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# Drivers' Activities and Information Needs in an Automated Highway System

Research and Development
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# FOREWORD

This report presents the results of 3 experiments in a series of 14 that investigated driver performance in a generic Automated Highway System configuration. The experimental research was conducted in an advanced driving simulator and involved: (1) looking at driver behavior while traveling under automated control, