to the driver. In addition to accomplishing the transition, the process of check-out requires the verification of the links between driver inputs and the vehicle actuators and the driver's control competency (links between driver controls and driver inputs). These links must be verified before the vehicle can be safely disengaged from the automated controls.

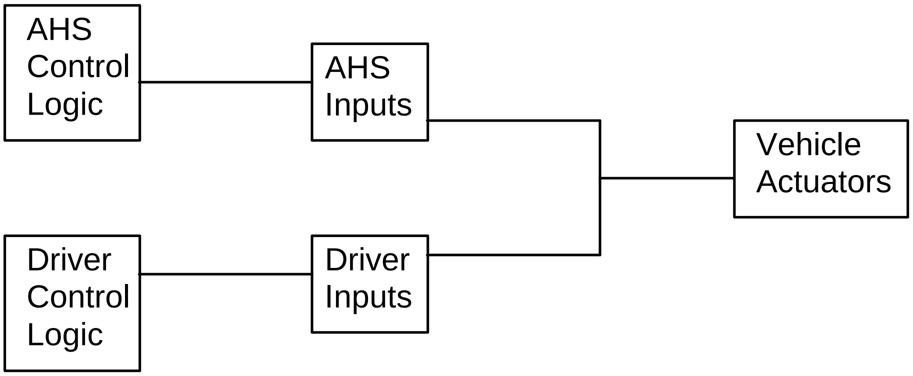

Figure 2-3. AHS Check-Out Model

Verification of driver control competency ensures that the driver is physically and mentally ready and able to drive the vehicle. For example, the driver must be able to use the steering wheel to turn and the brake pedal to slow down, and must be able to make decisions concerning the appropriate direction and speed of the vehicle. During check-out, the AHS system must ensure that the driver is ready and able to regain control of the vehicle. This is discussed further in section 3.2, "Driver Readiness Issues."

The second part of the check-out process deals with the link between the driver inputs and the vehicle actuators. It is concerned with ensuring safe mechanical connections between the driver inputs (e.g., steering wheel or brake pedal) and the actuators. For example, turning the steering wheel must cause the wheels to turn, and depressing the brake pedal must cause the vehicle to slow down and stop. During check-out, the AHS system must ensure that these mechanical links are complete; that all of the necessary mechanical components are functioning. This is discussed further in section 3.3, "Vehicle Issues."

For the check-out process to be effective, the AHS must be designed to allow for the necessary time, distance, and infrastructure for accomplishing the check-out functions. For example, transition lanes and exit ramps must be long enough for all necessary vehicle and driver testing, and transfer of control, to take place. Thus, it is important to consider the impact of any proposed check-out process on the roadway structure and the design of the AHS. We have considered these issues in the context of the RSCs. These issues are discussed further in section 3.4, "Highway/ AHS Design Issues."

3.2 DRIVER READINESS ISSUES

This section addresses the need to ensure that the driver is able, mentally and physically, to retake manual control of the vehicle after a period of automated driving. The effect of automation on performance is one that has been considered in many fields, especially in aviation. Many studies have been conducted to establish how people react to being part of an automated system. There are important lessons for AHS which may be drawn from many of these previous studies on automation, such as the increases in reaction time compared to time on task, or the effect of vigilance decrements on signal detection.

3.2.1 Theoretical Foundations and Basis of Concern

The basis of concern for the check-out process is that human performance may degrade after periods of non-involvement. AHS requires that drivers be out of the loop during the automated portion of the trip. Thus, the possibility exists that the driver will be asleep, unprepared, or otherwise impaired and unable to safely take control at the end of the trip. This section describes the various factors that may affect driver performance in AHS and specifically, during the transition back to manual driving mode.

3.2.1.1 Sources of Human Error Within Automated Systems

A large percentage of accidents on today's highways can be attributed to human error. This fact has encouraged the development of an automated highway system (AHS). In an AHS, automatic controls take over the tasks of steering and speed maintenance. The exact role of the driver is controversial and yet to be determined. This analysis assumes that the human driver is promoted to the post of system monitor, with the responsibility of ensuring that the automation is working properly throughout the trip. Unfortunately, humans are inherently bad at monitoring tasks. Humans are highly likely to miss critical signals, and to occasionally identify non-important signals as critical (false alarms). Thus, designers are often tempted to automate human error out of the system. However, it is questionable whether this is actually possible within a system like AHS where market costs are an important factor. It is presumed that the introduction of automation may in fact introduce new types of error into a system. The driver will be needed to monitor and back-up the automated system, at least until more advanced stages of AHS.

This discussion focuses specifically on the check-out process. As mentioned earlier, check-out can occur under either normal or emergency conditions. Normal check-out occurs at an exit from AHS, at the end of an automated trip; emergency check-out will usually occur unexpectedly during an automated trip. A successful emergency check-out will occur only if the human operator is monitoring the automatic system, and is prepared to perform the correct response to a signal from the automatic system. Thus, it is useful to examine the potential errors that can occur during interactions between a human operator and an automated system.

Wiener and Curry (1980) have identified six types of human error that may occur as a result of automation: (1) a human operator reacts incorrectly to a failure of the automatic equipment, causing a more serious result to occur; (2) a human operator incorrectly sets-up the automatic equipment, causing the automatic equipment to function incorrectly; (3) a false alarm in the automatic equipment prompts the human operator to take a corrective action when in fact nothing is wrong with the system; (4) the human operator may fail to react to an alarm (or a critical signal) from the automatic system; (5) the human operator fails to monitor the automatic system and is not aware of problems that may have arisen in the system operation; and (6) the automation may cause the human operator to have a loss of skill proficiency which may carry over into periods of manual operation. Some of these types of error can be mitigated through AHS design (e.g., design so that human inputs to set-up cannot lead to serious problems), while others must be prevented through adequate training and maintenance of vigilance. If a failure mode requires human intervention there is no substitute for a human who is alert and able to respond appropriately.

Sarter and Woods (1994) have studied problems that may exist with the interface between a human and an automated system. They identified four major issues that arise due to automated systems. First, they identified the possibility of confusion between various modes of system operation (manual and automated driving, in this case). A mode error may occur if the operator executes a response that is appropriate in one mode, while the system is actually in the other mode. The need to maintain awareness of externally induced changes in the state of the system (situational awareness) may induce new cognitive demands on the operator. Maintenance of situational awareness has been identified as critical in making the correct response in an emergency situation. In the case of AHS, a driver taking manual control will need to be aware of vehicle speed, the location and status of other vehicles, the vehicle status (e.g., are any systems malfunctioning), and so forth.

The AHS system itself imposes new knowledge requirements on the human operators. Operators must understand how the automation works, in order to recognize the correct responses in a non-routine situation. Sarter and Woods’ second issue emphasizes the need for operators to develop reliable mental models of the automated system, and to have these models corrected and elaborated as necessary. They advocate adequate training to ensure that operators understand how the system works, and necessary responses for operating the automated system under normal and emergency conditions. In addition, on-going training may be necessary to help experienced operators discover and modify incorrect aspects of their mental models, and further their understanding of how the automation works in non-normal situations.

Third, Sarter and Woods (1994) recognize a problem of knowledge miscalibration among operators of automated systems. People are said to be miscalibrated if they are overconfident about their knowledge, and believe that they understand areas in which their knowledge is in fact incomplete or limited. This is important because it is infrequent that operators ever encounter a situation where it is obvious that their knowledge is limited. On-going training that puts operators through infrequently encountered situations and gives feedback could help to fill in the knowledge gaps. Knowledge miscalibration is one factor that could lead to underreporting of problems with automation in survey studies.

Finally, the study by Sarter and Woods (1994) indicates that operators often become proficient on only a subset of the modes and options provided by an automated system. Thus, operators try to manage the system within a set of stereotypical responses, and try to protect themselves from having to make difficult decisions due to an increased number of alternatives. The implication is that operators are often inefficient in how they manage the automated resources available to them. On-going training that forces operators to use the automated system in non-routine situations may help broaden their knowledge of the system and its options.

In an attempt to prevent human errors in automated systems, and to deal effectively with other issues raised by the introduction of an automated system, the following guidelines have been proposed by Wiener and Curry (1980) for the design and use of automated systems:

- System operation should be easily interpretable or understandable by the operator to facilitate the detection of improper operation and the diagnosis of malfunctions.

- Design the automatic system to perform tasks the way the user wants or expects them to be done, consistent with other constraints (such as safety).

- Design the automation to prevent peak levels of task demand from becoming excessive.

- Train and motivate operators of an automated system to use the automation as an additional resource.

- Allow for different operator styles where feasible.

- Ensure that overall system performance is insensitive to different options, or styles of operation.

- Provide a means for checking the set-up and information input to automatic systems.

- Provide training for operators working with automated equipment, not only to ensure proper set-up and use, but to impart a knowledge of operational concepts and malfunction procedures.

- Monitoring tasks require training, both operational and motivational.

- If automation reduces task demands to low levels, provide meaningful duties to maintain operator involvement and resistance to distraction. It is extremely important that any additional duties be meaningful and directed toward the primary task.

- Keep false alarm rates within acceptable limits.

- Alarms with more than one mode, or more than one condition that can trigger the alarm for a mode, must clearly indicate the mode, and the condition responsible for the alarm.

- When response time is not critical, most operators will attempt to check the validity of the alarm. Provide information in an easily understood format so that this validity check can be made quickly and accurately and not become a source of distraction. Also, provide the operator with information and controls to diagnose the automatic system and warning system operation.

- The format of the alarm should indicate the degree of emergency. Multiple levels of urgency of the same condition may be beneficial.
- Devise training techniques and possible training hardware (simulators) to ensure that operators are exposed to all forms of alarms and to the many possible combinations of alarms. Ensure that they understand how to deal with each alarm possibility.

Applying these guidelines to the design of AHS, and to the check-out process in particular, should help to minimize the conflicts between the drivers and the automated system.

3.2.1.2 Information Processing Issues

Driving requires the continuous processing of information by the driver. In manual driving, the driver must constantly survey his/her surroundings (both inside and outside of the vehicle) to ensure that the vehicle is operating safely and correctly. The processing of this information consists of four major steps: detection and discrimination, recognition and comprehension, decision and response selection, and response execution (see figure 2-4). For satisfactory driving performance, the driver must be able to perform each of these steps. Shinar (1978) explains that “To negotiate a car on the road successfully, the driver has to continuously process new information and use it to make appropriate decisions...We act on our perceptions by making decisions. Making the right decision at the right time (particularly in emergency situations) is critical.” However, performance on these information processing steps depends on many factors which may be affecting the driver. For example, drivers who are inattentive or very sleepy may not be able to process information quickly enough to ensure safe driving performance. Thus, it is critical for the check-out process to ensure that drivers are able to process information (and perform each of these steps) before they can take control of the vehicle.

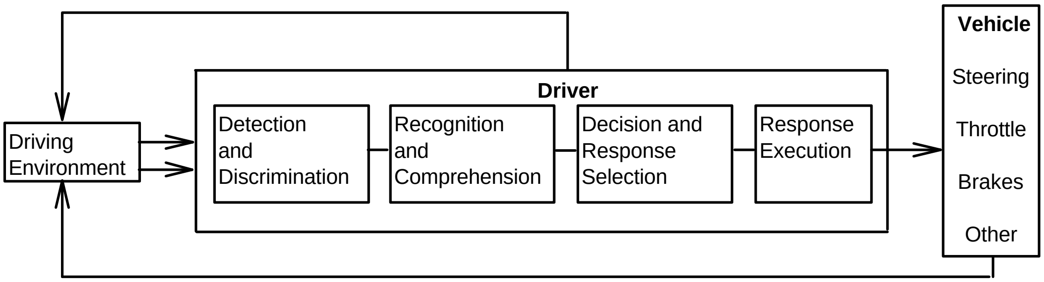

Figure 2-4. Information Processing Model

3.2.1.2.1 The Driver Information Processing and Control Model

The information processing model, shown in figure 2-4, describes the role of drivers in the manual driving task. Drivers must first detect and discriminate environmental stimuli; they must then recognize and comprehend those stimuli. Third, they must make decisions concerning the stimuli and choose an appropriate response. Finally, drivers must execute the selected response. This procedure is performed continuously throughout the driving task.

Detection and Discrimination

The first step in information processing is detection and discrimination. This involves the use of various senses, especially hearing and vision, to detect environmental stimuli. Discrimination of environmental stimuli involves the ability to sort out all of the incoming sensory data into meaningful patterns. These patterns represent the information needed to ensure safe driving.

The ability to detect visual stimuli while driving depends mainly on the visual fixation patterns of the driver. (Shinar, 1978) These patterns determine what objects the driver chooses to look at, the time spent focusing on each object, and the amount of information that can be gathered from each object. There are many factors that may affect the visual fixation patterns of a driver, including experience, age, fatigue, personal style, and situational needs.

Recognition and Comprehension

The second step in the information processing process is recognition and comprehension. Stimuli patterns are recognized when the driver is able to match the incoming stimulus information with information from either long term or short term memory stores. Comprehension of the stimuli patterns occurs when the driver is able to understand what the immediate implications of these patterns are to the present driving situation.

In certain situations, stimuli patterns are not recognized by association with a discrete state, but rather are recognized by a relative judgment of the position of the stimuli patterns along a continuous scale, with each position having a direct implication for action. (Wickens, 1992) Thus, a driver is able to perceive the relative importance of incoming stimuli patterns, and can recognize the need for immediate, more focused attention. For example, driving requires a constant tracking of the heading of the vehicle, with focused attention required only when a directional change is needed.

The ability to recognize and comprehend environmental stimuli is improved with increased available time to search the memory stores for a pattern match; increased incoming sensory information (until the senses become overloaded!); increased information available in the memory stores; improved effectiveness of memory recall; and increased familiarity with a particular stimuli pattern. It is easy to see the role of experience in this phase of information processing. Driving experience allows the driver to expand memory stores, practice recalling information under time pressure, and become familiar with a wide range of stimuli patterns.

Decision and Response Selection

The third step in information processing is decision making and response selection. Decision making involves the careful examination of the implications associated with the stimuli patterns, and the weighing of possible responses. The decision making process ends with the selection of a response, hopefully the most appropriate response, for the external stimuli pattern.

Decisions are made by integrating stimuli patterns to form one or more hypotheses. An attempt is then made to verify, or choose, the hypothesis that is most correct. This process usually involves obtaining further proof, through the perception of more environmental stimuli.

In familiar situations, a decision may be made rapidly, almost automatically, since the driver has encountered many similar situations in the past and knows immediately what the correct response should be. (Wickens, 1992) This type of decision places relatively little workload on the driver, since the decision is made without much conscious thought. In less familiar situations, the driver may need to consider and weigh more than one alternative (hypothesis) before deciding on the correct course of action. These situations impose a heavier workload on the driver, since the driver must consciously develop alternative hypotheses, and then choose the best one.

Response Execution

The fourth step in the Driver Information Processing and Control Model involves carrying out the response selected in the previous step. Once a decision has been made to generate a response, the driver must call up, and release with the appropriate timing and force, the necessary muscle commands to carry out the action. (Wickens, 1992) The response execution usually involves a physical response, e.g. hitting the brake pedal, but may involve carrying out a mental process; e.g., continue to monitor the situation. In the driving task, the response execution requires the driver to affect the vehicle in some manner.

3.2.1.2.2 Limitations in Human Information Processing Capabilities

Limitations of Attention (Detection and Discrimination)

It is obviously impossible for humans to process all of the information that is available to us in our daily lives. The limitations of human attention represent one of the most serious bottlenecks in the information processing process. (Wickens, 1992) There are three main categories of failures in attention: limits of selective attention, limits of focused attention, and limits of divided attention.

Limits of Selective Attention. In many situations, the driver may intentionally (although perhaps unwisely) choose to select specific aspects from the environment to process. (Wickens, 1992) The driver may choose to ignore stimuli that do not seem important, in order to concentrate on other stimuli. This may result in important information being precluded from processing.

Limits of Focused Attention. In many situations, the driver may be distracted, and thus unable to concentrate on any one source of environmental stimuli. Thus, although the driver may correctly choose the most important stimuli for focused attention, he/she is unable to “shut out” non-optimal or unimportant sources of information.

Limits of Divided Attention. In many situations, the driver is unable to divide his/her attention between all important stimuli (or tasks). Thus, the limits of divided attention are analogous to the driver’s limited ability to time-share performance between two or more tasks, or sources of stimuli. (Wickens, 1992)

Limitations in Perception (Recognition and Comprehension)

The human ability to recognize and comprehend information from the environment depends greatly on the form in which it is presented. For example, distance may be judged based upon the relative size of known landmarks, and it is easier to discern words than a grouping of unrelated letters. (Wickens, 1992) All humans have developed assumptions about how things are in the world, based upon their own past experiences. Drivers, especially, must depend on perceptual hypotheses about the way things are, based upon their own assumptions and experiences. (Wickens, 1992) In order to verify their perceptual hypotheses, drivers depend on redundant cues to provide the same information. However, if the cues are ambiguous, or if there are too few cues, incorrect assumptions may be made, and incorrect perceptual hypotheses may be verified. This can lead to misperception of the environment.

One example, described by Wickens (1992), is that people tend to assume an average size for all vehicles on the road, and use it as the basis for perceiving distance in traffic. Therefore, smaller than average cars are perceived to be farther away than they actually are, and the braking process is initiated later than it should be for these vehicles. In these situations, a large number of rear-end collisions tend to occur.

Limitations in Decision Making and Response Selection

Many aspects of decision making are not as optimal as they could be. The limitations in attention and information processing restrict the accuracy of diagnosis, and may lead people to develop mental shortcuts (heuristics) which often produce adequate, but not the best decisions. In addition to heuristics, humans have many biases that may further affect the decision making process, some of which are described below. These competing biases influence decisions in inappropriate ways.

The Salience Bias. This bias indicates that drivers tend to pay more attention to stimuli that are the most salient (brightest, largest, centered, loudest, moving, etc.). This may lead to over processing of some stimuli, while ignoring less salient, but possibly more important stimuli.

The "As If" Heuristic. This bias indicates that in many situations, the decision maker may treat all sources of information as if they are equally important. This assumption is not usually true, since certain stimuli are very supportive of a particular hypotheses, while other stimuli may provide little information about the same hypothesis. Therefore, drivers who consider unimportant stimuli with the same (or more) weight as the critical stimuli are likely to come to the wrong decision, leading to an incorrect response selection.

The Availability Heuristic. Drivers generally consider only hypotheses that are more available; that is, those that can be brought to mind easily. Therefore, it is often the case that only simple or more familiar hypotheses are considered. Under this heuristic, novel and unknown conditions are often mistaken for more common and familiar situations.

The Confirmation Bias. Once an initial hypothesis is chosen, drivers will tend to seek information to confirm their hypothesis. Stimuli, or other information, that can disconfirm this hypothesis is often ignored. Similarly, the initial stimuli provide a cognitive anchor to which all subsequently obtained information is related. New information is used only to shift the anchor, and is not given the same weight as the original stimuli were given. Therefore, the order in which stimuli are perceived may affect the hypotheses formed, and the decisions made.

Limitations in Response Execution

Generally, the limitations to response execution are imposed by physical limitations of the driver. For example, an older driver may not be able to generate the necessary braking force in an emergency, or may not be able to turn the steering wheel fast enough to avoid an accident.

3.2.1.3 Vigilance Issues

During AHS operation, drivers will serve as system monitors, but will not be actively involved in direct vehicle control. This reduced tasking environment could lead to a vigilance decrement (i.e., reduction in level of attentiveness), and cause important signals from the environment to be missed. The vigilance decrement is well documented for people in monotonous, “out-of-the-loop” situations, in which they must serve only as system monitors. In this section we address these vigilance concerns as related to AHS. Implications for the design of the check-out process are discussed in section 3.2.2.3.

Vigilance has been defined as “a state of readiness to detect and respond to certain specified small changes (targets) occurring at random time intervals in the environment.” (Davies and Tune, 1969) Thus, tasks requiring the monitoring of automated systems for any changes are considered to be vigilance tasks. Unfortunately, most people do not make good system monitors. After only a very short period of time (usually five minutes), performance on a vigilance task starts to degrade. This is referred to as the vigilance decrement, and is measured by a reduction in the number of correctly detected signals (increase in the number of missed signals), or by an increase in reaction time to a signal. The vigilance decrement is an important consideration for AHS, and is particularly important for check-out.

During AHS operation, drivers will be asked to monitor the automated system to ensure that it is working correctly. They will be required to detect problems and take steps to minimize the potential for accidents or other consequences of system failure. Consequently, drivers on the AHS must be ready to resume manual control of their vehicles during the check-out process (normal or emergency). Thus, to ensure safety, it is important that the drivers on the AHS are continuously effective in performing their jobs as system monitors.

3.2.1.3.1 Variables Affecting Vigilance Task Performance

There are many variables that affect performance on a vigilance task. These variables can be described as either task variables, subject variables, or environmental variables. Task variables are functions of the particular task to be performed, such as the manner in which the task is performed and the frequency of target signals, as described in table 2-4. Subject variables, described in table 2-5, are functions of the people assigned to perform the task, such as the amount of training obtained. Environmental variables are functions of the conditions under which the task is performed, as described in table 2-6.

Table 2-4. Task Variables

Variable	Definition	Description/Effect	Reference
Duration	The length of time that the task must be performed.	The performance decrement begins after five minutes on a task, and continues to decline throughout the first thirty minutes of the task.	Davies and Tune (1969)
Knowledge of Task Duration	The degree to which operator is aware of task duration, and the nature of that belief.	Operators who are expecting a task of long duration tend to exhibit rapid deterioration of performance almost immediately. Operators who are expecting a task of short duration tend to exhibit less rapid performance degradation. Operators who anticipate the imminent end of the task tend to exhibit an “end-effect”, during which performance on the task improves.	Davies and Tune (1969)
Rest Pause	A break from continuous performance.	Rest pauses seem to permit some recovery of performance, and may help prevent the vigilance decrement. Even a five-minute break can abolish the vigilance decrement if the placement in the task is appropriate.	Davies and Tune (1969)
Multiple Monitors	The use of more than one monitor for a system	Performance on vigilance tasks tends to improve when there is more than one system monitor (e.g., team inspection).	Davies and Tune (1969)

Table 2-4. Task Variables (continued)

Variable	Definition	Description/Effect	Reference
Time Sharing	The division of attention between two tasks.	Performance on a vigilance task may be further improved or degraded by timesharing. The effect depends on the mental requirements of the two tasks. For example, when performing two similar tasks simultaneously, performance on both tasks will suffer. Also, alternating between two tasks can have a beneficial effect on performance when one of the tasks is near the extreme in terms of stimulus level and the other is near the mean. Two high stimulus vigilance tasks will tend to have a detrimental effect on overall performance.	Wickens (1992)
Bi-Modal Tasks	The presentation of a signal to more than one sensory modality (e.g., visual and auditory).	The use of a bi-modal stimulus may produce better overall performance on a vigilance task than a task that presents the signal to only one sensory modality.	Craig, Colquhoun, and Corcoran (1976)
Incentives	The presentation of rewards for good performance, and punishments for poor performance.	A combination of rewards and punishments can be effective in maintaining vigilance performance at a high level. Substantial incentives may be sufficient to encourage performance improvements on a vigilance task and to prevent the vigilance decrement.	Boff and Lincoln (1988)
Knowledge of Results	The provision of feedback on task performance.	Operators who receive feedback on their performance tend to exhibit less performance degradation than operators who do not receive feedback on performance.	Mackworth (1950)
Practice	Repeated exposure to a task.	Increased task experience helps the operator to better discriminate signals from noise, while requiring less attention (vigilance) to do so. However, even experienced operators may have a vigilance decrement.	Binford and Loeb (1968)
Stimulus	The target that is to be detected by the human observer.	Characteristics of the stimulus (target) may affect performance on vigilance tasks.	Wickens (1992)

Table 2-4. Task Variables (continued)

Variable	Definition	Description/Effect	Reference
Stimulus Density	The number of stimulus presentations.	An increased number of stimuli enhances performance on vigilance tasks. The need to perform a visual search in order to detect a stimulus increases the amount of performance degradation that occurs on a vigilance task. However, improvements in detection associated with a more conspicuous signal are twice as great with a high stimulus density as with a low stimulus density.	Loeb and Alluisi (1970)
Stimulus Regularity	The occurrence of stimuli at regular intervals.	Temporal uncertainty concerning the appearance of a stimulus has been found to lower performance on a vigilance task, and increase the reaction time to the stimulus.	Davies and Tune (1969)
Stimulus Intensity	The salience of a stimulus.	More intense stimuli are more readily detected and have been associated with lower reaction times.	Weiner (1963)
Stimulus Duration	The length of time the stimulus persists.	The longer the stimulus persists in time, the easier it is to discriminate and detect. Thus, these stimuli are less affected by the vigilance decrement.	Baker (1963)

Table 2-5. Subject Variables

Variable	Definition	Description/Effect	Reference
Intelligence	The ability to grasp, comprehend, relate, and reason about facts and information.	No correlation has been found between intelligence and performance on vigilance tasks.	Smith, *et al.* (1966)
Age	The number of years that a person has lived.	As age increases, performance on vigilance tasks tend to decrease, due to increased reaction time (generally due to a decreased ability to physically react to a stimulus), and decreased capacity for information processing (ability to detect, recognize and decide how to handle a stimulus).	Deaton and Parasuraman (1993)
Sex	Whether the AHS driver is male or female.	No correlation has been found between the sex of the operator and performance on vigilance tasks.	Boff and Lincoln (1988)

Table 2-5. Subject Variables (continued)

Variable	Definition	Description/Effect	Reference
Personality	The two main personality types are introverts and extroverts.	Introverts generally have better performance on vigilance tasks than extroverts. This is attributable to the introverts' capability to maintain arousal without external stimulation.	Davies and Tune (1969)
Fatigue/Sleep Deprivation	The degree to which the driver is tired, either physically or mentally. Sleep deprivation refers to the lack of regular sleep experienced by the driver.	Operators who are tired generally perform poorly on vigilance tasks. Physical fatigue exerts comparatively little effect on vigilance performance, while mental fatigue causes considerable deterioration in vigilance performance.	Mackie (1977)

Table 2-6. Environmental Variables

Variable	Definition	Description/Effect	Reference
Temperature	The degree of hotness or coldness felt by the driver.	Both extreme hot and cold conditions tend to reduce the performance on a vigilance task. Heat also tends to promote the vigilance decrement.	Ramsey and Morrisey (1978)
Time of Day	Whether the driver is on the AHS during the morning, afternoon, or night.	Performance on a vigilance task does not remain uniform throughout a twenty-four period. Performance is generally best in the afternoon, and worst late at night. However, individuals have their own predisposition concerning the optimal time of day (i.e., each person has his or her own biological clock and optimal performance varies greatly across individuals).	Mackie (1977)

3.2.1.3.2 Theories of the Vigilance Decrement

There are three main theories that attempt to explain the vigilance decrement. None of these are completely successful. Each has important weaknesses with respect to specific applications and situations, as Wickens points out, “It is probably true that no single theory of the vigilance decrement is totally right and the others are wrong.” (Wickens, 1992) It seems that some aspects of all of the theories can be affecting the operator’s performance at any given time, and that overall performance reflects a combination of all three theories.

Expectancy Theory

The expectancy theory of vigilance performance, assumes that the operator's general expectancy about the appearance of a stimulus is determined by the course of stimulus events during his/her previous experience with the task. The level of expectancy determines the operator's level of vigilance on the task. (Davies and Tune, 1969) Thus, operators who, in the past, have encountered a large number of stimuli during the task, will expect stimuli to occur often in the present task and in the future. This high level of expectancy will encourage the operator to remain vigilant. Likewise, operators who have experienced a low number of stimuli while performing the task in the past will tend to have a low expectancy for stimuli in present and future tasks. These operators are more likely to experience a vigilance decrement.

Although there have been numerous studies providing support for the expectancy theory of vigilance, there are also some major objections to the theory that have been raised. One of the main objections is that the expectancy theory explains the vigilance decrement principally by relating the decrement to the initial level of performance. (Davies and Tune, 1969) The expectancy theory implies that operators who have a low level of initial performance will have an inaccurate perception of the temporal occurrence of signals, and will be unable to accurately develop expectancies for later stimuli, thus leading to a deterioration of performance. However, if an operator is able to correctly detect all of the stimuli at the beginning of the task, it is difficult to see why a performance decrement occurs at all (i.e., expectancy theory fails to explain the vigilance decrement under these conditions).

Another objection to the expectancy theory is that it requires operators to utilize stored information to formulate the expectancies. Thus, the operators must increase their workload, by retrieving and utilizing stored information, in order to calculate the expectancies for future stimuli. It is often difficult to determine expectancies with any accuracy, and it may be easier to continuously monitor the task for the appearance of the next stimuli. Therefore, Davies and Tune (1969) argue that the operator will use stored information about the temporal sequence of signals (expectancies) only if the task is difficult and other cues are unavailable.

Attention (or Fatigue) Theory

This theory is based on the fatigue that the vigilance task causes in the operator. Any vigilance task that imposes a sustained load on the operator (e.g., recalling what the target looks like, or maintaining highly focused attention), requires a continuous supply of mental resources. This demand may cause operator fatigue, leading to a reduced ability to sustain attention and remain vigilant. In addition, the physical demand to keep one's eyes open and fixated may add to the fatigue felt by the operator. Therefore, over time, the operator may become less sensitive to the appearance of a stimulus. (Wickens, 1992)

Arousal Theory

Arousal is generally accepted as a state of an individual which can affect his/her behavior. However, there is some argument over the exact definition of this state. Some definitions of arousal emphasize the intensity with which behavior occurs; others emphasize the intensity of the motivational factors to which the person is subjected; while still other definitions emphasize the person's level of alertness. (Davies and Tune, 1969) Often, arousal is measured by physiological factors, such as total metabolism, tension of the skeletal muscles, skin resistance and conductance, skin potential, blood pressure, heart rate, body temperature, and EEG frequency and amplitude.

The level of arousal is determined by many of the task, environmental and subject variables. Task variables which may influence arousal include incentives for good performance, knowledge of results, experience on the task, and various stimulus characteristics. Environmental variables may include extraneous auditory or visual stimulation, and temperature variations. Subject variables which may affect arousal are personality, age, sex, and fatigue level.

The relationship between arousal and performance is generally considered to be an inverted-U. Performance is poor at very low levels of arousal, and increases as arousal increases to an optimum point. Past this point, performance decreases as arousal continues to increase. The optimum point varies with the nature of the task and with the state of the operator. The arousal theory of vigilance assumes that performance on a vigilance task follows the inverted-U theory of arousal.

3.2.1.3.3 Techniques to Combat the Vigilance Decrement

As previously described in tables 2-4, 2-5, and 2-6, there are many variables that will affect the vigilance of drivers as they perform their role as system monitor. Due to the importance of recognizing a stimulus (i.e., a malfunction in the system), especially in the early stages of AHS, the system must try to prevent the decrease in vigilance performance (the vigilance decrement). As discussed above, the vigilance decrement may begin as soon as five minutes after the monitoring task is begun.

Unfortunately, there is very little that can be done to manipulate the environment and subject variables that may affect vigilance performance. Thus, AHS must concentrate on manipulating the task variables to combat the vigilance decrement. Some techniques that can be used to prevent (or mitigate) the degradation in vigilance performance are discussed below.

Increased Emphasis on the Criticality of Missed Stimuli

Emphasizing to operators the important, and potentially dangerous, consequences that may result from a missed stimulus may provide additional motivation for the operators to remain vigilant. A correct mental model of how the AHS system functions will also help operators in their understanding of problems caused by missed stimuli. For further incentive, the costs that may result from missed signals, such as being pulled over and charged a fee for towing, or the time inconvenience from being sent to the next exit or parked for further testing may be emphasized to AHS users.

Arousal Should be Sustained or Increased

Providing background stimulation, or interruptions, may help to prevent the decreased arousal that affects a person’s ability to maintain vigilance. Low arousal levels can result in a missed signal which could put the driver in danger or result in an inconvenience (e.g., fine, missed exit). It is possible to increase the arousal of AHS drivers, or prevent a decrease in arousal level, by increasing the role of the driver in AHS operation, or by increasing the level of external stimulation for the driver (e.g., playing the radio, conversing with the driver, etc.).

Feedback of Results

Operators who are unaware that they have missed a stimulus may form incorrect expectations for the next stimulus. Feedback helps operators improve their sensitivity, and correct the placement of their decision criterion for stimulus detection. Also, continuous feedback may help to maintain interest in the task, and help the operator to remain vigilant and improve performance on the monitoring task.

Stimulus Enhancement

Operators are more likely to detect stimuli that are very salient. It has also been found that to maintain detection performance, signal detectability must increase as time on task increases. (Wickens, 1992) Therefore, presenting stimuli to the operator in an obvious or unusual manner may help him/her to detect the stimuli, even if he/she is not highly vigilant. Unusual stimuli, such as lights coming on or the seat vibrating, could serve as a forewarning for upcoming messages to the driver.

Improve Operator Training

It has been proven that the magnitude of the vigilance decrement can be reduced by training subjects to respond repeatedly to the target stimuli. (Wickens, 1992) Repeated training causes the response to the stimulus to become more automatic, requiring less cognitive resources to perform. Training can be used to reduce uncertainty in locating the signal, increase sensitivity to the signal, and affect the decision criterion. (Boff and Lincoln, 1988)

Utilize More than One Modality for Stimulus Presentation

Vigilance performance has been shown to improve when a stimulus is simultaneously presented in both auditory and visual modalities. Operators are more likely to detect a stimulus that is presented in more than one sensory mode. This improvement is a result of the redundancy gain that occurs when the stimulus is presented simultaneously in two modalities. (Wickens, 1992)

Provide Memory Aids

Recalling what a stimulus looks or sounds like, and the appropriate response to each stimulus demands constant cognitive processing. Providing operators with a memory aid to help them recall what the stimuli looks or sounds like, and the appropriate responses, may help reduce the mental load on operators by reducing the cognitive resources required to perform the monitoring task. In turn, this may reduce the fatigue felt by operators, and make it easier for them to remain vigilant.

3.2.1.4 Driver Performance Issues

Beyond the research and theory relating to general human performance capabilities, there is a body of knowledge that deals with driver performance issues in the context of existing highways. There is considerable variation in the driving skills within the general population, and likewise, there will be considerable variation in the ability of users to adjust to the AHS. This variation may result from differences in age, physical abilities, mental abilities, or experience.

3.2.1.4.1 Age

Aging leads to physiological and psychological changes that affect driving skills. Obviously, everyone ages differently, so it is impossible to set particular age limits at which these changes will occur. This discussion is based on the changes that generally take place during some phase of the aging process, although some of these effects may be experienced by younger drivers as well. Generally, older drivers vary from younger drivers in terms of visual performance, reaction time, and information processing abilities.

Visual Performance

As people age, their eyesight tends to worsen. If not properly corrected, this may lead to an increased risk of accidents, due to an inability to detect oncoming hazards and obstacles. Weak eyesight may limit the ability of the driver to monitor the environment during the automated portion of the AHS trip. Many people require two sets of corrective glasses: one to improve long-distance viewing and one to improve reading at close distances. This may cause difficulties in operating the AHS system if drivers are required to monitor visual displays in the vehicle (near-distances) and signs on the roadway (far-distances).

Many studies have been conducted to identify the differences, in terms of visual performance, between younger and older drivers. Some of the key findings are presented below:

- Staplin, Lococo and Sim (1990) found that the contrast requirements for pavement markings are significantly greater for older drivers than for younger drivers.

- Evans and Ginsburg (1985) found that younger drivers are capable of discriminating road signs at greater distances than older drivers, despite equivalent corrected visual acuity. This study also found that older drivers had significantly lower contrast sensitivity than younger drivers.

- Poynter (1988) explored the brightness contrast necessary for letter recognition in normal, daytime lighting conditions. He determined that older subjects required an average of 2.13 times the contrast required by younger subjects, and were not able to discriminate color differences as well.

- Olson, *et al*. (1990) measured the comfort of the glare from an oncoming car's headlights on both a younger and older group of drivers. They found that although there were no significant differences in the willingness to look at the source of the glare, the older drivers tended to rate certain glare levels as more uncomfortable than the younger drivers.

- Sivak, *et al.* (1987) found that older drivers had longer glance times, longer eye transition times, and longer task completion times on various instrument panel tasks. This study also found that older drivers require higher luminance levels and perform poorly when required to read small character sizes. However, when luminance and size are sufficient for older drivers, the discrepancies between the age groups on the task performance were eliminated.

- Ball, *et al*. (1994) studied various measures of visual and mental functioning to predict the accident rate of older drivers. The study found that useful field of view (UFOV), the eccentricity at which a subject could localize a peripheral target correctly 50 percent of the time, was found to be a significant component of the predictive model developed. Reductions in UFOV corresponded to increases in the frequency of accidents. UFOV tends to decrease as age increases, however, this varies widely among individuals.

Reaction Time

Reaction time tends to increase (worsen) as age increases. As this occurs, responses become more variable and rely more on feedback control processes than on programmed responses to given situations. (Stelmach and Nahom, 1992) Increases in reaction time may be due to the inability to perceive stimuli, or to limitations in physical response capability.

Various studies have been conducted on the reaction time of older drivers. Olson and Sivak (1986) have found that 95 percent of drivers in both the young and old age groups were able to respond within the current standard for perception-response time currently used in determining stopping sight distances. However, a study by Staplin, *et al.* (1990) has found that response latencies for sequential control movements increase as the number of movements increase. Thus, although all age groups may be able to perform a predetermined single control movement, older drivers show a significant decrement in the performance of 2 or 3 sequential movements. These results indicate that older drivers may be at a disadvantage when a sequence of control movements is required.

Information Processing

Information processing abilities may also decline as drivers age. Stelmach and Nahom (1992) have identified four changes in the cognitive motor processes that result in a decrease of reaction time with age. Changes in response preparation and response selection may occur, as well as differences in the effects of task complexity and changes in the speed/accuracy tradeoff. Each of these changes will be discussed below.

Response Preparation. As people age, they require longer preparatory times to react to a stimulus. It takes an increasingly longer time to process the information from the stimulus, and to formulate the correct response. As stimuli become more complex, or if the response is more difficult to predict, reaction time for older drivers increases significantly over younger drivers. Studies have shown that older adults may be particularly impaired when preparation for a response is not possible. (Stelmach and Nahom, 1992) Goggin, Stelmach and Amrhein (1989) have determined that preparatory intervals and lengths of precue (time viewing the cue prior to required action) viewing times are the crucial determinants of age-related differences in movement preparation and planning. (Stelmach and Nahom, 1992)

In addition, experimental data have shown that as age increases, both concentration and vigilance become more difficult to maintain, speed and distance judgments become increasingly difficult, and judgments regarding when it is safe to enter a highway or pass a vehicle become harder to make. (Holland and Rabbitt, 1994) Thus, it is more difficult for older drivers to perceive informational cues from the environment, and to use these cues to recognize familiar driving scenarios.

Response Selection. Fozard (1981) has postulated that older drivers may need more time to identify a stimulus, and/or to distinguish between or among signals and select the appropriate response. (Stelmach and Nahom, 1992) Since driving involves the continuous detection and discrimination of stimuli, older drivers may be less likely than younger drivers to correctly detect critical stimuli and to choose appropriate responses before an accident occurs. As the uncertainty of a response increases (i.e., the driver is less sure of the correct response to a particular stimulus), older drivers are increasingly slower than younger drivers.

Task Complexity. Research in this area has shown that as task complexity increases, older adults have corresponding longer reaction times. Studies have indicated that younger adults are better able to deal with complex tasks, since they can process information faster than older adults, and are more likely to make corrections in their response after it is initiated. (Stelmach and Nahom, 1992) Hancock, Wolf, and Thom (1990) have shown that a complex driving maneuver requires more information processing capacity than a simple maneuver. Thus, in a complex situation, an older driver will be disadvantaged by the inability to process information quickly enough to develop the appropriate complex response.

Speed/Accuracy Trade-off. The speed/accuracy trade-off refers to the decision of whether to move and respond quickly, compromising accuracy; or to move and respond slowly with higher accuracy. The strategy selected is often based on the consequences of errors, or the reward for error-free performance. The research has indicated apparent differences in response strategies between older and younger drivers. Older drivers tend to be more conservative, sacrificing speed for accuracy. Younger drivers, on the other hand, tend to move faster, risking more errors. (Stelmach and Nahom, 1992)

3.2.1.4.2 Physical Abilities

People differ significantly in their physical ability (e.g., strength, speed of movement). Generally, driving does not require any extreme physical exertion, but it may do so in an emergency. A driver may be required to slam on the brakes, or to turn the steering wheel hard to avoid an accident. Variability in physical ability may be attributed to differences in sex, age, physical conditioning, or to the presence of physical disabilities. For example, it has been shown that the muscular strength of men is greater than of women, and that men are significantly quicker at carrying out functions which primarily depend upon speed of movement and strength. (Lings, 1991)

3.2.1.4.3 Cognitive Abilities

People vary significantly in their cognitive ability to drive. As discussed above, driving is a task which requires extensive information processing skills. Drivers are required to continuously sense information (stimuli) from their own and other vehicles, the road, and other moving and stationary objects in the environment. The driver must decide which stimuli are important, determine what the significance of these stimuli are to the current situation, and decide on the appropriate course of action. As discussed above, age is one factor that may affect information processing ability. However, even among drivers of similar age, there are wide variations in cognitive abilities.

Driving requires the continuous processing of information over time. When the amount of information that needs to be processed exceeds the capacity of the driver, a situation occurs which may lead to an accident. (Fergensen, 1971) In these situations, the driver becomes unable to process stimuli, decide on a course of action, and/or carry out the response in time to avoid a dangerous situation. Fergensen (1971) hypothesized that those individuals with a lower capacity to process information will more frequently be overloaded, and are more likely to be involved in an accident.

3.2.1.4.4 Experience

There are many differences between the driving ability of drivers with no experience (novice drivers), and those with years of experience (experienced drivers). Novice drivers are more likely to be in an accident than experienced drivers, even though most novice drivers are younger than experienced drivers. (Triggs, 1994) Thus, experience seems to be a mitigating factor to the degradation of driving skills that typically occur with age.

As drivers become experienced, they develop general situation awareness skills, as well as the ability to recognize specific hazards. (Triggs, 1994) Practice allows a driver to experience first hand many scenarios, and to commit the appropriate responses to memory. Drivers can learn how to detect important stimuli from the environment, which improves information processing while driving. Novice drivers are also able to enhance their knowledge of environmental stimuli and the appropriate response for each stimuli.

Experience also helps to combat the performance degradation that occurs with increasing age, as discussed above. (Holland and Rabbitt, 1994) Older drivers, who have many years of experience, may be able to compensate for their age with their expanded knowledge base of driving skills. For example, experienced older drivers do not appear to have difficulties with vehicle control skills, for example, smooth braking, or gear changes. (Holland and Rabbitt, 1994)

3.2.1.5 Accident Causal Factors

Many of the preceding discussions raise concerns about the ability of drivers to safely assume control of the vehicle after long periods of AHS operation, in which the level of tasking has been very low. To answer this question, we reviewed New York State Thruway accident data for the Williamsville toll booths. These barrier tolls, located just outside the Buffalo area, are encountered at the end of a long stretch of rural interstate (when approached from the east, traveling westbound). When approaching these tolls, drivers have (in many cases) experienced long periods of driving in which they were required to make only small lateral corrections and occasional speed adjustments (e.g., when cruise control developed small overtaking velocities with the vehicle ahead). Because these tolls are encountered just before drivers encounter a perimeter interstate for a major metropolitan area, the rural conditions of the interstate quickly turn into highly congested stop-and-go traffic conditions. As these toll booths are approached, the driver must take over all longitudinal control, manage large speed adjustments, and integrate many additional parameters (e.g., more lanes, many toll booths to select from, backed-up traffic in stop-and-go conditions, large changes in ambient lighting, etc.).

This situation is very similar to the situation encountered on an AHS when drivers approach their desired exit and must assume vehicle control responsibility. For this reason, we studied the accident data from the Williamsville toll booths in an attempt to learn where people have had problems in making this transition. Data from this analysis are summarized in table 2-7. A complete presentation of the data is available in Appendix A.

Preliminary review of data from the Williamsville toll barrier has suggested that there may be an increased number of accidents following travel in a low traffic density rural area. This could indicate that drivers are not as vigilant following travel in a low event area. They have had little reason to pay close attention, and are not prepared to do so when reaching the toll barrier. However, the data are not extensive enough to allow us to draw powerful conclusions, since factors other than vigilance may be involved. Further study may be necessary to separate the relevant factors.

It is recommended that accident data for a large number of toll booth areas be examined to see whether this pattern holds throughout a roadway system. It is also important to consider that many other factors may affect the potential for vigilance related accidents, including time of day, weather conditions, type of accident (rear-end, single vehicle, etc.), infrastructure design, type of traveler (commuter or long-distance), and cause of accident (inattention, improper lane change, excessive speed, etc.).

The Team encourages extreme caution in drawing even preliminary conclusions from the limited data. More complete data or controlled studies are needed to support definite conclusions.

Table 2-7. Williamsville Toll Barrier Accident Data (1990-1992)

	Eastbound		**Westbound**	
	Frequency	**Percent**	**Frequency**	**Percent**
Total Number of Accidents	27	36	48	64
Location: Within 50 feet of the Toll Island	14	18.7	19	25.3
Location: More than 50 feet from Toll Island	13	17.3	27	36
Cause: Driver Inattentiveness*	17	22.7	36	48
Cause: Other Causes	10	13.3	12	16

* The accident causes that were attributed to driver inattentiveness include: driver inattention, driver fell asleep, following too closely, turning improperly, unsafe speed, passing or lane usage improper, and unsafe lane change.

3.2.1.6 Traditional Approaches to Human Performance Testing

Traditionally, researchers have used extensive test batteries to measure human performance and capabilities. These tests generally are based on evaluating manual and cognitive skills that are either directly or indirectly related to the specific task of interest. Unfortunately, measuring human performance is not an exact science.

3.2.1.6.1 Underlying Problems of Human Performance Measurement

The *Guide to Human Performance Measurements,* published by the American Institute of Aeronautics and Astronautics (AIAA) (1993), has identified the underlying problems of using traditional measurement techniques in human performance testing:

- In many situations, it may not be possible to relate, through a general theory, the behavior of an individual to his/her performance on a particular test. Similarly, it may not be possible to identify a general theory that relates test performance (e.g., reaction time test) to total task performance (e.g., driving).

Many testing situations require the researcher to draw hypotheses concerning these relationships.

- There is an inverse relationship between the need to control for extraneous variables and the resultant lack of generalizability of an experimental measurement setting. If tests are used that are intended to isolate the effects of certain variables on performance, it is very difficult to do so in a completely realistic situation. Thus, one must trade-off the realism of a testing environment with the need to control for certain variables.

- There are a large number of factors that affect human performance. Some of these factors play a significant role, others are less important. However, the importance of such factors may change over time, and with different scenarios. Therefore, it is difficult to obtain a true picture of human performance without using a large number of tests, in an attempt to identify all factors that may be affecting performance.

- For complex tasks, and tasks that require performance that is not directly observable, it is difficult to develop objective measures that capture human performance. Thus, it may be necessary to use subjective measures that offer more insight on human performance. Subjective data is often less accurate and reliable than objective data.

- Results obtained from a traditional experimental test of human performance may not be generalizable to the real world. Thus, although the data indicate a certain performance level in an experimental setting, similar results may not be obtainable in a real world setting. The results on the performance tests may have occurred only because of the experimental setting.

- Performance on cognitive tasks is inherently more difficult to measure than performance on physical tasks. Cognitive activity cannot be observed directly; it requires analysis of the output consequences of the cognition, as well as other subjective measures (i.e., self-reported measures).

- For most tasks, there is currently a lack of objective performance criteria. The lack of criteria makes it difficult to assess performance quality and sufficiency, and to identify the type of performance measurement techniques required to operationally define significant differences in performance.

3.2.1.6.2 Selection Criteria for Human Performance Measures

The selection of a test to measure human performance must consider the selection criteria outlined in table 2-8, as described in the *Guide to Human Performance Measurements* (1993).

3.2.1.6.3 Examples of Traditional Human Performance Tests

There are many well established tests that have been developed to measure human performance. Many of these tests are general, and can be used to evaluate performance on a wide range of real-world tasks. Each test is designed to evaluate performance on general skills that are important components of real-world tasks. A few commonly used tests are discussed below. Information about the wide range of additional tests that are available can be found in *The Guide to Human Performance Measurements,* published by the American Institute of Aeronautics and Astronautics (1993), or the *Unified Tri-Service Cognitive Performance Assessment Battery (UTC-PAB), Design and Specification of the Battery,* published by the Naval Medical Research and Development Command (Englund, et al., 1987).

Choice Reaction Time Task

In a choice reaction time task, a subject is required to memorize an appropriate response to each possible stimulus before the test begins. During the test, a stimulus is presented randomly to the subject, and the subject is required to make the appropriate response. Alternatively, a stimulus may be presented in one of four quadrants on a display, and the appropriate response is to press a particular key that corresponds to the quadrant in which the stimulus was displayed. The reaction time, the time from the presentation of the stimulus until the response is initiated, is recorded.

To perform satisfactorily on this test, the subject must be able to quickly detect and discriminate the stimulus when it is presented, and must decide on the appropriate response based on the recognition and comprehension of the stimulus. Thus, choice reaction time is a good representation of information processing skills. Choice reaction time tests have been shown to be particularly sensitive to fatigue and sleep deprivation. (Englund, *et al*., 1987)

Table 2-8. Human Performance Measurement Test Criteria

Criteria	Description
Appropriate Level of Detail	The test should measure the performance with sufficient detail to allow useful and meaningful conclusions to be drawn.
Reliability	The repeatability of a test. If the same behavior is measured in exactly the same way, a reliable test should provide the exact same result. However, to account for individual differences and variations, a test is defined as reliable if it produces the same distribution of responses upon repeated testing.
Validity	• Face Validity - How well does a test represent the performance that it is intended to measure? • Concurrent Validity - How well does a test correlate with other tests designed to measure the same performance? • Content Validity - How well does a test (or battery of tests) measure all aspects of task performance? • Construct Validity - How well does a test correlate with a construct, theory, or model? • Predictive Validity - How well does a test represent future performance, or how well does an experimental test predict performance in a real-world situation?
Sensitivity	A test must be sensitive to the performance that it is intended to measure. It must be able to detect differences in performance.
Diagnosticity	The characteristic of a test which provides the information that will tend to isolate the cause of good or bad performance. A diagnostic test allows the causes behind performance to be identified.
Non-intrusiveness	A test requiring the use of a measurement technique, or equipment, that attracts the attention of the subject may affect the subject's task performance. Such a test is considered intrusive.
Implementation Requirements	The test must be designed with consideration to the time, budget, personnel (training and operation), supplies, equipment, logistics, etc. required for implementation.
Operator Acceptance	Users must accept that a test covers the important aspects of the task, and that it is actually measuring what it is intended to measure.
Fairness	The data collected by the test should describe a fair representation of performance.
Accuracy	"The accuracy of a test refers to the precision, reliability and minimization of measurement error." (Edwards and Verdini, 1986)
Simplicity	It is more desirable to use a simple test, rather than a complex test, wherever possible.
Timeliness	It is important that performance data be provided, and evaluated at the proper time.
Objectivity	A test must give an objective view of performance, without bias.
Quantitativeness/Qualitativeness	It should be the goal of all human performance measurements to record quantitative measures. (AIAA, 1993) Quantitative measures are concerned with how much there is (the quantity) of whatever is being measured.
Cost	The financial costs of test implementation and use must be considered.
Flexibility	Tests and testing equipment should be designed in a manner that will enhance the ability to make changes in the tests as situations demand.

Tracking Task

In a tracking task, a subject uses a manual control device (e.g., a mouse, trackball, or lightpen) to follow, or track, a visual stimulus as it moves across a display. (AIAA, 1993) Tracking tasks require the subject to minimize the error between the desired (position of the stimulus) and the actual position (position of the control device cursor). Tracking tasks are a sensitive measure of workload, and are generally used when a continuous measure of workload is required.

To perform at a satisfactory level on this test, the subject must be able to quickly process information about the position of the stimulus, and must quickly execute the correct response of moving the control device appropriately.

Alpha-Numeric Visual Vigilance Task

In the alpha-numeric visual vigilance task, randomly selected stimulus (alphabetic characters or numbers) are presented on a visual display at random intervals. Each stimulus remains on the screen for 10 ms. When particular stimuli are presented, subjects are required to press a switch with their thumb. Generally, this test is performed for at least a 30-minute period. During this test various measures are collected, including reaction time (time between the presentation of the stimulus and the initiation of the response), and the number of omissions (failure to respond to a stimulus).

To perform satisfactorily on this test, the subject must be vigilant, and must remain vigilant throughout the entire test. A subject is considered to be vigilant if he/she has few stimulus omissions, and is able to maintain a relatively fast reaction time throughout the test.

Pattern Comparison Task

In the pattern comparison task, two stimuli are presented to the subject simultaneously. The stimulus on the left is designated the target pattern, and the stimulus on the left is designated the test pattern. Alternatively, the target stimulus may be presented before the test stimulus. The subject is required to identify whether or not the two stimuli are identical. This test is designed to test for perceptual speed, pattern recognition ability, and short-term spatial memory (in the case where the stimuli are presented successively). (Englund, *et al*., 1987)

Visual Search Task

In the visual search task, subjects are asked to scan an area of distracter stimulus in search of one or more target stimuli. (Englund, *et al*., 1987) The subject is required to identify when the target stimulus is found, and to indicate where the target stimulus is located on the display. During this test, the search time (time to detection of the target stimuli) and the accuracy of the target search are recorded. Thus, this test is designed to measure the ability of the subject to detect and recognize a target stimulus among a large number of extraneous stimuli. To perform satisfactorily on this test, the subject must remain vigilant to the task, and must continuously monitor the display for the appearance of the target stimulus.

Additionally, the subject may be required to search the display for more than one target stimulus. Upon successful completion of a search, the subject may be required to make a decision about the appropriate response for each particular target stimulus. Adding this component to the task further tests the subject's ability to process information and make appropriate decisions.

3.2.2 Implications of Driver Readiness Issues for the Design of Check-Out

3.2.2.1 Avoiding Sources of Human Error

The AHS check-out process must be designed to minimize the risks of human error, as discussed in section 3.2.1.1, “Sources of Human Error Within Automated Systems.” Experience has shown that it is not feasible (or even beneficial) to eliminate all human intervention in an automated system. Thus, the check-out process must be designed to minimize the opportunities for human error. For example, the check-out process should be designed with consideration of the six major categories of human error that can occur as a result of human interaction with automation. Some of these design considerations are discussed below in table 2-9.

It is also important to consider the guidelines for the design of user interfaces to automated systems in the design of the check-out process. These guidelines can help in designing a system which effectively uses all available resources from both the automation and human intervention. Some of these guidelines are reiterated below, in table 2-10, along with a corresponding AHS design approach.

3.2.2.2 Consideration of Human Processing Capabilities for AHS Check-Out

Information processing issues, such as those discussed in section 3.2.1.2 “Information Processing Issues,” are critical to the success of the driver in safely retaking manual control of his/her vehicle. As discussed above, there are inherent limitations that affect the ability of a driver to process information. In addition, it may require more time for the driver to process information after a period of inactivity. Thus, it is important to consider how AHS may be designed to mitigate the degradation in information processing skills (table 2-11).

3.2.2.3 Consideration of Vigilance Issues for AHS Check-Out

Vigilance issues, such as those discussed in section 3.2.1.3 “Vigilance Issues,” will pertain to AHS operation in which the driver will be required to act as a system monitor. The maintenance of vigilance is especially important for situations in which an emergency check-out is required. In these situations, the driver will be require to detect and respond to stimuli very quickly, with little time to prepare. If the driver is allowed to experience a degradation in vigilance performance after check-in, it is very likely that he/she will be unable to perform an emergency check-out if necessary.

Table 2-9. AHS Design Considerations to Minimize Human Error

Type of Human Error	AHS Design Consideration
The driver reacts incorrectly to a failure in automation.	Drivers must be instructed and trained in the correct responses to particular warnings and stimuli. Training should be repeated periodically, to ensure that drivers remember what they have learned. In addition, memory aids should be provided to all AHS users to help them recall the correct emergency procedures.
The driver incorrectly sets up the automation.	This is not directly applicable to AHS, since the drivers will have no role in setting up the automation. However, the driver will affect the disconnection of the automation (through the check-out process). Thus, the check-out process must ensure that a vehicle can only exit AHS if the driver is able to safely drive his/her vehicle.
A false alarm in automation prompts the driver to take corrective action when in fact nothing is wrong.	The driver must have an understanding about how the system operates, and what each stimulus represents. Drivers should be able to verify information through redundant channels (e.g., through multiple displays of related information).
The driver fails to react to an alarm, warning, or stimulus from the system.	The AHS system should prevent drivers from being too far out of the loop. If the driver fails to respond to system messages, the system may automatically park the vehicle in the breakdown lane.
The driver fails to monitor the automation, and is unaware of problems that arise.	The system must provide information to the drivers about the status of system operation. Information must be salient, and able to capture the attention of the system users. Drivers must be trained in the importance of system monitoring, and the consequences of failing to do so effectively.
The automation may cause the driver to lose skill proficiency.	Drivers will be required to drive manually to reach the check-in for the AHS. Drivers must pass the check-out test each time they exit the AHS. This will allow drivers to routinely practice the skills needed in a normal check-out. Drivers should have an opportunity (either required by the system or voluntarily) to practice emergency skills while on the AHS.

Table 2-10. Sample Automation Guidelines and Example AHS Implementations

Guideline	Example AHS Design Approach
If automation reduces task demands to low levels, provide meaningful duties to maintain operator involvement and resistance to distraction.	• Remind drivers about approaching exits and request desires for continuing or exiting. • Provide information about the system and trip status for driver review. • Provide access to on-line AHS training material.
If alarms have more than one mode, or more than one condition that can cause the alarm, clearly indicate the mode or condition.	• Clearly indicate nature of AHS failure condition (especially if driver must respond).
When response time is not critical, provide information to allow the validity of alarms to be established quickly and accurately.	• Present AHS status information in addition to alarm condition.
Provide training for operators working with automated equipment not only to ensure proper set-up and use, but to impart knowledge of operational concepts, malfunction procedures, and monitoring requirements.	• Make AHS operation extremely simple and/or provide training.
System operation should be easily interpretable or understandable by the operator to facilitate the detection of improper operation and to facilitate the diagnosis of malfunctions.	• Train system users (drivers) to understand how the AHS system works. • Design AHS displays to provide all of the necessary information required for malfunction diagnosis.
Devise training techniques and possible training hardware to ensure that operators are exposed to all forms of alarms and to the many possible combinations of alarms. Ensure that the operators understand how to deal with each alarm possibility.	• Train all system users to understand all of the emergency conditions that may occur, and the appropriate response to each condition. Provide frequent retraining to users, to ensure that skill degradation does not occur.

Table 2-11. AHS Design Considerations for Limitations in Information Processing

Information Processing Limitation	AHS Design Consideration
Limitations in Attention	• AHS must help the driver to focus his/her attention. • During a normal check-out, the driver must prove to the system that he/she is focused on the pertinent environmental stimuli. • Prior to an emergency check-out, the system must provide all necessary information to the driver, in a way which focuses attention on the critical displays.
Limitations in Perception	• Information must be presented to the driver in such a way as to facilitate recognition and comprehension of necessary stimuli.
Limitations in Decision Making and Response Selection	• For emergency situations, drivers should be trained to handle a variety of possible situations. They should be aware of what various conditions may occur, and the appropriate response for each condition. • Drivers should also be trained in the normal check-out process, so that they are aware of the correct decisions and response that must be made to exit the system.
Limitations in Response Execution	• Drivers must be given enough time to react to a stimulus and carry out the appropriate response. Drivers should not be required to perform a physical response requiring extreme physical exertion.

3.2.2.3 Consideration of Vigilance Issues for AHS Check-Out

Vigilance issues, such as those discussed in section 3.2.1.3 “Vigilance Issues,” will pertain to AHS operation in which the driver will be required to act as a system monitor. The maintenance of vigilance is especially important for situations in which an emergency check-out is required. In these situations, the driver will be require to detect and respond to stimuli very quickly, with little time to prepare. If the driver is allowed to experience a degradation in vigilance performance after check-in, it is very likely that he/she will be unable to perform an emergency check-out if necessary.

In addition, at the end of an AHS trip, the driver must pass the normal check-out process. Thus, at this point, the driver must be able to safely retake manual control of the vehicle. Vigilance is an important component of safe driving ability.

3.2.2.3.1 AHS Check-Out Design Considerations for Variables that Affect Performance on a Vigilance Task

Tables 2-4, 2-5, and 2-6, in section 3.2.1.3, described many of the variables that affect performance on a vigilance task. In this section, Tables 2-12, 2-13, and 2-14 describe AHS design considerations that can be made to combat the vigilance decrement, and to ensure that drivers remain vigilant throughout the AHS trip.

Table 2-12. AHS Design Considerations for Vigilance Task Variables

Variable	Description/Effect	AHS Check-Out Design Consideration
Duration	The performance decrement begins after five minutes of a task, and continues to decline within the first thirty minutes of a task.	Vigilance decrement counter measures should be started after five minutes on the AHS.
Knowledge of Task Duration	Operators who are expecting a task of long duration tend to exhibit rapid deterioration of performance almost immediately. Operators who are expecting a task of short duration tend to exhibit less rapid performance degradation. Operators who anticipate the imminent end of the task tend to exhibit an “end-effect”, during which performance on the task improves.	• Rural AHS implementations should consider intensifying vigilance decrement countermeasures. • Urban AHS implementation can relax vigilance decrement countermeasures.
Rest Pause	Rest pauses seem to permit some recovery of performance, and may prevent the vigilance decrement.	After long periods of inactivity, invite drivers to listen to music, open the windows, and/or remind drivers of rest stops. If vigilance measures indicate poor performance, the system should recommend or encourage stopping.

Table 2-12. AHS Design Considerations for Vigilance Task Variables (continued)

Variable	Description/Effect	AHS Check-Out Design Consideration
Multiple Monitors	Performance on vigilance tasks tends to improve when there is more than one system monitor (e.g., team inspection).	Display warnings so that passengers, as well as drivers, can see or hear them.
Time Sharing	Performance on a vigilance task may be improved or degraded by timesharing. The effect depends on the mental requirements of the two tasks. For example, when performing two similar tasks simultaneously, performance on both tasks will suffer. Also, alternating between two tasks can have a beneficial effect on performance when one of the tasks is near the extreme in terms of stimulus level and the other is near the mean. Two high stimulus vigilance tasks will tend to have a detrimental effect on overall performance.	After long periods of inactivity, invite drivers to examine vehicle parameters (e.g., gas mileage, or engine temperature), or to review travel specifications (e.g., gas mileage since start, miles traveled since engine start, or since entry to AHS). These "services" could actually improve AHS vigilance performance.
Bi-Modal Tasks	The use of a bi-modal stimulus may produce better overall performance on a vigilance task than a task that presents the signal to only one sensory modality.	Display warnings to appeal to more than one sensory modality.
Incentives	A combination of rewards and punishments can be effective in maintaining vigilance performance at a high level. Substantial incentives may be sufficient to encourage performance improvements on a vigilance task and to prevent the vigilance decrement.	It may be necessary to inform AHS users about the importance of maintain vigilance during the automated portion of the trip. The consequences of the loss of attention should be emphasized.
Knowledge of Results	Operators who receive feedback on their performance tend to exhibit less performance degradation than operators who do not receive feedback on performance.	Provide feedback to drivers during both normal and emergency check-out. This will allow drivers to monitor their own performance on the AHS, and their performance during the check-out process.
Practice	Increased task experience helps the operator to better discriminate signals from noise, while requiring less attention (vigilance) to do so. However, even experienced operators may have a vigilance decrement.	Allow drivers to review (even practice) check-out procedures during AHS operation. This will provide a secondary task to prevent the vigilance decrement, and will allow practice of important skills.
Stimulus	Characteristics of the stimulus (target) may affect performance on vigilance tasks.	---

Table 2-12. AHS Design Considerations for Vigilance Task Variables (continued)

Variable	Description/Effect	AHS Check-Out Design Consideration
Stimulus Density	An increased number of stimuli enhances performance on vigilance tasks. The need to perform a visual search in order to detect a stimulus increases the vigilance decrement. However, improvements in detection associated with a more conspicuous signal are twice as great with a high stimulus density as with a low stimulus density.	• Remind drivers of upcoming exits and require responses from the drivers. • Increase stimulus density of AHS monitoring tasks through the use of techniques that measure signal rate (e.g., remind drivers of exits, ask drivers to review trip and vehicle parameters, etc.). • Use standard locations and signals for warnings.
Stimulus Regularity	Temporal uncertainty concerning the appearance of a stimulus has been found to lower performance on a vigilance task.	The above requirement of responding to exit announcements will be regular and will enhance performance on the vigilance task.
Stimulus Intensity	More intense stimuli are more readily detected and have been associated with lower reaction times.	Make important warnings very salient and, if needed (e.g., for emergency check-out), attention-getting.
Stimulus Duration	The longer the stimulus persists in time, the easier it is to discriminate and detect.	Maintain critical warnings until response is obtained from the driver.

Table 2-13. AHS Design Considerations for Vigilance Subject Variables

Variable	Description/Effect	AHS Check-Out Design Consideration
Intelligence	No correlation has been found between intelligence and performance on vigilance tasks.	---
Age	As age increases, performance on vigilance tasks tend to decrease, due to increased reaction time (generally due to a decreased ability to physically react to a stimulus), and decreased capacity for information processing (ability to detect, recognize and decide how to handle a stimulus).	Designers may want to consider implementing more than one check-out process to accommodate variations in age, and corresponding skill level.
Sex	No correlation has been found between the sex of the operator and performance on vigilance tasks.	---
Personality	Introverts generally have better performance on vigilance tasks than extroverts. This is attributable to the introverts' capability to maintain arousal without external stimulation.	Allow drivers to select the frequency of vigilance countermeasures. This will allow drivers who are more likely to experience a serious vigilance decrement to have more frequent vigilance countermeasures.
Fatigue/Sleep Deprivation	Operators who are tired generally perform poorly on vigilance tasks. Physical fatigue exerts comparatively little effect on vigilance performance, while mental fatigue causes considerable deterioration in vigilance performance.	Enhance countermeasures during night and early morning AHS driving, or when physical measures (e.g., eye movements) indicate sleepy conditions.

Table 2-14. AHS Design Considerations for Vigilance Task Variables

Variable	Description/Effect	AHS Check-Out Design Consideration
Temperature	Both extreme hot and cold conditions tend to reduce the performance on a vigilance task. Heat also tends to promote the vigilance decrement.	Consider equipping AHS capable vehicles with temperature control thermostats.
Time of Day	Performance on a vigilance task does not remain uniform throughout the twenty-four hour day. Performance is generally best in the afternoon, and worst late at night. However, individuals have their own predisposition concerning the optimal time of day (i.e., each person has his or her own biological clock, and optimal performance varies greatly across individuals).	The check-out process may need to be varied according to the time of day. Drivers on the AHS at night may be more susceptible to fatigue, and may require more extensive countermeasures to help prevent the vigilance decrement.

3.2.2.4 Accommodating the Range of Driver Capabilities

As discussed in section 2.3.1.4, there are a number of factors that cause a wide variation in the driving skills within the general population. This variation may have some serious implications for the design of the check-out process. The check-out process must be able to accommodate the variation in individual abilities, and must be able to correctly predict the safe driving ability of all drivers.

The most significant determining factor of individual differences is the age of the driver, and the changes that occur naturally as age increases. Other factors, including differences in physical abilities, cognitive abilities, and experience may also cause a wide variation in driver skills. In fact, even within an individual, performance capabilities vary over time. The check-out processes used in AHS must ensure an adequate level of competency without being influenced by individual characteristics.

3.2.2.5 Consideration of Accident Causal Factors

Upon further examination of accident data at toll barriers, it may be possible to make some firm conclusions about the potential for accidents on the existing roadway system. Preliminary examination of accident data at the Williamsville Toll Barrier, in Buffalo, New York, has suggested that there may be an increased number of accidents after travel in a low density rural area. If such results are found throughout the roadway system, it may be useful in determining the types of driving skill degradation that occur after long periods of relative inactivity.

Information regarding driving skill deterioration can be used in two ways. First, it can be used to determine the types of skills that the driver needs to keep from degrading at any time during the trip, and the tests that can be used to keep those skills up to par in the event they are needed in an emergency situation. Second, the information will point to the skills that will need to be tested during a normal check-out process, in order to determine the driver’s ability to retake control of the vehicle.

3.2.2.6 Applying Human Performance Testing Technology within AHS Check-Out

The task of driving may be broken up into a series of general subtasks (e.g., information processing, visual search, motor control, etc.). In fact, research has identified approximately 1500 different perceptual and motor tasks that a driver must master in order to negotiate safely on the highway. (Shinar, 1978) It is possible to develop a battery of traditional performance tests that can measure the driver's performance on these tasks. Each test in the battery would correspond to a particular skill involved in a typical driving task. Although it may be possible to physically implement such a test battery into the AHS check-out process, to do so may be quite impractical.

Many of the traditional check-out tests can be implemented using a simple computer. They require a display screen, and a simple manual control device (keypad, mouse, lightpen, etc.). This type of equipment should be easy to implement in an AHS vehicle. However, most of the tests must be performed for periods of time (at least five minutes) that are impractical for the check-out process. In addition, to evaluate performance on these tests, most require extensive data manipulation, and even statistical analysis. This requirement will add further to the time needed to use any of these tests. Thus, the Team has determined that using the traditional performance tests is not the most practical method to evaluate the driver's ability to drive safely.

Instead of using traditional performance tests, it is recommended that the driver assessment procedure be accomplished within the process of transferring control from AHS to the human driver. The check-out process should be designed to include both the assessment of the driver’s capability to manually drive the vehicle, and the steps to physically transfer control. A general model of a potential check-out process is described in table 2-15.

An important feature of this check-out process is that the driver is required to **take control** of the vehicle from the automated system, rather than the system giving control back to the driver. The distinction is that by forcing the driver to take control, this provides an indication to the system that the driver really desires control of the vehicle, and that the driver is prepared to assume manual control of the vehicle. Alternatively, if the system were to give control back to the driver, an additional test must be conducted to ensure that the driver really has control of the vehicle.

3.2.3 AHS Check-Out Design Aspects

There are many AHS design issues that will impact the design of check-out procedures, as discussed in the following subsections.

Table 2-15. A Generic Model of the Check-Out Process

Driving Subtask	Example Driver Assessment Approach
Detect and discriminate roadway stimuli	• The process of assuming vehicle control must ensure that the driver is attending to the roadway ahead. The signal that the vehicle is ready to relinquish control can be in the forward field of view. • The timing of vehicle ready signals should be determined on the basis of the time needed for worst-case drivers to gain a sufficient sense of the dynamic roadway cues for an adequate level of situation awareness and pursuit-tracking performance (i.e., lane keeping).
Recognize and comprehend driving situation	• The response to the vehicle ready signal can be simple yet one that requires recognition and comprehension. For example, hit a button on the steering wheel that relates to correct vehicle speed or a road sign ahead (could be a variable message sign showing a random number). • Special roadway condition information can be provided verbally during process (verbally so as not to compete with ongoing visual processes).
Demonstrate adequate decision and response capability	• Correct response to vehicle ready signal above provides some evidence of adequate decision and response functioning.
Demonstrate correct response execution	• Driver must have hands on the wheel and feet on the pedal(s) (or the appropriate pedal). Driver may be required to initiate an appropriate steering wheel input (as determined by AHS sensors or just turn the wheel back and forth once) and tap the brake (as currently done for disengaging cruise control).

3.2.3.1 Implication of Driver Role

In this analysis, we have assumed, as described in section 2.3, that drivers will be required to remain awake and perform a monitoring role during AHS operation. This requirement stems from the need for driver intervention in case of a system malfunction, especially during the early stages of AHS implementation.

However, the driver's role in AHS operation may actually depend on the RSC configuration, the requirements specified by other PSA tasks (e.g., malfunction management, lateral/longitudinal control, etc.), as well as the reliability of the technology used in the implementation of the system. Therefore, it is not possible to identify the necessary driver role at this stage of the design process, although it must be considered during a future design phase.

It is useful to consider the effect that the driver role during AHS operation has on the check-out process. As AHS evolves, it is expected that the driver will be required to take a less active role in system operation. In I2 and I3 RSC configurations especially, there will be fewer requirements for driver intervention as the reliability of the system is improved. The system may become better able to detect and handle emergency situations, and the driver may eventually be able to sleep until reaching his/her desired exit. Thus, the need for an emergency check-out process will be eliminated.

Prior to reaching the driver's desired exit, which may need to be indicated at AHS check-in, the system must begin a process of ensuring that the driver is awake. This must occur before the normal check-out process can begin. In addition, the normal check-out process may need to perform more extensive testing than the previously described check-out process, which was based on the driver's maintaining a monitoring role throughout AHS operation. Our analysis has assumed that a normal check-out process will occur after a period in which the driver was alert and vigilant. The driver is expected to remain aware of the current state of the system and his/her individual vehicle.

If the driver role is lessened in the future, more extensive testing may be necessary to ensure that the driver is capable of retaking manual control of the vehicle after a period of total inactivity. The check-out test may need to include additional components to ensure that the driver has regained an understanding of the current state of the vehicle, and of the system.

3.2.3.2 Frequency of Tests and Nature of Tests

It must be determined whether it is necessary to test the driver throughout the AHS trip to ensure that the driver maintains a vigilant state, or whether it is acceptable to wait until manual driving is required before testing for the driver's readiness to regain manual control. This is an especially important issue for emergency check-out, since drivers must be prepared at any time to retake control of the vehicle. As noted earlier, this analysis has assumed that there will be a driver role for system monitoring and malfunction management for the early stages of AHS implementation.

If only a normal check-out process were necessary, it would be possible to test for driver readiness only at the end of an AHS trip. At this point, the system must first bring the driver back "into the loop", and should ensure that the driver is able to drive safely on the manual highway. During the trip on the AHS, it will be unnecessary for the driver to maintain vigilance and no performance tests will be required. Performance tests will not have to begin until immediately before the driver's specified exit.

As discussed earlier, vigilance will tend to degrade after only five minutes after entering AHS. Performance degradation will continue throughout the task, although the rate of degradation will eventually slow after about 30 minutes. Therefore, it may be necessary to vary the normal check-out process to accommodate the driver's duration on AHS. Drivers who have been on the system for long periods of time may require more extensive testing than those drivers who have spent only a short duration on AHS.

However, it is envisioned that the driver will, especially during the early stages of AHS, be required to respond to emergency situations during the automated trip. Thus, it will be necessary to ensure that the driver is maintaining a vigilant state throughout the AHS trip. In this case, the driver must undergo performance testing throughout the entire AHS trip. These intermediate tests may not be the same as the check-out test given at the end of the AHS trip, and in fact, may even be less extensive. These tests are simply intended to ensure that the driver is awake and vigilant, in the unlikely event of a system malfunction.

The design of intermediate tests must be done with extreme caution. The tests must not be too intrusive, or drivers may become annoyed with them, and become reluctant to use AHS. However, the tests must be able to involve the driver enough to ensure that performance is sufficient, in case of an emergency situation. The intermediate tests must also be meaningful to the larger task at hand (travel on AHS). Meaningless tests may be considered unimportant by system users, and will therefore not be taken seriously. This attitude may cause the driver to perform poorly on the tests, which may not actually reflect the true state of the driver. It is suggested that the intermediate tests be related to the task at hand (e.g., the

AHS trip). (Price, 1985) This allows drivers to feel as if they are involved, and actively contributing to the AHS trip, rather than wasting their time and energy on meaningless tasks.

One possible suggestion for the design of intermediate tests is to base these tests on the exits and rest areas along the AHS highway. Before each exit, the system may inform the driver about the services, resources, and connecting roadways available at the upcoming exit. The driver will be required to respond to the system concerning his/her intention to leave the system at that exit, or to remain on the system. Additionally, the system may provide periodic messages, alarms, or signals to the driver, to help the driver maintain a vigilant and alert condition. It may be possible to allow the driver to choose how often these periodic signals will occur, and perhaps even the nature of the signal, based upon his/her own preferences, tendencies toward vigilance performance degradation, and length of trip. Possible signal types include navigation (or route selection) advice, review of AHS procedures, auditory alarms, etc.

One design alternative is to allow the driver, on long trips, to suppress frequent system messages and intermediate tests. However, after a given length of time with no communication, the system may initiate a ‘conversation’ with the driver. The ‘conversation’ is intended to ensure that the driver is remaining vigilant and attentive to his/her duty as the system monitor. For example, the AHS may encourage the driver to take a break at the next rest stop, or may give the driver a specific task (somehow related to the AHS trip) to perform.

3.2.3.3 Training Implications

Studies have shown that human operators are more comfortable using automated systems when they are able to develop a mental model of the system. A correct mental model is developed only when the operator can understand how the system is supposed to operate, and what types of malfunctions can occur. Price (1985) suggests that if humans are unable to maintain a mental model of an automated system, they may lack confidence in the system and may try to override it. Alternatively, a human operator may lose complete interest in the automated system, allow the automation to have total control, and find that in an emergency situation they are unable to intervene effectively, or even decide what the problem is. (Price, 1985) For example, Wiener (1977) has identified a class of airline accidents, controlled flight into terrain accidents, “in which an aircraft, in normal flight regime, with no emergencies and no warning to the crew of any impending trouble, impacts the terrain (or water) at some place other than the runway.” Many of these accidents have been attributed to the lack of vigilance by the flight crew, who trusted the automated system entirely, and failed to monitor critical displays and systems that may have alerted them to the problem. (Wiener, 1977)

If drivers are required to perform in an emergency check-out, they must know (and understand) what is required of them. In an emergency check-out, drivers must know AHS "rules of the road" to maximize safety, and the procedures for quickly assuming control of the vehicle. It may be necessary to train all AHS users in the necessary emergency procedures.

Price (1985) emphasizes the need to “ensure that both the driver and the AHS each know what the other is doing. The driver must understand the objectives of the automatic control, and the allocation of responsibility between himself/herself and the automated system.” He also advocates that an automated system must “recognize the need for cognitive support. Make certain that the human (driver) maintains an active, current model of the system in his or her head. Ensure that the human has all of the information needed in an emergency, either through training, established procedures, or the instrument displays in the vehicle. Make certain that the human is not only informed, but is also actively involved and alert." For an emergency check-out process, it is especially important to follow these suggestions.

The drivers on AHS must understand how the system is supposed to function before they are allowed to travel on the AHS. They must understand what role they are to play during normal system operation, as well as during emergency situations. Training must encompass both normal and emergency situations. Possible areas in which training is necessary include:

- Knowledge of various system warnings, and the appropriate response to each.
- The conditions under which the driver should override the automation and retake manual control of the vehicle.
- The conditions under which the driver should simply use the 'panic button' and allow the system to park the vehicle without ever retaking manual control.
- How to use the check-out process, and the importance of intermediate tests.
- The significance of a failed check-out process, and the appropriate actions to take once the check-out is failed.

The specific areas in which training is needed will depend on the eventual design of the check-out process, and the expected driver role in the automated system. In addition, the question of how much training is required must be addressed. Unfortunately, the training of system users is an expensive process. Boehm-Davis, *et al.* (1983) have recognized that the question is partially one of cost effectiveness; is training users for a rare event (e.g., an emergency check-out) worth the time and cost associated with it? In addition, they have identified that the problem is complicated by the fact that even after a complete training program has been implemented, system users may have had their skills deteriorate to a non-useful level by the time they need to be used in an emergency. Boehm-Davis, *et al.* (1983) feel that the necessity of training may hinge on a question of liability (i.e., who is responsible for an accident caused by a failure of an emergency check-out), rather than the issue of cost effectiveness.

3.2.3.4 Criteria for Pass/Fail

The skill levels of drivers using the AHS will vary considerably. This variability needs to be taken into consideration when designing pass/fail criteria for the check-out process. The tests will be given to the driver to ensure that they are ready and able to re-take control of the vehicle. To confirm the readiness of the driver to resume control, a minimum performance level (pass criteria) must be determined. Drivers performing above this level would be judged capable and allowed to re-take control of their vehicle. Performance below the minimum value would constitute a failure in capabilities at that time. To determine the minimum performance level, safety and practicality must be traded-off. The performance level must be low enough to accommodate the wide variation of performance skills among the users of the AHS, but be high enough to ensure the safety of other vehicles on and off the AHS, when the driver assumes control of the vehicle.

Signal Detection Theory (SDT) helps to further explain the setting of the minimum performance level and the tradeoff between safety and practicality. Two factors are involved in the detection of signals, or as in AHS, the determination of whether a driver passes or fails the check-out process. These two factors are sensitivity (d′) and criterion (β). Sensitivity will depend on the performance test that is chosen. AHS should use a test with a large d′ because of its ability to correctly determine whether or not a driver can successfully re-take control of the vehicle. Since sensitivity will be fixed by the chosen test, the major concern is the β used, or the minimum acceptable performance level. The decision made regarding the status of the driver will fall into one of four categories: hit, miss, correct rejection, or false alarm. A hit indicates that a driver was correctly judged as able to re-take control of the vehicle; likewise, a correct rejection occurs when a driver is correctly classified as unable to re-take control. False alarms occur when a driver is falsely judged as unable to re-take control, and a miss is classified as a driver who is judged as capable of assuming control when he or she is not actually able to re-take control safely.

The tradeoff between safety and practicality will determine where β is set. Ideally the number of hits and correct rejections will be 100 percent, while the number of false alarms and misses will be 0 percent, but this is usually not possible to obtain. In the tradeoff between safety and practicality researchers will have to compromise on the β setting. Lowering β will improve safety by decreasing the number of misses, but also inconvenience more people by increasing the number of false alarms Likewise, increasing The β will inconvenience fewer people, but will reduce safety. From the standpoint of liability and safety it may be better to inconvenience some drivers (false alarms) than allow an incapable driver (miss) to jeopardize the safety of others.

During the AHS design process, experiments need to be conducted in order to determine the most sensitive performance tests for driving ability, and the optimal placement of β. The results from these experimental studies will allow the check-out process to maximize safety while minimizing inconvenience to AHS users.

3.2.3.5 Implication of Check-Out Failure

Since it is not expected that all drivers will be able to pass the normal check-out process on the first try, some allowance for retesting must be designed into the AHS check-out. It is necessary that drivers be allowed to retake the check-out process, once or even twice, upon failing the first check-out process. Retesting allows the check-out process to better identify those drivers who are unable to retake control of their vehicles than if only one test is given. It is possible that a driver may simply make an error on the first test, or that the action of taking (and even failing) the first test may awaken the driver enough so that he/she passes on the next try. Allowing drivers to retake the check-out test will help to minimize the number of false alarms (drivers who are found to be unable to retake control when they are capable of doing so), and the inconvenience to those drivers.

If a driver does fail all of the normal check-out tests for his/her desired exit, the AHS system may either keep the vehicle on the AHS to allow for check-out at the next exit, or may automatically park the vehicle at the driver’s desired exit. The first option, keeping the driver on the AHS system, allows the system to use the time between exits to communicate with, and “wake up” the driver. However, if the exits are located a far distance apart, this may be impractical. Forcing drivers to remain on the system may require them to travel long distances out of their way before they can exit the system. The second option, parking the vehicle at the driver’s desired exit, requires the construction of additional infrastructure. For example, either a breakdown lane or parking lot will be necessary to store the vehicles until the driver is able to safely drive himself/herself off the system.

The impact of driver failure has a different significance for the emergency check-out process. In an emergency check-out process, the driver will have less time to prepare, and the test will be performed more quickly. Thus, there will be less time for retesting drivers who fail the test on the first try, although it may be possible for retesting to occur. Thus, it is critical to ensure that drivers are maintaining a minimum level of alertness, using intermediate testing of drivers, so that there will be very few failures on the emergency check-out process. The failure of an intermediate test should be considered serious by the system. If the driver fails to respond to an intermediate test, the system should continue to prompt the driver for a response. If no response is obtained after a set time, the system may need to park the vehicle in the breakdown lane.

3.3 VEHICLE CHECK-OUT ISSUES

This section addresses check-out requirements for verifying the link between device control inputs (e.g., steering wheel inputs) and the vehicle actuators. The following vehicle components model describes these relationships (see figure 2-5).

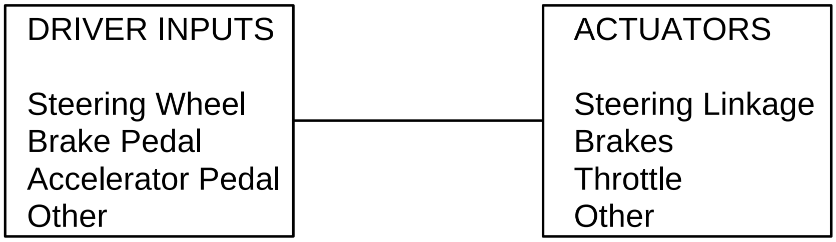

Figure 2-5. Vehicle Components Model

This model is applied to ensure that all mechanical links between controls and actuators are solid and properly functioning, and to ensure that no failures in these critical systems have occurred during the automated portion of the trip. This section identifies components that must be checked, and how these mechanical connections can be checked during the check-out process.

3.3.1 Components to be Checked at Check-Out

Every AHS trip will begin with a manual portion. Thus, by demonstration, the vehicle manual systems were operational at the beginning of the trip. It must be ensured that all of these systems are still functional when the driver retakes control at check-out. The need to perform vehicle check-out tests on all components is minimal since most vehicle systems have operated reliably during the automated portion of the trip, as evidenced by the safe arrival at the check-out station. The only components that must be checked are those that are unique to manual driving, and critical to vehicle control safety. As noted above, this includes not just the components themselves, but also the links between the manual controls and the vehicle actuators. This is critical for safe vehicle control during manual mode. This section presents a list of the components to be checked during the check-out process, as well as the assumptions and rationale that helped to develop that list.

3.3.1.1 Check-In Components

During check-in, the AHS tests the vehicle to ensure that all vehicle and AHS systems are working correctly. Additionally, many of these systems are frequently monitored during the automated portion of the trip. The vehicle and AHS components that are checked during check-in (and throughout the AHS trip) are presented in tables 2-16, and 2-17. Obviously, the check-in list is inclusive, and all of the most critical systems are continuously monitored for a malfunction during the trip. Any malfunction that is detected during check-in will prevent the vehicle from entering the AHS. A malfunction that is detected while on the AHS will result in an immediate response by the system to exit the vehicle from the AHS, or in a critical situation, an immediate parking of the vehicle.

Check-out will not require as extensive a vehicle check as that for check-in, since most of the vehicle systems have been continuously in use and monitored during the automated portion of the trip. Therefore, it is only necessary to check components that are specifically required by the manual portion of the trip.

Table 2-16. Vehicle Systems Check-In Functions

Item	Criticality	Measurability	Frequency of Tests
Oil Pressure	2	A	S
Fuel Level	2	A	M
Battery Charging System	2	A	M
Tire Pressure	2	B	S
Coolant Pressure	2	A	S
Lights	4	B	CI
Periodic Inspection	-	B	CI
Brakes	1	B	PI
Coolant Level	2	B	M
Power Steering Fluid	2	B	C
Power Train	2	B	S

Table 2-17. AHS System Check-In Functions

Item	Criticality	Measurability	Frequency of Tests
Longitudinal Control Loops	1	B	C
Throttle Actuator	1	B	C
Brake & Brake Actuator	1	B	C
Lateral Control System	1	B	C
Steering Actuator	1	B	C
Lateral Guidance Sensor System	1	B	C
High Speed Stability Test	2	B	CI
Communications Systems	1	B	C
Navigation Systems	1	B	C

Legend (for tables 2-16 and 2-17)

Criticality	Measurability	Frequency of Tests*
1 - Very serious, e.g. loss of lateral control 2 - Somewhat serious, e.g. overheating 3 - Somewhat serious, unlikely 4 - Less Serious, e.g. tail light out	A - Available. B - Possible at all times but not yet available	C - Continuously (several times per second) S -Every few seconds M - Every few minutes CI - Check-in PI - Periodic Inspection *All functions checked at Check-In

3.3.1.2 Check-Out Components

The components that are used exclusively in the manual mode depend on the specific design chosen for the AHS. The Team has identified three major design approaches. In the first approach, the manual input systems (steering wheel, brake pedal, etc.) must be physically disconnected from the actuators, in order to connect the automated input systems. In the second approach, both control systems (driver and AHS) remain connected to the actuators at all times. In this case, a controller is used to tell the vehicle which system should be responded to at a given time. In the third approach, both the manual and automated input systems remain physically connected to the actuators at all times. The actuators can accept commands from either control system.

3.3.1.2.1 Manual and Automated Vehicle Control Components are Connected and Disconnected in a Mutually Exclusive Manner

In this approach, there are two distinct control modes for the vehicle, one for manual driving, and one for automated driving (see figure 2-6). Only one mode can be engaged at a time, and during check-in the AHS system must verify the engagement of the AHS mode before the disengaging the manual mode. Similarly, during check-out, the AHS system must verify the engagement of the manual mode before disengaging the automated mode.

For this approach, it is necessary to use mechanical fail-safe devices for the connections between the control systems and the actuators. This will ensure that transitions between control modes cannot occur by accident, or until the transfer between control modes is complete.

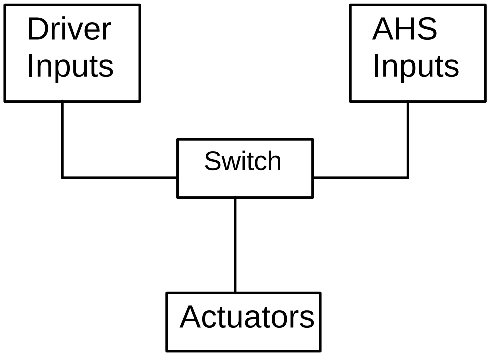

Figure 2-6. Design Approach One

3.3.1.2.2 Vehicle-Control Components For Manual and Automated Modes Are Both Always Connected, But Only One Can Operate At A Time

In this approach, both control modes remain connected to the vehicle actuators at all times. The switching between modes is accomplished by a controller, which acts as a switch between the two control modes (see figure 2-7). The transfer between control modes is initiated by a particular driver input to the manual mode, essentially a manual override to the automated mode. An analogy would be the cruise control system, in which the driver regains control by depressing the brake pedal.

3.3.1.2.3 Vehicle-Control Components For Manual and Automated Are Both Always Connected and Can Both Operate Simultaneously

In this approach, both control modes remain connected to the vehicle actuators at all times (see figure 2-8). The actuators can accept commands from both the AHS and the driver control inputs. This could lead to a potentially dangerous situation, since a driver could inadvertently provide a system input by bumping one of the control devices (e.g., steering wheel). This input may interfere with AHS operation, causing the vehicle to behave unexpectedly, and resulting in a dangerous situation.

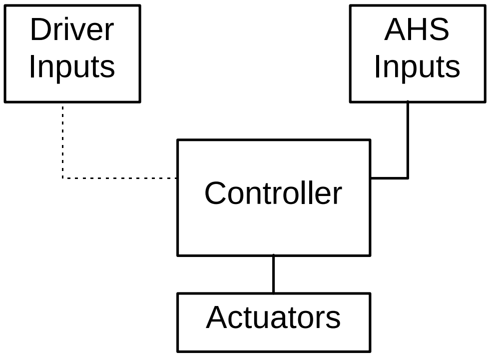

Figure 2-7. Design Approach Two

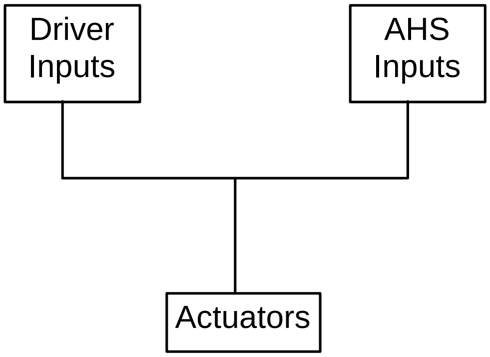

Figure 2-8. Design Approach Three

3.4 HIGHWAY/AHS DESIGN ISSUES

This section addresses the AHS design considerations that must be taken into account to accommodate the check-out process. Due to the need for human involvement throughout the AHS trip, and the need for intervention during emergency events, the check-out process is likely to impose some limitations or requirements on the highway infrastructure used for AHS. Some examples of these requirements are the following:

- The length of check-out tests and the procedures used for moving vehicles on and off of AHS (i.e., all vehicles checked out for an exit before new vehicles allowed to check in) will need to be considered when calculating the required length of transition lanes. A tradeoff may need to be made between the time required for testing, and the length of the transition lanes.
- AHS may need to park drivers who fail the check-out test in a temporary parking area. These parking areas would need to be built at every exit.
- Breakdown lanes may be needed in the event that, for whatever reason - system, vehicle or human - the vehicle can not continue travel on the AHS.

In the scope of this analysis there are two types of check-out that will have to be considered when designing the basic highway infrastructure: normal check-out and emergency check-out. In a normal check-out, everything proceeds as expected. Transition lanes are used properly and the vehicle leaves AHS at the driver's desired exit. In an emergency check-out, the driver needs to quickly take control of the vehicle, as in the event of a system failure. The easiest situation to design for is the normal check-out. However, emergency situations, even infrequent ones, must be considered for safe travel by everyone on AHS. Table 2-18 is a top-level view of what infrastructure may be needed to cope with the conditions, that may be expected to occur on AHS, which would require an emergency check-out.

Table 2-18. Highway Design Considerations

Condition	Required Infrastructure
Failure of the driver to pass the check-out test	Parking area or extended transition lane for car to merge back into automated traffic or to exit highway
Failure of the automated car on the roadway	Breakdown lane or parking area for vehicle to exit the AHS lanes
Spacing of vehicles is too close for safe manual driving	Extended transition lane for vehicle to increase gap (spacing) between it and other vehicles before driver re-takes control
Poor weather or roadway conditions	Extended transition lane to increase gap (spaces) between vehicles because of reduced control; drivers may need additional (or more stringent) testing for retaking control under poor driving conditions
AHS system failure	Breakdown lane or parking area; extended transition lanes
Driver/Passenger emergency	Breakdown lane or parking area for the AHS to park the vehicle

3.4.1 Implications of Check-Out Process for Highway Design

As mentioned in section 3.2.3.4, a tradeoff exists between practicality and safety in the check-out process. The system needs to be sure the driver can safely take control of the vehicle, but the check-out process cannot take many miles of roadway to complete. This tradeoff will become even more critical as the level of automation increases. If the driver is on AHS for long periods of time, without many tasks to perform, his/her level of arousal will be low. Low arousal will affect the detection of stimuli and reaction time. It is expected that the AHS check-out process will have to verify that the driver is competent to control the vehicle. The process must be accomplished quickly, so that the process is complete in as short a distance as is safe.

Issues related to highway design include the number of times a driver may be retested during the check-out process if the initial test is failed, and what happens if the driver fails to accurately respond within the time allowed. The AHS highway design must factor in the time for the tests and allowable retests; the checkout process must start well before the exit is reached. Time in the transition or exit lanes can become unreasonably long with extensive testing in the check-out process. However, the process must be started early enough so that control, if the driver passes, can be transferred to the driver in time to leave the system at the desired exit.

At AHS driving speeds, large distances are covered in a short period of time, so the process of testing the driver must be necessarily short to keep transition and exit lane lengths within reason. At 60 miles per hour, the vehicle will cover a quarter of a mile: 396 m (1320 ft) during a 15-second test; for three sequential tests at 120 miles per hour the distance increases to 1.5 miles. Figure 2-9 shows the distance traveled, at various speeds, for one, two and three 15-second tests. Longer tests would, of course, require more time prior to the driver taking control at check-out.

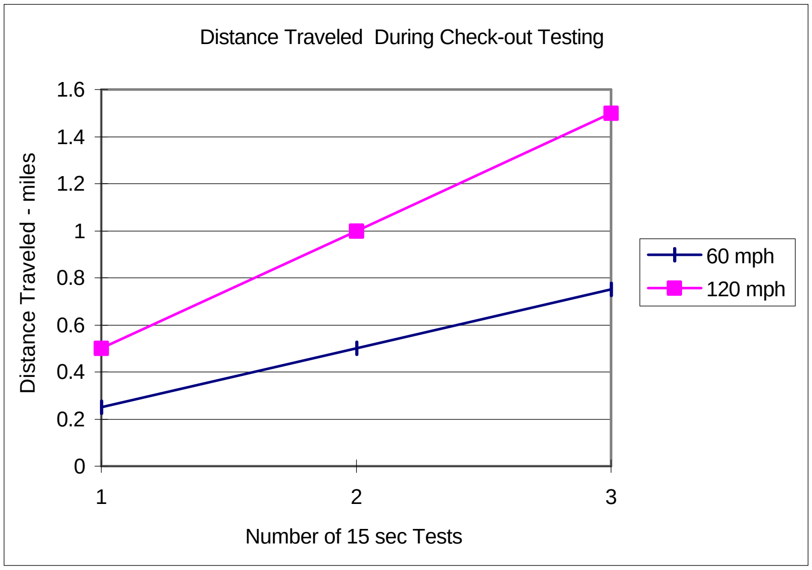

Figure 2-9. Typical Distances Traveled During Testing

If drivers fail to accurately respond to the check-out process, they are considered unable to safely control the vehicle. In this case, AHS will not allow drivers to retake manual control. AHS must either pull drivers into a temporary parking area or merge them back into the automated lane to continue to the next exit. Both of these options give drivers more time to become alert and respond accurately the next time they try the check-out process. If pulled into a temporary parking area, drivers will be able to get out and walk around or summon help, if necessary. If drivers are sent to the next exit they will have time to roll down the window and become more alert. The drawback with AHS sending vehicles to the next exit will be that drivers may be taken many miles from their destination. Either of these options affect the infrastructure needed. If temporary parking is used, then parking areas must be built at every exit. If AHS sends vehicles on to the next exit, the longer transition or exit lanes will be needed so that AHS can keep control of the vehicle and merge it back into the automated lane.

3.4.2 Speed, Spacing, and Timing Issues

For drivers to retake control of the vehicle from the AHS system, they must successfully complete the check-out process of AHS within the accepted time. The process must start early enough before the exit to allow for human response time in the testing interval, and the time to transfer into the transition or exit lane. The speeds of the vehicles in the automated and manual lanes, and the spacing between vehicles in both lanes, affect human response time and thus the start of the check-out process and length of transition and exit lanes.

3.4.2.1 Honeywell Driving Simulator Study

The Honeywell Technology Center performed a number of simulated studies of the effect on response time when variables such as vehicle gap and speed were manipulated. These studies can help determine how early the check-out process must begin to allow for adequate time for completion of all tests, based on human reaction time, vehicle speed, etc. To ensure safety, it must be determined whether or not (or how much) the vehicles must be spaced out and/or slowed down before allowing the driver to retake control. These results may impose restrictions on the design of the check-out process.

This section is based on the results of a study conducted by the Honeywell Technology Center, Bloomfield, *et al*., (1994) utilizing the Iowa driving simulator. The study investigated a driver's ability to retake control under different speed, spacing and headway conditions. In this study, the drivers were asked to resume manual control of their vehicle from an automated state and execute a lane change to the right. Although the conditions of the study do not address all anticipated AHS configurations, some insight into speed, spacing, and timing issues can be obtained from their results. The experimental configuration was a three-lane expressway with AHS vehicles traveling in strings of three or four in the left lane, while the vehicles under manual control were traveling in the center and right lanes. There was no transition lane and no barrier between automated and unautomated lanes. Experiments focused on the transfer of control from AHS to the driver, essentially a check-out process.

At the start of each experiment, the vehicle was traveling in the automated lane. The driver’s task was to take control of the vehicle, drive from the automated lane into the center lane, move to the right lane, then leave the freeway at a specified exit. Experiments investigated the effects of driver performance by manipulating the following variables:

- The design velocity of the automated lane (65, 80, 95 mph)
- The size of the gap between the vehicles within the strings of automated vehicles (0.0625, 0.25, 1.0 seconds). (In normal expressway traffic, drivers tend to space themselves no closer than 2 seconds behind the car in front.)
- The density of the vehicles in the unautomated lanes (2.62, 6.55 seconds between vehicles at 55 mph)
- Driver’s age (24 to 34 years, 65 years or older)

These experiments did not include any testing of driver readiness to retake control of the vehicle. Driver response time was defined as the time between an audible exit-advisory, and the time the driver put their hands on the wheel and touched either the brake or accelerator pedal.

The objective of the Honeywell study was to determine the best conditions under which control can be transferred from the AHS to the driver, with regard to maximizing safety and minimizing interference to the flow of traffic in both the automated and manual lanes. Since there was no transition lane, and there was a speed difference between the automated and manual lanes, the driver had two options: (1) to slow down while in the automated lane before merging, thus slowing down automated traffic behind him, or (2) try to quickly merge into a gap in the manual lane before slowing, thus risking a rear-end collision with a slower car ahead. Results showed that drivers slowed during the merging process, using both lanes to complete the transition to 55 miles per hour.

Although the Honeywell study utilizes different conditions from any of the RSCs under our study, some of the findings are of value. For instance, response times on the order of 8 to 17 seconds are reported; these will be useful in determining allowable times for driver readiness testing, and hence, the lane lengths needed for check-out. Vehicle speed in the automated lane was found to significantly affect driver response time. In addition, the time spent in the automated lane when the driver had control of the vehicle was affected by the traffic density in the manual lane, vehicle speed in the automated lane, and gap size in the automated lane.

The impact for our study from these findings is that additional transition or exit lane lengths are needed when: (1) automated vehicle speeds increase, or (2) traffic density in the manual lanes increases. Gap size in the automated lane may or may not affect transition time since transfer of control to the driver may occur in the transition lane, not in the automated lane. The time spent in the center lane before the merge into the rightmost exit lane was found to be dependent on the age of the driver, with the older drivers taking more time. This indicates that longer transition lanes may be needed to accommodate older drivers.

3.4.2.2 Traffic Speed, Density, and Flow

In situations where the velocity in the AHS lanes is greater than the velocity in the manual lanes, additional footage is needed in the transition lanes to decelerate vehicles exiting AHS and accelerate vehicles entering AHS. A simulation obtained the results for deceleration times and distances shown in table 2-19. (PSA of AHS Team Report, Vol. 4, Chapter 4) These distances must be considered when determining the lengths of transition and exit lanes needed for AHS.

Table 2-19. Time and Distance Required to Reach Final Velocity

AHS Velocity (mph)	Elapsed Time (sec)	Actual Distance Traveled (m)*	Minimum Distance Traveled (m)**
120	10.1	406.53	335.49
90	6.6	222.39	177.72
75	4.6	137.40	110.25
60	0	0	0

* Additional exit distance needed to decelerate vehicles from AHS velocity to a manual velocity of 60 mph.
** Assumes constant deceleration with no acceleration and time delays.

The values in table 2-19 assume a single decelerating vehicle and do not include any extra distance for gaps to open for safe merging. The transition lane is utilized for both entering and exiting vehicles. Due to the potential conflict between accelerating and decelerating vehicles, the gaps in the transition lane between vehicles must be large enough to prevent collisions. One possible solution for the AHS is to give priority to the exiting vehicles, so that a gap in the automated lane will be available for a vehicle entering the automated lane. By giving priority to exiting vehicles and removing them from the transition lane, the conflict between entering and exiting vehicles is minimized. However, there still needs to be a gap in the transition lane for an exiting vehicle to enter. At busy exits, the density in the transition lane may increase. Two options may result from the increased density: 1) the check-out procedure will have to be initiated earlier in high traffic density situations so that everyone wanting to exit can do so. This will, in turn, require longer transition or exit lanes, or 2) the density in the transition lane may prevent some drivers from checking out at their desired exits.

3.4.2.3 Roadway Conditions

It may be necessary to have different check-out requirements to accommodate differing road conditions, such as snow or rain. All of the previous discussion related to optimal road conditions: dry pavement, clear visibility, and roads in good repair. In actuality, the AHS may operate under many different conditions. There must be a safety factor designed into the system to account for less than optimal weather and road conditions. Rain, snow, or sleet severely affects road traction and requires longer distances for safe acceleration and deceleration. Fog may not affect the nominal operation of AHS, but may affect the check-out procedure if the driver cannot see well enough to safely take control.

In addition, it is generally considered more difficult to drive under poor weather or road conditions due to the increased chance of skidding, and decreased feedback from steering and braking inputs. The normal check-out process may have to be more stringent, and this may entail more testing, requiring more time to complete. Additional testing time must be reflected in the length of the transition lane. The AHS system, if intended to be operational under many different conditions, must be designed to handle worst-case scenarios.

3.4.3 Infrastructure Design Issues

There may be engineering requirements for the roadway design, based on the needs of the check-out process. Table 2-20 provides an overview of potential infrastructure changes, or additions, which may be required, as well as the types of check-out and the AHS highway configurations affected.

Table 2-20. Summary of Highway Infrastructure Issues

Potential Infrastructure Additions or Changes	Comments	Type of Check-Out (Normal or Emergency)	Relevant AHS RSC
Create Wider Roadways, Bridges, Underpasses, and Tunnels	An existing highway may be expanded to include extra designated lanes for AHS. This situation may require widening current highway structures. Also, breakdown and/or transition lanes may be required along the entire length of the roadway.	Normal, Emergency	I2, I3
Create Transition Lane	Transition lanes may be required for driver testing and retesting to exit AHS. Transition lane length may depend on the design and specification of the check-out process.	Normal	I2
Lengthen Exit Lane	Exit lanes may need to be extended for high-speed AHS controlled exits.	Normal	I3
Create Breakdown Lane	Breakdown lanes may be required along the entire length of the AHS in case of vehicle failure, AHS failure, or human emergencies. They help to prevent disabled vehicles from impeding traffic in the travel lanes.	Emergency	I3
Add Parking Area	AHS may remove the vehicle from the roadway due to check-out failure at exits. There may also be situations in which the driver needs to park the vehicle off the roadway, using the panic response.	Normal	I2, I3
Create New Rest Areas	Long distance travel on AHS may require more rest areas, so that drivers have more opportunities to rest (to counteract the vigilance decrement). Also, in I3 configurations, the AHS roadway may be totally separate from existing roadways to facilitate access of AHS vehicles. Thus, there may be a need to build additional facilities to service the AHS traffic.	Normal	I2, I3

The table does not discuss the RSC configuration I1, which specifies the use of existing highway structures with mixed traffic and conventional entry/exit procedures.

4.0 CONCLUSIONS

The check-out process is a critical component for ensuring AHS safety. It concerns the process of ensuring safe transfer of control from the automated driving system to human drivers. From our analysis, we have developed a list of issues and risks (table 2-21), based on human factor considerations, that must be addressed during the design of the check-out process to ensure driver safety.

4.1 CHECK-OUT ISSUES AND RISKS

Table 2-21 summarizes the issues and risks in the check-out process.

Table 2-21. Check-Out Issues and Risks

Issue No.	Issue/Risk Descriptive Title	Description/ Recommendation	RSC Impact	Where Discussed
1	Check-out requirements will be more time-constrained during AHS emergencies, requiring more driver intervention than during normal check-out.	There will be a requirement for two types of check-out, normal and emergency. Emergency Check-out will be necessary if there is an AHS system failure requiring the human to take over quickly. Emergency check-out will require a much shorter check-out process than normal check-out.	all RSCs	2.1
2	Drivers who break the law can pose hazards on AHS as on any other road.	AHS may help mitigate hazards associated with law breakers (e.g., vehicle inspection verified at check-in, minimal required driver capability verified at check-out). However, some risks from law breakers cannot be totally avoided (e.g., non-AHS-certified drivers using someone else's license, alcohol consumption while on AHS). Potentially serious hazards will need to be addressed through enforcement measures.	all RSCs	2.3.1
3	Requirements for emergency check-out and driver intervention may require drivers to remain awake during AHS use.	AHS failure modes that require drivers to quickly assume vehicle control will require that drivers stay awake at all times. The time required to rouse a sleepy driver and to attain adequate levels of alertness and attention to task will exceed the time available for dealing with emergency situations that require immediate driver intervention.	all RSCs	2.3.2

Table 2-21. Check-Out Issues and Risks (continued)

Issue No.	Issue/Risk Descriptive Title	Description/ Recommendation	RSC Impact	Where Discussed
4	There are two parts to the check-out process: testing vehicle components, and testing driver readiness.	The check-out model (see figure 2-6) describes the relationship between the automated and manual systems within a vehicle. The check-out process must be designed to ensure that the manual system is operational. For the manual system to operate safely, both the link between the driver inputs and the vehicle actuators (vehicle components), and the link between the driver's control and the driver's inputs (driver readiness), must be intact.	all RSCs	3.1
5	Existing information processing and vigilance research foundations should be applied to the design of the check-out process.	Much is known about how humans process information and make judgments and decisions within dynamic, information-rich environments. This understanding must be applied to the design of the check-out process considering the real world constraints of AHS (e.g., high vehicle flow-rate requirements, impatient drivers, the wide range of driver backgrounds and skill levels, etc.)	all RSCs	3.2.1.1
6	During the process of transition from automated to manual driving, the driver should take control rather than have the vehicle relinquish control.	In the process of taking control from the vehicle, the driver is required to initiate a positive action using the vehicle's manual control. Since the driver must initiate the process, the AHS knows that the driver is in fact ready to take control. If the vehicle were to give control of the vehicle back to the driver, the AHS would then need to verify that the driver actually took the control.	all RSCs	3.2.2.6
7	The check-out test of driver readiness should be an integrated portion of the larger check-out process.	Traditional performance tests are not appropriate for implementation during AHS checkout for many reasons. Many of these tests require too much time to complete, and too much time to analyze the results. Thus, due to the time restrictions imposed by check-out, we suggest that the driver tests be integrated into the larger check-out process. The actual process of taking manual control should itself be a test of the driver's readiness to retake control of the vehicle.	all RSCs	3.2.2.6

Table 2-21. Check-Out Issues and Risks (continued)

Issue No.	Issue/Risk Descriptive Title	Description/ Recommendation	RSC Impact	Where Discussed
8	If check-out tests are required during the automated portion of the trip (to ensure that vigilance is being maintained), these tests should be meaningful and not artificial and extraneous.	Intermediate tests (tests performed during the automated portion of the trip) may be needed to ensure that drivers are awake and alert throughout the trip. These tests must not be too intrusive or too meaningless. Intrusive tests will annoy the AHS users, and meaningless tests will seem unimportant to the drivers. Drivers may fail to take these tests seriously, and may perform poorly on the test.	all RSCs	3.2.3.2

4.2 RECOMMENDATIONS FOR FUTURE WORK

Based on our analysis, it is not possible to specifically design an appropriate check-out process. Check-out is dependent on the design of many other AHS components, as well as the representative system configuration. However, based on our knowledge of what issues must be addressed during the check-out process, we can make the following recommendations for future work. First, additional study on the ability of a driver to retake manual control of his/her vehicle at high speeds and close headways is warranted. In addition, we recommend an experimental approach to the determination of the passing criteria for the check-out process. Individual variability, as well as the level of participation in the eventual AHS design, must both be taken into account. Finally, we stress the importance of designing the check-out process based on human factors considerations (e.g., information processing, vigilance, and interaction with automation), and in cooperation with other AHS design tasks (e.g., entry/exit, malfunction management, and lateral/longitudinal control).

APPENDIX A: LITERATURE REVIEW

“Douglas New Systems Automation Policy to Ensure Minimal MD-11 Pilot Workload.” *Aviation Week and Space Technology,* June 4,1990.

Summary: McDonnell Douglas engineers have implemented an innovative systems automation philosophy that ensures minimal workload for MD-11 pilots, while still leaving the crew in full control of their aircraft. Most systems on the MD-11 are configured automatically for a particular flight segment, precluding direct pilot interaction. Preconditions are established that "tell" the computer what will logically follow next, and the system reacts accordingly. The flight crew can always override the automatic input, however. Douglas' philosophy is that, "Computers should never prevent a pilot from doing anything. They should certainly discourage him from doing certain things, and they should prevent him from inadvertent excursions, but should not deny him access to his full control authority."

Driver Performance Data Book Update: Older Drivers and IVHS. Transportation Research Board, National Research Council, March 1994.

Summary: A compilation of summaries of driver performance data from two areas of research: older drivers and intelligent vehicle highway systems (IVHS). The summaries were written in a format similar to the one used in the National Highway Traffic Safety Administration’s 1987 Driver Performance Data Book. This circular has the same objective as the Driver Performance Data Book: to provide summaries of research data relevant to understanding driver performance capabilities and limitations that can influence crash prevention. Both documents are intended to provide users with a quick overview of available data on a particular topic and a reference to use for finding more detailed information.

Guide to Human Performance Measurements, American Institute of Aeronautics and Astronautics, May 1992.

Summary: This guide provides methods for measuring human performance for the purpose of scientific research and system evaluation. The guidelines are intended to assist scientists and systems specialists in selecting human performance measurement methods appropriate to the situation being studied or the system being evaluated.

Alexander, Gerson, and Lunenfeld, Harold. *Positive Guidance in Traffic Control.* U.S. Department of Transportation, Federal Highway Administration, April 1975.

Summary: Positive guidance is based on the premise that a driver can be given sufficient information where he needs it and in the form that he can best use to avoid hazards. This report documents the progress that has been made in developing the positive guidance concept. It discusses the meaning of positive guidance, the philosophy of driver performance upon which it is based, the nature of the driving task at those locations where positive guidance is applicable, and a procedure for its application.

Alicandri, Elizabeth and Golembiewski, Gary A*. Improved Highway Design Standards for Older Drivers.* Vol. 6, #2: Communications D'Ordre General, 1994.

Summary: The United States Department of Transportation/Federal Highway Administration's ongoing program "Improved Highway Travel for an Aging Population" is identifying, developing , and evaluating engineering enhancements to the highway system to meet the needs of older road users. Research findings in the areas of traffic control device design show that the needs of older drivers will be better met with changes to current text and symbol signs, as well as modifications to delineation systems. Perception-reaction time (PRT) values used in certain geometric design standards, including stopping sight distance and intersection sight distance, appear adequate for older drivers, but decision sight distance PRT values require further evaluation. Program goals include summarizing the findings for implementation by traffic engineers to increase the safety and mobility of all drivers.

Ball, K., Owsley, C., Sloane, M.E., Roenker, D.L., and Bruni, J.R. "Visual attention problems as a predictor of vehicle crashes in older drivers." *Investigative Ophthalmology & Visual Science*, in press.

Summary: Performance on various measures of visual and mental functioning was used to predict at-fault crash experience of older drivers. Useful field of view (UFOW) was found to contribute significantly to predictive models developed. Reductions in UFOW corresponded to increases in at-fault crashes. Results indicate that any policy to restrict driving privileges solely on age would not be well founded. Decisions on the suitability of licensure in the older population should be based on more objective performance measures.

Baker, C.H. "Signal Duration as a Factor in Vigilance Tasks." *Science*, 141, 1963, pp. 1196-1197.

Summary: The effect that manipulating the duration of a presented signal has on the vigilance decrement.

Bergeron, Hugh P. and Hinton, David A. "Aircraft Automation: The Problem of the Pilot Interface." *Aviation, Space, and Environmental Medicine*, 56, 1985, pp. 144-148.

Summary: Aircraft operations, particularly in the IFR environment, are rapidly becoming very complex. Studies have shown that this complexity can frequently lead to accidents and incidents. Results of studies performed at NASA and elsewhere are presented one of the major themes evident in both the accidents and incidents and in the research performed to solve the problems associated with them is that of human error. Examples of various incidents and blunders, recorded in several studies, illustrate and emphasize the hypothesis: "As systems become more and more automated and complex, the more they become prone to human error. The problem can be eliminated or reduced only if good human factors principles are incorporated in the implementation of the systems, to guarantee a good man/machine interface." Aircraft systems technology, however, (e.g.: electronics, avionics, automation) is evolving and developing at a very high rate, Examples of research are presented showing where the emerging technology has been employed to reduce the complexity and enhance the safety and utility of the aircraft operations.

Binford and Loeb. “Variation in performance on auditory and visual monitoring tasks as a function of signal and stimulus intensities.” *Perception and Psychophysics*, 4, 1968, pp. 361-367.

Summary: Studies the effects on auditory and visual performance by manipulating signal and stimulus frequencies.

Bloomfield, J.R., et al. Human Factors Design of AHS. Experiments #1 and #2. The Effects of Design Velocity, Intra-String Gap Size Traffic Density and Driver’s Age on the Transfer of Control from the Automated Highway System to the Driver. Honeywell Technology Center, May. 1994

Summary: The first two experiments in a series designed to explore human factors issues related to the projected Automated Highway System (AHS) have been completed. They were conducted using the Iowa Driving Simulator. They focused on the AHS configuration that requires the least structural alteration to the current freeway system. In this configuration the left lane is reserved for automated vehicles, the center and right lanes are reserved for unautomated vehicles, and there is no transition lane and no barriers between the automated and unautomated lanes. The two experiments were closely related. In the first, 36 younger drivers, between the ages of 25 and 34 years , were positioned in the driving seat of the simulator vehicle. At the start of each experimental trial, this vehicle was traveling, under automated control, in a string of vehicles, in the automated lane. Each driver was asked to take control of the vehicle, drive from the automated lane into the center lane and leave the freeway at a specified exit. This experiment investigated the effects of varying 1) the design velocity of vehicles in the automated lane. 2) the intra-string gap and 3) traffic density in the unautomated lanes. The experiment was repeated using a group of 24 older drivers who were age 65 or more.

Boehm-Davis, Deborah, *et al.* “Human Factors of Flight-Deck Automation: Report on a NASA-Industry Workshop.” *Ergonomics,* 26(10), 1983, pp. 953-961.

Summary: With the advent of microprocessor technology, it has become possible to automate many of the functions on the flight deck of commercial aircraft that were previously performed manually. However, it is not clear whether these functions should be automated, taking into consideration various human factors issues. A NASA-industry workshop was held to identify the human factors issues related to flight-deck automation which would require research for resolution. The scope of automation, the benefits of automation and automation-induced problems were discussed, and a list of potential research topics generated by the participants. This report summarizes the workshop discussions and presents the questions developed at that time. While the workshop was specifically directed towards flight-deck automation, the issues raised and the research questions generated are more generally applicable to most complex interactive systems.

Boff and Lincoln, Engineering Data Compendum: Human Perception and Performance, Wright-Patterson Air Force Base, 1988

Summary: A compendium dealing with all types of human perception and the related factors that affect performance.

Braune, Rolf and Wickens, Christopher D. “The Functional Age Profile: An Objective Decision Criterion for the Assessment of Pilot Performance Capacities and Capabilities.” *Human Factors*, 27(6), 1985, pp. 681-693.

Summary: The initial development of a computer-based information-processing performance battery with aviation-relevant task structures is reported. it is shown that the currently existing prototype is sensitive to individual differences within chronological age groups as well as to age-related changes across different age groups. The utilization of such a test battery for the longitudinal assessment of aviator performance capabilities is discussed.

Bristow, J., Kirwan, B., and Taylor, D.H. “Cognition and Affect in Measures of Driving Style.” *Ergonomics* 25(10), 1982, pp. 935-940.

Summary: The study of the dispositions of drivers to drive in particular styles provides important clues to the likelihood of unsafe actions occurring in their driving. In this paper, data of occurrences and non-occurrences of certain actions during test drives, collected by S.W. Quenault, are analyzed in a two-dimensional framework of cognitive and affective styles. Some other driver performance studies are then reviewed in this light, and some new data are reported arising from the use of Quenault's reported technique on male and female groups of drivers matched for age and experience.

Chambers, Alan B., and Nagel, David C. “Pilots of the Future: Human or Computer?” *Communications of the ACM,* 28(11), 1985, pp. 1187-1199.

Summary: This article addresses the question: Should the automated system serve as the human pilot's assistant, or vice versa? The major issues discussed are: 1) has the quantity and nature of pilot error been altered by technology and increased automation?, 2) should system designers automate by replacing or by enhancing pilot performance?, and 3) what problems stand in the way of achieving the ambitious goals of high performance and high system reliability?

Charles, Michael Maya. “Changing Horses.” *Flying,* October. 1991

Summary: This article is an editorial written by an airline pilot who is going to cease flying the 'manual' Boeing 727, to begin flying the highly automated McDonnell Douglas MD-11. The author discusses the benefits and drawbacks of the cockpit automation, and his feelings on making the transition.

Coblentz, A. (editor), *Vigilance and Performance in Automatized Systems*. Kluwer Academic Publishers, 1989.

Summary: This book contains a collection of papers presented at the NATO Advanced Research Workshop on Vigilance and Performance in Automatized Systems, in September 1988. Papers address four main topic areas: (1) methods of vigilance and human performance evaluation, (2) workload and automation, (3) circadian rhythms, fragmented sleep-wake schedules, and (4) pharmacology, vigilance, performance.

Cooper, Peter J., *et al.* “Vehicle Crash Involvement and Cognitive Deficit in Older Drivers.” *Journal of Safety Research*, 24(1), 1983, pp. 9-17.

Summary: The driving records of 165 older persons who were classified as having dementia in clinic assessment were examined in this study. These records were compared with those of a stratified random sample selected from the population of drivers in British Columbia. The dementia group was found to have been involved in over twice the number of collisions as their controls were during identical time periods. Further, over 80% of the dementia group who experienced a crash event (and who were almost all judged at fault) continued driving for up to 3 years following the event, and during this time over one third of these had at least one more accident.

Craig, A., *et al.* “Combining evidence presented simultaneously to the eye and the ear: A comparison of some predictive models.” *Perception and Psychophysics*, 19, 1976, pp. 473-484.
A comparison of predictive performance models using bi-modal detection.

Damos, Diane (editor), *Multiple-Task Performance*. Taylor & Francis, 1991.

Summary: This book is divided into four sections., The first contains four chapters, three of which are concerned with theories of multiple-task performance. These chapters provide different perspectives on multiple-task performance. The second section is concerned primarily with learning and performance. The two chapters on learning and motor performance are unique contributions to the multiple-task literature because workload experiments are frequently conducted in a multiple-task environment. The third section of the book is completely devoted to mental workload. The primary chapters in this section focus on various assessment techniques. The last section deals with individual differences. Two chapters here are devoted to aging because of its increasing social and scientific importance.

Davies, D.R. and Tune, G.S. *Human Vigilance Performance*. American Elsevier Publishing Company, Inc, 1969

Summary: This book attempts to provide a review of the literature concerned with human vigilance performance. Although experimental studies of vigilance have considerable relevance for jobs involving the monitoring of displays, the authors chose not to emphasize this relevance but rather to evaluate the contributions these studies make to theory, in the belief that the development of a satisfactory theory of human vigilance is a pre-requisite for the profitable application of laboratory data to 'real life' situations. This book does not set out to supply such a theory; although the authors hope that it will suggest explicitly or implicitly lines of experimental inquiry which have theoretical relevance and which have previously been under-emphasized.

Deaton, John and Parasuraman, Raja. “Sensory and Cognitive Vigilance: Effects of Age on Performance and Subjective Workload”, *Human Performance*, 6(1), 1993, pp. 71-97.

Summary: Sensory and cognitive vigilance were compared as a function of age, subjective workload response, and event rate. Sensory and cognitive differences were directly evaluated in the same subjects by using tasks having the same stimuli (digits) equated for pre-session performance levels and differing only in the type of

discrimination required for target detection. Over the course of a 32-min vigil, detection rate for the sensory task showed the normal vigilance decrement, whereas the detection rate for cognitive task performance remained stable. However, the decrease in hit rate with an increase in event rate was more pronounced for the cognitive than for the sensory task. Older adults had lower detection rates than younger adults for both hits and higher false alarm rates for the sensory but not the cognitive task. Subjective workload was rated at relatively high levels and increased significantly from pretest to posttest. The cognitive task was rated as higher in workload then the sensory task. These results are discussed in relation to three issues: (a) implications of sensory and cognitive differences for a vigilance taxonomy, (b) workload demands of monitoring tasks, and (c) age differences in vigilance.

De Waard, Dick, and Brookhaus, Karel, "Assessing Driver Status: A Demonstration Experiment on the Road", *Accident Analysis and Prevention*, 23(4), 1991, pp. 297-307.

Summary: Twenty subjects completed an on-the-road experiment that consisted of two parts on two separate days. One was a one-hour driving test under the influence of alcohol (BAC < = .05%), the second a two-and-a-half hour driving test under vigilance conditions. Impairment of driving performance was measured in a car-following test as well as in a standard driving test. Changes in relevant physiological parameters, such as ECG and EEG, reflected changes in driver status and predicted driving performance impairment.

Dingus, Thomas, Hardee, H. Lenora, and Wierwille, Walter. "Development of Models for On-Board Detection of Driver Impairment." *Accident Analysis and Prevention,* 19(4), 1987, pp. 271-283.

Summary: Two of the leading causes of automobile accidents are driver impairment due to alcohol and drowsiness. Apparently, a relatively large percentage of these accidents occur because drivers are unaware of the degree to which they are impaired. The purpose of this research was to develop models, utilizing changes in driver behavior, which could detect driver impairment due to alcohol, drowsiness, or the combination of alcohol and drowsiness, and which could be practically implemented in an automobile, A computer-controlled automobile simulator was used to simulate a nighttime highway driving scenario for six drivers who participated in each of four conditions: a control condition, and alcohol condition, a sleep-deprived condition, and a combined alcohol and sleep-deprived condition. The results indicated that a useful on-board drowsiness detection device is possible and practical for highway driving. The results also showed that on-board alcohol impairment detection may be possible at levels below the legal driving limit in most states (BAC .1%).

Drory, Amos. "Effects of Rest and Secondary Task on Simulated Truck-Driving Task Performance." *Human Factors,* 27(2), 1985, pp. 201-207.

The study was designed to examine the effects of extra task stimulation and extra rest on performance and fatigue of haul truck drivers engaged in a simulated driving task. Sixty male subjects, randomly selected from the population of truck drivers in a large mining company, operated a driving simulator for a period of 7 hours. A 2 X 3 experimental design was employed including two levels of rest conditions and three levels of secondary-task manipulations. The results show that performance and perceived fatigue were significantly higher when a secondary task involving voice communication was added to the basic driving task, but an added vigilance task had less effect. An extra 30-minute rest period in the middle of the experimental session significantly alleviated the reported experience of fatigue but did not affect performance. The results are discussed in terms of their relevance to actual industrial driving tasks.

Edwards, M.R. and Verdini, W.A. “Engineering and Technical Management: Accurate Human Performance Measures = Productivity.” *Society of Research Administrators Journal,* 1986

Summary: A study on how accurate human performance measures can boost human productivity.

Englund, C.E., et al. Unified Tri-Service Cognitive Performance Assessment Battery (UTC-PAB)---1. Design and Specification of the Battery. Naval Health Research Center, NHRC Report # 87-10,1987.

Summary: The Unified Tri-Service Cognitive Performance Assessment Battery (UTC-PAB) represents the primary metric for a Level II evaluation of cognitive performance in the JWGD3 MILPERF chemical defense biomedical drug screening program. Emphasis for UTC-PAB development has been on the standardization of test batteries across participating laboratories with respect to content, computer-based administration, test scoring, and data formatting. This effect has produced a 25-test UTC-PAB that represents the consolidation and unification of independent developments by the Tri-Service membership. Test selection was based upon established test validity and relevance to military performance. Sensitivity to effects of hostile environments and sustained operations were also considerations involved in test selection. Information processing, decision-making, perception, and mental workload capacity are among the processes and abilities addressed in the battery.

The UTC-PAB represents a dynamic approach to battery development. The nature of the biomedical drugs screened and information from performance centered task analyses will direct the form of future versions of the battery.

Engum, Eric S., *et al.* “Cognitive Behavioral Driver's Inventory.” *Cognitive Rehabilitation*, 6(5), 1988, pp. 34-50.

Summary: This article describes an operational test battery that is easy to administer and which assesses the requisite skills for safe operation of a motor vehicle. The battery, the Cognitive-Behavioral Driver's Inventory (CBDI) was designed to elicit those operational behaviors which most closely resemble the sustained attention, cognitive control, and perceptual quickness crucial to the driving task. The study described in this report seeks to outline the features of the CBDI, the criteria that have been used to make decisions about driving safety, a report of internal reliability, and brief estimates of test validity based on patients' actual ability to operate a motor vehicle as independently evaluated by a driving instructor.

Evans, David W. and Ginsburg, Arthur P. “Contrast Sensitivity Predicts Age-Related Differences in Highway-Sign Discriminability.” *Human Factors,* 27(6), 1985, pp. 637-642.

Summary: This study was conducted to determine if contrast sensitivity could predict age-related differences in the ability to discriminate similar road signs, as these differences have not been predicted by Snellen visual acuity. Contrast sensitivity, Snellen visual acuity, and discrimination distances for projected images of highway signs were measured for 7 older observers, ages 55 to 79, and 13 younger observers, ages 19 to 30. All subjects had 20/20 visual acuity or better, but the older group had significantly lower contrast sensitivity than did the younger group at three spatial frequencies: 3, 6, and 12 cycles/deg of visual angle. The older group required a significantly larger sign symbol in order to determine if it denoted a + or T intersection. Correlations between measures showed that highway-sign discrimination distance was significantly related to contrast sensitivity at two spatial frequencies, 1.5 and 12 cycles/deg, but discrimination distance was not related to visual acuity. Implications for highway-sin design and driver vision standards are discussed.

Fergenson, P. Everett. “The Relationship Between Information Processing and Driving Accident and Violation Record.” *Human Factors,* 13(2), 1971, pp. 173-176.

Summary: Seventeen subjects matched for driving experience were divided into four groups according to their accident and traffic violation records. They were tested for their ability to process information. Subjects who had a high accident record processed information at a significantly ($p < .01$) lower rate than non-accident subjects. Subjects who had many violations, but no accidents, were the best information processors. There was a significant ($p < .01$) interaction between accident and violation record. These results and their implications are discussed.

Fildes, Brian and Lee, Stephen. Older Road User Problems on Urban Roadways. Volume 6, Number 2. Communications D’Ordre General, 1994.

A study is reported of a survey of 1600 old and young drivers and pedestrians in two capital cities in Australia. Results included information from drivers on weekly driving patterns, car dependency, driving habits and difficulties, problems and preferences with roads and traffic control devices and past crash history. Pedestrians provided data on their weekly travel patterns, driving experience and exposure, walking habits and road difficulties, and recent pedestrian accidents. These data are intended to improve knowledge of older road user habits and difficulties and point to interventions to reduce road trauma.

Fozard, J.L. “Speed of Mental Performance and Aging: Costs of Age and Benefits of Wisdom.” In *Behavioral Assessment and Psychopharmacology*, by F.J. Pirozzolo and G.J. Maletta (Eds.). 1981, pp. 59-94.

Summary: A tradeoff exists between the slowdown in reaction time and the knowledge that is gained as humans age.

Goggins, *et al.* “Effects of Age on Motor Preparation and Restructuring.” *Bulletin of the Psychonomic Society*, 27, 1989, pp. 199-202.

Summary: How aging affects motor skills and perception.

Haber, Ralph Norman. “Why Low-Flying Fighter Planes Crash: Perceptual and Attentional Factors in Collisions with the Ground.” *Human Factors,* 29(5), 1987, pp. 519-532.

Summary: A detailed analysis of a recent jet fighter mishap is made in terms of perceptual and attentional factors that may have contributed to or caused the mishap. The crash occurred in clear air while the fighter was maneuvering over rugged terrain of irregular and unpredictable features. There were no mechanical failures and no evidence of pilot error. The analysis concentrates on the effects of the under-informativeness of the terrain; the difficulties of perceiving distance, ground clearance, and position under these conditions; the consequences of the high gravitational forces generated by the jet just prior to impact; and the competition for the pilot's visual attention. the effects of the combinations of these various factors are then considered. Finally, specific suggestions are made for improvements in training for low-altitude flight.

Hancock, Wolf and Thom. "Driver workload during differing driving maneuvers." *Accident Analysis and Prevention*, 22, 1990, pp. 281-290.

Summary: A study at the driver workload that is felt through various driving maneuvers.

Hartman, Bryce E. and Secrist, Grant E. "Situational Awareness is More than Exceptional Vision." *Aviation Space and Environmental Medicine,* 62, 1991, pp. 1084-1089.

Summary: Superior situational awareness, an extraordinary awareness of the total flight environment and aerial combat situation, is a significant contributor to success in aerial engagement. Review of over 1,000 published sources has led to the formulation of situational awareness as being principally in the cognitive domain. Superior awareness involves exceptional sensitivity to performance-critical cues in the operational environment, an exceptional capacity to anticipate changes in system states and operational conditions, and the ability to act on those changes in a proactive mode. Three important constructs are described: 1) automatic information processing; 2) near-threshold processing; and 3) skilled memory. In combination, they constitute a pilot attribute which uniquely facilitates the full armamentarium of skills and abilities of the superior tactical pilot.

Hicks, Thomas G, and Wierwille, Walter W. "Comparison of Five Mental Workload Assessment Procedures in a Moving-Base Driving Simulator." *Human Factors,* 21(2), 1979, pp. 129-143.

Summary: Five methods of measuring mental workload (secondary task performance, visual occlusion, cardiac arrhythmia, subjective opinion rating scales, and primary task performance) were compared for sensitivity to changes in operator loading. Each was used to differentiate among low, medium, and high levels of workload defined in terms of the application point of crosswind gusts in a driving task.

The driving task was produced using an automobile driving simulator with a six-degree of freedom computer generated display, a four-degree of freedom physical motion system, and a four-channel sound system. Techniques of mental workload measurement that have shown promise in previous studies were used as a between-subjects factor, and subjects were presented with a within-subject factor of wind gust placement. Gusts at the front of the vehicle represented high workload levels, and gusts toward the center of the vehicle represented progressively lower levels of workload.

The results showed significant differences among workload levels for subjective opinion scales and primary performance measures of lateral deviation, yaw deviation, and steering reversals. A relative sensitivity estimate of these would be, from highest to lowest sensitivity, steering reversals and yaw deviation, rating scales, and lateral deviation. The techniques of occlusion, cardiac arrhythmia, and secondary task performance yielded no significant workload effect.

Hockey, G. Robert, and Tattersall, Andrew J. “The Maintenance of Vigilance During Automated Monitoring.” In *Vigilance and Performance in Automatized Systems,* edited by A. Coblentz, Kluwer Academic Publisher, 1989.

Summary: This paper is concerned with the maintenance of vigilance in modern, complex human-machine systems. It questions the applicability of models of the human operator derived from traditional studies of watchkeeping, since these assume a 'passive' attentional state. It argues instead for a model in which the operator actively regulates his cognitive state to adapt to changes in prevailing task and internal demands, through the adoption of strategies which permit a trade-off between energy costs and performance benefits.

Hoffman, Errol R. and Joubert, Peter N. “The Effect of Changes in Some Vehicle Handling Variables on Driver Steering Performance.” *Human Factors,* 8(3), 1966, pp. 245-263.

Summary: The literature on vehicle handling is summarized. Experiments were carried out to determine the effect of vehicle response time, steering gear ratio, and near- and far- sight distances on driver performance on a tracking task consisting of driving through a narrow winding course marked by traffic cones. The vehicle response time was found to affect greatly the number of cones touched by the vehicle during a set testing time. On the particular track used in these tests, the driver performed best when the vehicle response time was .20 seconds. The near and far distances over which the driver could see the test course were also found to be of importance. Increasing near-sight distance, with no limit on the far-sight distance produced poorer driver performance. This also occurred for the case of decreasing far-sight distance with fixed near-sight distance. Tests with variations of steering ratio and steering torque produced little change in driver performance, although there was a weak minimum in conescores at a steering reaction G=24. In some of the experiments reported here, spare mental capacity was measured during the test period. For this indirect measurement of task difficulty, changes in the spare mental capacity of the driver were found to have the same sensitivity to changes in the vehicle, as did the change in the number of comes touched by the vehicle.

Holland, C.A., and Rabbitt, P.M.A. “The Problems of Being an Older Driver: Comparing the Perceptions of an Expert Group and Older Drivers.” *Applied Ergonomics,* 25(1), 1994, pp. 17-27.

Summary: Driving instructors' observations of older drivers were compared with the experiences of older drivers themselves using two questionnaires. Instructors were asked to compare the ease or difficulty of teaching different skills to old and young pupils, and were asked about skills they would expect to have deteriorated in an experienced driver aged 70. Instructors found teaching most skills to older pupils more difficult than to younger pupils, especially vehicle control and where more than one source of information needed attention at once. Older pupils learned skills involving attitude and safety mindedness more readily than younger ones. Accident statistics suggest that junctions are dangerous places for older drivers and specific difficulties suggested by the instructors gave clues as to why junctions should be so problematic. Some skills seem to be intrinsically difficult for older people, in that instructors suggested them for both older pupils and experienced drivers: for example, vigilance, speed and distance judgments and coordination. There were also skills that instructors noted learners found difficult that experienced older drivers did not, namely vehicle control skills, and there were problems older drivers had that older learners did not, namely complacency and poor attitude towards safety. Older drivers were unaware of many of the problems suggested by driving instructors and by previous research. Comparison of these problems (e.g., failures of attention) with those that the drivers were aware of (e.g., fatigue) suggested that part of the reason for this lack of insight may be poor feedback. This is discussed with reference to directions for remediation. Finally, the effect of greater experience on older people's insight and willingness to make sensible adjustments to their driving was examined.

Hughes, David, *et al.* “Automated Cockpits: Keeping Pilots in the Loop.” (A collection of articles.) *Aviation Week and Space Technology,* 136(12), 1992, pp. 48-70.

Summary: The debate over man-machine interfaces dates to the time when man first began utilizing machines, including flying ones. As aircraft became more complex, automation increasingly was employed ostensibly to reduce pilot workload. The evolution of the highly automated glass cockpit, especially in commercial air transports, has focused renewed attention on the challenge of maintaining pilots' situational awareness during flight operations keeping them in the loop.

Kennedy, John L. “Some Practical Problems of the Alertness Indicator,” In *Fatigue*, edited by W.F. Floyd, and A.T. Welford, 1953, pp. 149-153.

Summary: This article is concerned with a device, developed in Germany during World War II, which used brain-waves as a physiological indicator of the alertness condition of the subject, particularly the slowing of alpha frequency which occurs when the subject is drowsy. The device was constructed so that an alarm or alerting signal would be turned on by the change in frequency of the alpha rhythm. The article discusses various problems that the author encountered when trying to validate the performance of the alertness indicator. The author generally found the device unsatisfactory, since it could not give reliable measures of alertness for all individuals.

Kessel, Colin J., and Wickens, Christopher D. “The Transfer of Failure-Detection Skills Between Monitoring and Controlling Dynamic Systems.” *Human Factors,* 24(1), 1982, pp. 49-60.

Summary: Eighteen subjects either controlled or monitored the system dynamics of a two-dimensional pursuit display. Detection of changes in system dynamics was faster and more accurate when subjects controlled them then when they monitored. The skill acquired by controlling transferred positively to the monitoring mode, producing enhanced detection performance. There was no transfer from the monitoring mode to the controlling mode. Monitors of automatic systems who have had prior manual experience rely upon different perceptual cues in making their detection response than do those who have had no experience. The training implications of these findings are discussed.

Kramer, U. and Rohr, G. "A Model of Driver Behavior." *Ergonomics,* 25(10), 1982, pp. 891-907.

Summary: The driver-vehicle-environment system is characterized by the driver's ability to receive information from the environment and to react upon it by activating the controls of the vehicle. Modeling this system one has to take into account that it is complex. After introducing the model the required operations for the driver's eye and hand movements are demonstrated by means of selected examples drawn from driving-simulator runs. First analyses indicate the principal applicability of the fuzzy driver model for further research.

Lewin, Isaac. "Driver Training: A Perceptual-Motor Skill Approach." *Ergonomics,* 25(10), 1982, pp. 917-924.

Summary: Driving behavior was analyzed in the light of cognitive psychology and perceptual-motor skill learning and categorization of the causation of driving errors was suggested. On this bases, two techniques aimed at correcting inappropriate driving habits were derived and tried out experimentally: a) mass observation and personal communications; and b) self-recording of near accidents and mental (imagery) practice. Findings show the efficiency of both these techniques.

Lings, S. "Assessing Driving Capability: A Method For Individual Testing." *Applied Ergonomics,* 22, April 1991.

Summary: The part played in traffic safety by driver illness or disability is uncertain or unknown. So also are the specific identity and degree of the disorders which necessitate the use of driving aids or which completely incapacitate a person from driving. Despite the gravity of the problems, the question of fitness to hold a driving license is decided throughout the world mainly on the basis of subjective assessment. Controlled experiments exploring the significance of disorders have only been carried out on a restricted scale. In this paper a description is given of a mock car, which is used both for research and individual assessment. It enables the measurement of strength application, steering wheel turn speed, simple reaction times when operating pedals and steering wheel, erroneous reactions, and choice reaction times.

Experiments involving 109 able-bodied and healthy persons showed, as expected, that the muscular strength of men was greater than of women, and that men were significantly quicker at carrying out functions which primarily depend upon speed of movement and of strength. Apart from this, however, there were no significant sex-related differences. Almost all variables showed age dependence, this being most pronounced in the case of men. Thirty-two percent of the test candidates committed errors like braking instead of turning the wheel or turning the wheel or turning to the wrong side. Neither the incidence nor the seriousness of errors bore any relation to sex or age.

Fifty-two persons suffering from paraparesis inferior were compared with the 109 ale-bodied subjects. The degree of paresis co-varied with reaction times, but the degree of spasticity only to a minor extent. The results indicate that at a speed of

80 km/h, `slight paresis' increases reaction distance by around 2-3 m (15%), and `moderate paresis' by the region of 50 m.

Loeb and Alluisi. "Influence of Display, Task and Organismic Variables on Indices of Monitoring Behavior." *Acta Psychologica*, 33, 1970, pp. 343-366.

Summary: The influence on monitoring that occurs by varying the display and stimuli.

Lisper, H.O., Laurell, H., and Van Loon, J. "Relation Between Time to Falling Asleep Behind the Wheel on a Closed Track and Changes in subsidiary Reaction Time During Prolonged Driving on a Motorway." *Ergonomics,* 29(3), 1986, pp. 445-453.

Summary: Twelve subjects drove on a closed 5-km track until they fell asleep behind the wheel or quit for other reasons. The instances of falling asleep occurred after 7 to 12 hours of driving. Falling asleep could be characterized by nodding of the head, closing of the eyes and the car continuing in its previous course. On none of these occasions did the experimenter have to take over the control of the car and all subjects woke by themselves. The average duration between three instances of falling asleep was 24 minutes. After a break with a brisk walk the subjects fell asleep again after an average of 23 minutes. Two preceding sessions of 3 hours of driving on a motorway with subsidiary reaction time measurements predicted (r = - .72 and - .17) the endurance on the closed track.

Mackie, Robert (editor). Vigilance: Theory, Operational Performance, and Physiological Correlates, Plenum Press, 1977.

Summary: This book is a collection of papers on vigilance. The main topics included in this text are: vehicle operation, monitoring and inspection, physiological correlates, stress effects, individual differences, and theoretical considerations.

Mackworth, N.H. "Research in the Measurement of Human Performance." (MRC Special Report Series #268) *Selected Papers on Human Factors in the Design and Use of Control Systems* (Reprinted, ed. W. Sinaiko), 1950.

Summary: A collection of papers dealing with the design and use of control systems.

McClellan, J. Mac. "Don't Blame Autopilots." *Flying,* July 1991

Summary: This article is an editorial which discusses the failure of the FAA and the general aviation training system to adequately train pilots to use autopilots. The author raises concerns that pilots generally do not understand how the autopilot works, or more importantly, how to handle the automated system in an emergency. He advocates that every pilot be required to undergo training on the use of autopilots, so that they may use the autopilot system effectively and safely.

McKenna, Frank P., Duncan, John, and Brown, Ivan D. "Cognitive Abilities and Safety On The Road: A Re-Examination of Individual Differences in Dichotic Listening and Search for Embedded Figures." *Ergonomics,* 29(5), 1986, pp. 649-663.

Summary: Five cognitive ability tests were administered to a sample of 153 bus-driver trainees. The embedded figures test (EFT) of Witkin (1950) and the dichotic listening test (DLT) of Gopher and Kahneman (1971) were chosen on the basis of previously reported correlations with driving accident rate. The remainder were designed to cast light on what cognitive processes the EFT and DLT measure, and hence why they should relate to driving ability. The EFT correlated only marginally with success in driver training and with accident rate in a follow-up period of two years. There was support for the hypothesis that this test measures a general ability to resist the influence of dominant stimuli. Instead a substantial correlation (.64) was obtained with a typical 'intelligence' test. The DLT showed no correlations with driver performance measures, thus failing to replicate earlier findings. There was no support for the hypothesis that this test measures a general ability to switch from one task or mental set to another. We suggest that analysis of the cognitive processes of driving cannot be based on overall measures such as accident rate. Instead, the task must be studied at the level of component skills.

Muto, William and Wierwille, Walter. “The Effect of Repeated Emergency Response Trials on Performance During Extended-Duration Simulated Driving.” *Human Factors,* 24(6), 1982, pp. 693-698.

Summary: This investigation studied the effects of 30, 60, and 150 minutes of continuous driving on drivers' response times to repeated response trials in a simulated emergency --the sudden deceleration of a lead vehicle in a simulated car-following scenario. The results indicated that mean response times of early trials tended to be slower than those of later trials and those of baseline trials. These data imply that repeated response trials can modify decrements normally associated with fatigue mechanisms, and that studies using repeated response trials during driving may not yield valid indications of fatigue-induced performance decrements.

O'Hare, David and Roscoe, Stanley. Flightdeck Performance: The Human Factor. Iowa State University Press, 1990.

Summary: "Learning, memory, attention, perception, thinking and problem solving, verbalization, and social facility are traditional subject divisions within psychology. A complex activity like flying involves all of these capacities...[There] has been a widespread recognition of the need to understand the abilities and limitations of the human in performing the complex activity of flying an aircraft. An important aspect of this is that more detailed attention is now given to the causes of error and the necessity to consider the human and technological aspects of flying as mutually interdependent rather than entirely separate factors. Pilot error is being tied ever closer to the design of equipment and air traffic procedures, to inadequate and sometimes inappropriate training, and to questionable operational doctrine by management The information considered in this book is concerned with the more fundamental limitations of our sensory systems and our strategies for dealing with information. These set the limits on what is possible for the pilot and contribute to our understanding of errors in performance. This book also presents much of what is known about human behavior that is relevant to the primary task of designing aircraft to make them safer to fly and selecting and training pilots to achieve the same goal."

Olson, Paul L., and Sivak, Michael. “Perception-Response Time to Unexpected Roadway Hazards.” *Human Factors,* 28(1), 1986, pp. 91-96.

Summary: Perception-response (PR) time, the time from the first sighting of an obstacle until the driver apples the brakes, is an important component of stopping sight distance. The purpose of this study was to measure the PR time of unalerted subjects to an obstacle in their lane encountered while cresting a hill. Data were obtained from 64 subjects, of whom 49 were young and 15 older. Measures were made of the time from first sighting of the obstacle until the accelerator was released, as well as accelerator-to-brake time. The results indicate a 95th percentile PR time of about 1.6s for both age groups.

Olson, *et al.* Development of a Headlight System Performance Evaluation Tool (Final Report). National Highway Traffic Safety Administration, U.S. Department of Transportation, University of Michigan, 1990.

Orlady, Harry W. "Flight Crew Performance When Pilot-Flying and Pilot-Not-Flying Duties are Exchanged*." Proceedings of the Human Factors Society--26th Annual Meeting*, 1982.

Summary: This study uses reports from the ASRS database depicting operational anomalies related to night crew performance when pilot-flying and pilot-not-flying duties were exchanged. A greater number of near midair collisions, takeoff anomalies, and crossing altitude deviations were reported when the Captain was flying. More altitude deviations, near midair collisions during approach landing incidents occurred when the First Officer was flying. There were differences in monitoring effectiveness and in the type and distribution of information transfer problems associated with the anomalies. In addition, a number of crew performance factors were noted that were not affected by the exchange of duties. Several of these were deemed important enough to be included as matter of general interest.

Parasuraman, Raja. "Human-Computer Monitoring." *Human Factors,* 29(6), 1987, pp. 695-706.

Summary: Attentional factors can influence user interaction with automated and semi-automated monitoring systems. Three aspects of human-computer monitoring are considered in this paper: (1) vigilance effects in complex monitoring tasks, (2) factors influencing optimal combination of human and computer monitors, and (3) effects if increased automation of the relationship between mental workload and vigilance. Results of laboratory and simulation studies suggest that vigilance effects can limit performance in complex monitoring tasks. Performance deficits may occur because of either vigilance decrement over time or sustained low levels of vigilance. However, the specific factors that influence sustained performance with complex displays have not been identified precisely. Computer assistance to enhance performance is feasible but may not be effective in all cases. Performance gain is dependent on several factors, including the decision rule for combining human and computer decisions and the level of mental workload imposed on the human monitor. Finally, in assessing the impact for increased automation the beneficial effects on mental workload have to be traded off against possible adverse effects on vigilance. The implications of these factors for the design of automated monitoring systems are discussed.

Parasuraman, Raja, Mooloy, Robert and Singh, Indramani L. “Performance Consequences of Automation-Induced ‘Complacency’.” *The International Journal of Aviation Psychology,* 3(1), 1993, pp. 1-23.

Summary: The effect of variations in the reliability of an automated monitoring system on human operator detection of automation failures was examined in two experiments. For four 30-minute sessions, 40 subjects performed and IBM PC-based flight simulation that included manual tracking and fuel-management tasks, as well as a system-monitoring task that was under automation control. Automation reliability --the percentage of system malfunctions detected automation routine--either remained constant a low or high level over time or alternated every 10 minutes from high to low. Operator detection of automaton failures was substantially worse for constant-reliability than for variable-reliability automation after about 20 minutes under automation control, indicating that the former condition induced "complacency". When system monitoring was the only task, detection was very efficient and was unaffected by variations in automation reliability. The results provide the first empirical evidence of the performance consequences of automation-induced "complacency". We relate findings to operator attitudes toward automation and discuss implications for cockpit automation design.

Perez, William A., et al. Unified Tri-Services Cognitive Performance Assessment Battery: Review and Methodology. Systems Research Laboratories, Inc., Armstrong Aerospace Medical Research Laboratory, AAMRL-TR-87-007, 1987.

Summary: The Unified Tri-Services Cognitive Performance Assessment Battery (UTC-PAB) represents the primary metric for a Level 2 evaluation of cognitive performance in the JWGD3 MILPERF chemical defense biomedical drug screening program. The UTC-PAB contains a menu of 25 tests that were selected from test batteries in existence throughout the Department of Defense Research Laboratories. Test selection was based upon established test validity and relevance to military performance. Sensitivity to effects of hostile environments and sustained operations were also considerations involved in test selection.

Summary: This report presents a scheme for organizing the tests in the UTC-PAB. Also, extensive documentation for each test is presented in the following areas: background literature review focusing on the theoretical basis of the test; information regarding the reliability, validity, and sensitivity of the test; data specifications; and instructions to subjects. This information is presented to guide researchers in the selection and interpretation of tests in the UTC-PAB.

Poynter, D. The Effects of Aging on Perception of Visual Displays. SAE Technical Paper Series, Passenger Car Meeting and Exposition, 1988.

Summary: Difference in the perception of visual displays in older drivers.

Price, Harold E. “The Allocation of Functions in Systems.” *Human Factors,* 27(1), 1985, pp. 33-45.

Summary: A systematic approach for allocating functions to humans and machines has been an elusive goal of human factors specialists for more than 30 years. The author has fortunately been able to obtain contract support for reviewing the earlier techniques and methods in the literature and deriving "lessons learned" to guide the development of the approach reported here. The approach is believed to be systematic and embedded in the overall system design process. This paper describes the systems approach to design and how the allocation of functions is a part of it, as a five-step procedure with four principal rules for arriving at a hypothetical allocation.

Ramsey and Morrisey. “Isodecrement Curves for Task Performance in Hot Environments.” *Applied Ergonomics*, 9, 1978, pp. 66-72.

Summary: The effects of hot environments on the vigilance decrement.

Ranney, Thomas A., *et al.* “Nonintrusive Measurement of Driving Performance in Selected Decision-Making Situations.” Transportation Research Record # 1059, 1986, pp. 17-23.

Summary: Driving simulators and instrumented vehicles both require subjects to control an unfamiliar apparatus, which can result in a potential confounding of task variables and individual differences in adaptability. An experimental methodology, which allows subjects to use their own vehicles on a closed driving range, was developed together with inductive loops to record vehicle speed and position at selected locations are controlled by a PDP 11/23 computer located in an instrumented van beside the intersection. Auxiliary signs and distracters are used together with instructions to present a variety of driving decision situations. Research objectives and limitations of the system are discussed.

Reeves, D.L. and Throne, D.R. *A Synopsis of UTC-PAB Development.* Naval Medical Research and Development Command, AAMRL-TR-87-007, 1986.

Summary: This report provides a brief overview of the Unified Tri-Services Cognitive Performance Assessment Battery, including reasons behind its development, as well as the methodology used in the development process.

Reeves, D.L., et al. The Unified Tri-Services Cognitive Performance Assessment Battery (UTC-PAB)--2. Hardware/Software Design and Specifications. Naval Aerospace Medical Research Laboratory, Walter Reed Army Institute of Research, NAMRL - WRAIR SR89 -1, 1988.

Summary: The Tri-Service Joint Working Group on Drug Dependent Degradation of Military Performance (JWGD3-MILPERF) has been given responsibility for developing and implementing a program to screen medical chemical defense pretreatment and treatment drugs. The screening program is based on a multiple level assessment of performance. This report provides a description of the hardware and software environment that is being developed in support of the Level II Unified Tri-Services Cognitive Performance Assessment Battery (UTC-PAB). The objective of the present effort is to establish a performance assessment system (PAS) that will promote standardization and interoperability, and provide a vehicle for establishing an interlaboratory communications and data network among the participating JWGD3 MILPERF military and civilian contractor laboratories.

Regina, Edmund, *et al.* “Effects of Caffeine on Alertness in Simulated Automobile Driving.” *Journal of Applied Psychology,* 59(4), 1974, pp. 483-489.

Summary: Thirty minutes after ingesting 200 milligrams of caffeine or a placebo, each of 24 male subjects drove an automobile simulator for 90 minutes. Immediately thereafter, the subject ingested a supplemental dose of the medication taken initially (200 milligrams of caffeine or placebo), and then drove for another 90 minutes. The simulator provided a comprehensive and coherent set of stimulus inputs which produced a degree of realism not usually found in laboratory studies. Both the initial and the supplemental doses of caffeine significantly enhanced performance beyond that found with placebo, on each of four measures of alertness.

Rumar, Kare. “The Basic Driver Error: Late Detection.” *Ergonomics,* 33(10/11), 1990, pp. 1281-1290.

Summary: Over the past two or three decades we have been quite successful in reducing injuries of car occupants by the use of energy-absorbing techniques; but we have not been as successful in reducing the risks of having collisions. When drivers are asked why an accident occurred very often they claim that they saw the other road user too late to avoid collision. This paper discusses the basic road user error of failing to see another road user in time, why such errors happen, and how they can be reduced.

A detection error is basic, because without detection no processing of information, no decision process including that road user, takes place. Among the many causes of detection error two of the more important are: 1) A lapse of cognitive expectation, illustrated by the failure to scan for a particular class of road user, or to look in the appropriate direction; and 2) A difficulty with perceptual thresholds, illustrated by the failure to discern the relevant stimuli in lower levels of ambient illumination or in situations where vehicles approach in the peripheral visual field of road users.

Sarter, Nadine B. and Woods, David D. “Pilot Interaction With Cockpit Automation: Operational Experiences With the Flight Management System.” *The International Journal of Aviation Psychology,* 2(4), 1992, pp. 303-321.

Summary: Due to recent incidents involving glass cockpit aircraft, there is growing concern about cockpit automation and its potential effects on pilot performance. However, little is known about the nature and causes of problems that arise in pilot-automation interaction. In this article, we report the results of two studies that provide converging, complementary data on pilots' difficulties with understanding and operating one of the core systems of cockpit automation, the Flight Management System (FMS). As vehicles to gather a corpus on the nature and variety of FMS-related problems, we used a survey asking pilots to describe specific incidents with the FMS, and we used the observations of pilots undergoing transition training to a glass cockpit aircraft. The results of both studies indicate that pilots become proficient in standard FMS operations through ground training and subsequent line experience. But even with considerable experience, they still have difficulties tracking FMS status and behavior in certain flight contexts, and they show gaps in their understanding of the functional structure of the system. The results attest that design-related factors such as opaque interfaces contribute to these difficulties, which can affect pilots' situation awareness. The results of this research are relevant for both the design of cockpit automation and the development of training curricula specifically tailored to the needs of glass cockpits.

Sarter, Nadine B. and Woods, David D. “Pilot Interaction With Cockpit Automation II: An Experimental Study of Pilots' Model and Awareness of the Flight Management System.” *The International Journal of Aviation Psychology,* 4(1), 1994, pp. 1-28.

Summary: Technological developments have made it possible to automate more and more uses on the commercial aviation flight deck and in other dynamic high-consequence domains. This increase in the degrees of freedom in design has shifted questions away from narrow technological feasibility. Many concerned groups, from designers and operators to regulators and researchers, have begun to ask questions about how we should use the possibilities afforded by technology skillfully to support and expand human performance. In this article, we report on an experimental study that addressed these questions by examining pilot interaction with the current generation of flight deck automation. Previous results on pilot-automation interaction derived from pilosurveys, incident reports, and training observations have produced a corpus of features and contexts in which human-machine coordination is likely to break down (e.g., automation surprises). We used these data to design a simulated flight scenario that contained a variety of probes designed to reveal pilots' mental model on one major component of flight deck automation: the Flight Management System (FMS). The events within the scenario were also designed to probe pilots' ability to apply their knowledge and understanding in specific flight contexts and to examine their ability to track the status and behavior of the automated system (mode awareness). Although pilots were able to "make the system work" in standard situation, the results reveal a variety of latent problems in pilot-FMS interaction that can affect pilot performance in non-normal time critical situations.

Shinar, David. Psychology on the Road: The Human Factor in Traffic Safety. John Wiley & Sons, 1978.

Summary: This book introduces the role of psychology in highway safety. It provides an opportunity for traffic engineers to appreciate better the role of driver behavior in their, and traffic safety experts to understand the effects of human behavior on the road. This book contains sections on driving research methodology, individual differences, the driver as an information processor, human factors in highway traffic accidents, implications for safety and the pedestrian.

Sivak, Michael, *et al*. “Brake Lamp Photometrics and Automobile Rear Signaling.” *Human Factors,* 29(5), 1987, pp. 533-540.

Summary: The objective of this study was to evaluate the relationship of lamp photometrics to differentiation between brake and presence signals. To asses this relationship, signal identification was evaluated as a function of lam photometric under simulated dusk/dawn conditions. the following were the main results: (1) Luminous intensity was a better predictor of signal identification than was average luminance. (2) The likelihood of identifying a signal as a brake signal was a monotonic function of lamp intensity. (3) Reaction time was positively related to the degree of subjects’ uncertainty (as measured by the relative likelihood of “brake” responses): reaction time was slowest when the likelihood of “brake” or “presence” responses was close to 50%.

(4) Reaction time in a condition simulating typical U.S. rear-lighting configuration was significantly faster than in a condition simulating typical European configuration. The present results provide support for retaining luminous intensity as the relevant parameter of automobile brake-lighting specifications. Furthermore, these results argue against reducing the current minimum of 80 cd for the brake-lamp luminous intensity.

Smith, R.L., *et al.* “Effects of Anticipatory Signals and a Compatible Secondary Task on Vigilance Performance.” *Journal of Applied Psychology*, 50, 1966, pp. 240-246.

Summary: The effects of manipulating signals while performing a compatible secondary task.

Stanney, R., et al. Modeling the Unified Tri-Services Cognitive Performance Assessment Battery. Naval Aerospace Medical Research Laboratory, 1989.

Summary: This report describes three models of performance assessment tests drawn from the Unified Tri-Services Cognitive Performance Assessment Battery. Discussed are Four-Choice Visual Reaction Time, Grammatical Reasoning, and the Manikin Spatial Perception tests. The Four-Choice Reaction Time model is an information accumulation model with variable decision criteria; major performance limits are imposed by sensory- and memory-system noise. The Grammatical Reasoning model is a transformational-syntax model; major performance limits are imposed by working memory capacity. The Manikin Spatial Perception Test admits several different strategies, one of which appears to involve mentally rotating an image of the test stimulus. Performance, when the rotational strategy is used, engages an imagery system that probably includes portions of the central visual system as defined by conventional anatomical criteria.

Staplin, L., Lococo, K., Sim, J. Volume II: Traffic Control Design Elements for Accommodating Drivers with Diminished Capacity. U.S. Department of Transportation, 1990.

Summary: A study of ways to accommodate drivers with disabilities in the traffic system.

Stelmach, George E. and Nahom, Ariella. “Cognitive-Motor Abilities of the Elderly Driver.” Human Factors, 34(1), 1992, pp. 53-65.

Summary: This article reviews literature that documents the effects of age on motor performance as it relates to driving behavior. Movement initiation is the focal point of the first part of the article, and it is considered in terms of absolute age differences when functional manipulations are made, such as response preparation, response selection, response programming, and complexity. The second part of the article addresses age difference in the context of movement execution characteristics; differences in movement speed, force production, limb coordination, and sensory motor integration are considered. Movement time and movement kinematics and kinetics are the principal dependent measures reviewed. Adults were found to initiate and execute movements more slowly and with less precision as they age, which may contribute to the decline of their driving skill. Most of the data reviewed were obtained in laboratory settings; nevertheless, they suggest how age may impair the elderly driver.

Triggs, Thomas J. “Human Performance and Driving: The Role of Simulation in Improving Young Driver Safety” International Ergonomics Association, Annual Meeting. Volume 1: Regards Internationales, 1994.

Summary: Recent significant improvement in the capabilities of transportation simulators have provided an impetus to their increased use in the study of human performance associated with driving.

How driving simulators can be used as a central component of a young driver road safety program will be discussed in this paper. The significant over involvement of young and/or inexperienced drivers in crashes is a well established phenomenon and is recognized to be a most intractable road safety problem.

There still exist major shortfalls in our understanding of what constitutes safe driving. Modern simulation provides a means by which a performance-based approach can be adopted in the development of a detailed model of the young driver, and some simulation research on the attentional aspects of driving will be reported in this paper. Additionally, how simulators might be developed as effective driver training tools will be discussed. Simulation brings a number of capabilities to the training process which previously have not been available and are likely to generate positive training benefits.

Vidulich, Michael A., *et al.* “Performance-Based and Physiological Measures of Situational Awareness.” *Aviation, Space and Environmental Medicine*, 65(5, Supplement), 1994, pp. A7-A12.

Summary: Several situational awareness (SA) and workload measurement techniques were investigated in simulated air-to-ground missions. These techniques included measures of effectiveness, subjective ratings, performance measures, and physiological measures. The results demonstrated strengths and weaknesses in all of these techniques. Measures of effectiveness and subjective ratings suggested that the experimental manipulations were effective in altering SA. The performance measures produced mixed results. Physiological measures detected some intriguing effects in the EEG. overall, the complexity of the relationship between SA and workload encourages the use of multiple tools in any SA evaluation.

Waag, W.L. and Houck, M.R. “Tools for Assessing Situational Awareness in an Operational Fighter Environment.” *Aviation, Space and Environmental Medicine,* 65(5, Supplement), 1994, pp. A13-A19.

Summary: Three Situational Awareness Rating Scales (SARS) were developed to measure pilot performance in an operational fighter environment. These instruments rated situational awareness (SA) from three perspectives: supervisors, peers, and self-report. SARS data were gathered from 205 mission ready USAF F-15C pilots from 8 operational squadrons. Reliability of the SARS were quite high, as measured by their internal consistency (.95 to .99) and inter-rater agreement (.88 to .97). Correlations between the supervisory and peer SARS were strongly positive (.89 to .92), while correlations with the self-report SARS were positive, but smaller (.45 to .57). A composite SA score was developed from the supervisory and peer SARS using a principal components analysis. The resulting score was found to be highly related to previous flight experience and current flight qualification. A prediction equation derived from available background and experience factors accounted for 73% of its variance. Implications for use of the composite SA score as a criterion measure are discussed.

Wetherell, Anthony. “The Efficacy of Some Auditory-Vocal Subsidiary Tasks as Measures of the Mental Load on Male and Female Drivers.” *Ergonomics,* 24(3), 1981, pp. 197-214.

Summary: Eight male and eight female drivers took part in a study to assess the efficacy of a number of auditory-vocal subsidiary tasks as measures of the mental load imposed by driving under standardized conditions. Performing the subsidiary tasks appeared to interfere with female driving ability, but not with that of males. Some differences in subsidiary task performance were found between driving and non-driving conditions for both males and females. However, no one task appeared outstanding as a measure of mental load, and the performance decrements may have been due as much to auditory masking by the car noise as to competition for information processing resources. The validity of dual-task methods is discussed, and it is argued that the use of common sensory or response modes cannot be avoided, but may in some cases be used to advantage.

Wickens, Christopher. “Processing Resource Demands of Failure Detection in Dynamic Systems.” *Journal of Experimental Psychology,* 6(3), 1980, pp. 564-577.

Summary: The information -processing channels, proprioceptive versus visual, that are used to detect changes in the response of dynamic systems are investigated using a loading-task methodology. Conditions are compared in which subjects either control the dynamic system (MA mode) or monitor an autopilot controlling the same system (AU mode). Failure detection in these two modes of participation is evaluated when subjects perform the task alone and concurrently with either a tracking loading task or a mental arithmetic-memory loading task. The former task disrupted MA detection but not AU detection, whereas the converse results were obtained with mental-arithmetic task. The results, interpreted within the framework of a structure-

specific resource theory of human attention, suggest that AU detection relies exclusively on processing resources associated with perceptual/central-processing stages. MA detection in contrast relies on separate-processing resources residing in a response-related reservoir.

Wickens, Christopher. Engineering Psychology and Human Performance. Harper Collins Publishers, 1992.

Summary: This book examines human capabilities and limitations in the specific area of information processing. It also demonstrates how knowledge of these limitations can be applied in the design of complex systems within which humans interact.

Wiener, Earl L. “Controlled Flight into Terrain Accidents: System Induced Errors.” *Human Factors,* 19(2),1977, pp. 171-181.

Summary: Controlled flight into terrain accidents are those in which an aircraft, under the control of the crew, is flown into terrain (or water) with no prior awareness on the part of the crew of the impending disaster. This paper examines recent experience with these accidents, seeing them as the result of errors generated by a complex air traffic control system with ample opportunities for system-induced errors. Such problem areas as pilot-controller communication, flightdeck workload, noise-abatement procedures, government regulation, visual illusions, and cockpit- and ground-radar warning devices are discussed, with numerous examples of recent accident cases. The failure of the human factors profession to play a more significant role in the air traffic complex is also considered.

Wiener, Earl L. “Beyond the Sterile Cockpit.” *Human Factors,* 27(1), 1985, pp. 75-90.

Summary: The rapid advance of cockpit automation, enabled by microprocessor technology and motivated by the quest for safer and more efficient flight, has both its supporters and its detractors. Even the supporters tend to view the march toward computer-directed flight as a mixed blessing. Certain dramatic accidents and incidents in recent years, as well as the destruction of Korean Airlines Flight 007, have been interpreted by many as automation induced. Many of the critics outside of the aviation community, journalists, and the general public, have harped on the negative side of flight-deck automation without recognizing its positive aspects. The author advances the view that the time-honored recommendation that humans should serve as monitors of automatic devices must be reconsidered, and that the human must be brought back into a more active role in the control loop, aided by decision support systems.

Weiner, Earl L. “Knowledge of Results and Signal Rate in Monitoring.” *Perceptual and Motor Skills*, 18, 1963, p. 104+.

Summary: How feedback affects detection performance.

Wiener, Earl L., and Curry, Renwick E. “Flight-Deck Automation: Promises and Problems.” *Ergonomics,* 23(10), 1980, pp. 995-1011.

Summary: Modern microprocessor technology and display systems make it entirely feasible to automate many of the flight-deck functions previously performed manually. There are many benefits to be derived from automation; the question today is not whether a function can be automated, but whether it should be, due to various human factors issues. It is highly questionable whether total system safety is always enhanced by allocating functions to automatic devices rather than human operators, and there is me reason to believe that flight-deck automation may have already passed its optimum point. This is an age-old question in the human factors profession, and there are few guidelines available to the system designer.

This paper presents the state-of-the-art in human factors in flight-deck automation, identifies a number of critical problem areas, and offers broad design guidelines. Some automation-related aircraft accidents and incidents are discussed as examples of human factors problems in automated flight.

Wooller, J. “The Measurement of Driver Performance.” *Ergonomics,* 15(1), 1972, pp. 81-87.

Summary: Four subjects drove the same car over a predetermined route with approximately ten replications each. Measurements of driver performance were derived from data collected photographically. Individual patterns of behavior were identified and measured. A hypothesis is proposed whereby a driver's performance may be specified.

Yoss, Robert E., *et al.* “Commercial Airline Pilot and His Ability to Remain Alert.” *Aerospace Medicine,* 41(12), 1970, pp. 1339-1346.

Summary: Fifty commercial airline pilots were studied, by means of infrared pupillography, as to the ability of each to remain alert while sitting in darkness for 15 minutes. The pupils of those who remained alert were large and stable; if drowsiness developed the pupils became smaller and papillary waves appeared, with ptosis or eyelid closures. The performance of each subject was placed in one of four categories: superior, average, marginal, or unsatisfactory. Of the 32 pilots who were regarded as well rested, 28 performed in either a superior or an average manner; the performance of 3 was marginal; and 1 gave an unsatisfactory performance. Pilots with inadequate rest did less satisfactorily in their tests, as a group. it is recommended that testing of this type be studied further, since the ability to remain alert at present is not included in the assessment of pilots for medical certification by the Federal Aviation Administration.

APPENDIX B: WILLIAMSVILLE TOLL BARRIER DATA

The following data was obtained from the New York State Thruway Authority. The data included in these tables is from 1990-1992, for the Williamsville Toll Barrier.

Table 2-B1. Day of the Week Accident Analysis

	Eastbound		Westbound		Grand Total	
Day of the Week	**Frequency**	**Percent**	**Frequency**	**Percent**	**Frequency**	**Percent**
Monday	8	10.67	6	8.00	14	18.67
Tuesday	3	4.00	7	9.33	10	13.33
Wednesday	3	4.00	6	8.00	9	12.00
Thursday	2	2.67	7	9.33	9	12.00
Friday	5	6.67	12	16.00	17	22.67
Saturday	1	1.33	5	6.67	6	8.00
Sunday	5	6.67	5	6.67	10	13.33
Grand Total	27	36.00	48	64.00	75	100.00

Table 2-B2. Hour of Day Accident Analysis

	Eastbound		Westbound		Grand Total	
Time of Day	**Frequency**	**Percent**	**Frequency**	**Percent**	**Frequency**	**Percent**
12:00 am	1	1.33	0	0.00	1	1.33
1:00 am	2	2.67	3	4.00	5	6.67
2:00 am	0	0.00	2	2.67	2	2.67
3:00 am	5	6.67	1	1.33	6	8.00
4:00 am	2	2.67	0	0.00	2	2.67
5:00 am	0	0.00	1	1.33	1	1.33
6:00 am	0	0.00	1	1.33	1	1.33
7:00 am	0	0.00	0	0.00	0	0.00
8:00 am	0	0.00	1	1.33	1	1.33
9:00 am	0	0.00	2	2.67	2	2.67
10:00 am	1	1.33	2	2.67	3	4.00
11:00 am	2	2.67	3	4.00	5	6.67
12:00 pm	2	2.67	2	2.67	4	5.33
1:00 pm	1	1.33	3	4.00	4	5.33
2:00 pm	1	1.33	5	6.67	6	8.00
3:00 pm	2	2.67	2	2.67	4	5.33
4:00 pm	4	5.33	2	2.67	6	8.00
5:00 pm	1	1.33	3	4.00	4	5.33
6:00 pm	1	1.33	4	5.33	5	6.67
7:00 pm	1	1.33	5	6.67	6	8.00
8:00 pm	0	0.00	1	1.33	1	1.33
9:00 pm	0	0.00	2	2.67	2	2.67
10:00 pm	0	0.00	2	2.67	2	2.67
11:00 pm	1	1.33	1	1.33	2	2.67
Grand Total	27	36.00	48	64.00	75	100.00

Table 2-B3. Number of Vehicles Involved in Accident

	Eastbound		Westbound		Grand Total	
Number of Vehicles Involved	**Frequency**	**Percent**	**Frequency**	**Percent**	**Frequency**	**Percent**
1	10	13.33	8	10.67	18	24.00
2	14	18.67	37	49.33	51	68.00
3	2	2.67	3	4.00	5	6.67
4	1	1.33	0	0.00	1	1.33
Grand Total	27	36.00	48	64.00	75	100.00

Table 2-B4. Occupants Injured in Accident

	Eastbound		Westbound		Grand Total	
Number of Persons Injured	Frequency	Percent	Frequency	Percent	Frequency	Percent
0	22	29.33	40	53.33	62	82.67
1	4	5.33	6	8.00	10	13.33
2	1	1.33	2	2.67	3	4.00
Grand Total	27	36.00	48	64.00	75	100.00

Table 2-B5. Analysis of Crash Location

	Eastbound		Westbound		Grand Total	
Crash Location	**Frequency**	**Percent**	**Frequency**	**Percent**	**Frequency**	**Percent**
Toll Island (+/- 50 feet)	14	18.67	19	25.33	33	44.00
Toll Plaza	13	17.33	27	36.00	40	53.33
Parking Area	0	0.00	1	1.33	1	1.33
Employee Parking Area	0	0.00	1	1.33	1	1.33
Grand Total	27	36.00	48	64.00	75	100.00

Table 2-B6. Light Conditions at Time of Accidents

	Eastbound		Westbound		Grand Total	
Light Conditions	**Frequency**	**Percent**	**Frequency**	**Percent**	**Frequency**	**Percent**
Daylight	16	21.33	25	33.33	41	54.67
Dawn	0	0.00	1	1.33	1	1.33
Dusk	2	2.67	1	1.33	3	4.00
Dark Road - Lighted	9	12.00	18	24.00	27	36.00
Dark Road- Unlighted	0	0.00	3	4.00	3	4.00
Grand Total	27	36.00	48	64.00	75	100.00

Table 2-B7. Traffic Control Analysis

	Eastbound		Westbound		Grand Total	
Traffic Control	**Frequency**	**Percent**	**Frequency**	**Percent**	**Frequency**	**Percent**
None	27	36.00	47	62.67	74	98.67
Construction Work Area	0	0.00	1	1.33	1	1.3
Grand Total	27	36.00	48	64.00	75	100.00

Table 2-B8. Analysis of Roadway Characteristics

	Eastbound		Westbound		Grand Total	
Roadway Character	**Frequency**	**Percent**	**Frequency**	**Percent**	**Frequency**	**Percent**
Straight and Level	26	34.67	47	62.67	73	97.33
Straight and Grade	0	0.00	1	1.33	1	1.33
Curve and Level	1	1.33	0	0.00	1	1.33
Grand Total	27	36.00	48	64.00	75	100.00

Table 2-B9. Road Surface Conditions at Time of Accidents

	Eastbound		Westbound		Grand Total	
Roadway Surface Condition	**Frequency**	**Percent**	**Frequency**	**Percent**	**Frequency**	**Percent**
Dry	23	30.67	35	46.67	58	77.33
Wet	4	5.33	11	14.67	15	20.00
Snow/Ice	0	0.00	2	2.67	2	2.67
Grand Total	27	36.0	48	64.00	75	100.00

Table 2-B10. Weather Conditions at Time of Accidents

	Eastbound		Westbound		Grand Total	
Weather Conditions	**Frequency**	**Percent**	**Frequency**	**Percent**	**Frequency**	**Percent**
Clear	17	22.67	24	32.00	41	54.67
Cloudy	6	8.00	14	18.67	20	26.67
Rain	4	5.33	7	9.33	11	14.67
Snow	0	0.00	3	4.00	3	4.00
Grand Total	27	36.00	48	64.00	75	100.00

Table 2-B11. Primary Action in Accident

	Eastbound		Westbound		Grand Total	
Primary Action	**Frequency**	**Percent**	**Frequency**	**Percent**	**Frequency**	**Percent**
Rear-End Collision	10	13.33	28	37.33	38	50.67
Side-Swipe Collision	5	6.67	10	13.33	15	20.00
Backing Up Collision	3	4.00	2	2.67	5	6.67
Entered Right Shoulder	0	0.00	1	1.33	1	1.33
Collision with Object on Pavement	1	1.33	0	0.00	1	1.33
Struck Toll Booth	1	1.33	0	0.00	1	1.33
Ran into Attenuation Device	3	4.00	5	6.67	8	10.67
Ran into Toll Booth Island	4	5.33	2	2.67	6	8.00
Ran into Right Guide Rail	0	0.00	0	0.00	0	0.00
Grand Total	27	36.00	48	64.00	75	100.00

Table 2-B12. Secondary Action in Accident

	Eastbound		Westbound		Grand Total	
Secondary Action	**Frequency**	**Percent**	**Frequency**	**Percent**	**Frequency**	**Percent**
None	25	33.33	46	61.33	71	94.67
Ran into Attenuation Device	1	1.33	1	1.33	2	2.67
Ran into Toll Booth Island	1	1.33	0	0.00	1	1.33
Ran into Right Guide Rail	0	0.00	1	1.33	1	1.33
Grand Total	27	36.00	48	64.00	75	100.00

Table 2-B13. Cause of Accident

	Eastbound		Westbound		Grand Total	
Cause	**Frequency**	**Percent**	**Frequency**	**Percent**	**Frequency**	**Percent**
Alcohol Involvement	1	1.33	1	1.33	2	2.67
Backing Unsafely	1	1.33	1	1.33	2	2.67
Driver Inattention	3	4.00	9	12.00	12	16.00
Fell Asleep	0	0.00	1	1.33	1	1.33
Following Too Closely	5	6.67	10	13.33	15	20.00
Passing or Lane Usage Improper	1	1.33	3	4.00	4	5.33
Turning Improperly	1	1.33	0	0.00	1	1.33
Unsafe Speed	2	2.67	6	8.00	8	10.67
Unsafe Lane Change	5	6.67	7	9.33	12	16.00
Other Human Cause	1	1.33	4	5.33	5	6.67
Brakes Defective	2	2.67	3	4.00	5	6.67
Oversized Vehicle	3	4.00	1	1.33	4	5.33
Tire Failure or Inadequate	0	0.00	1	1.33	1	1.33
Other Vehicular Cause	1	1.33	0	0.00	1	1.33
Obstruction/Debris	1	1.33	0	0.00	1	1.33
View Obstructed or Limited	0	0.00	1	1.33	1	1.33
Grand Total	27	36.00	48	64.00	75	100.00

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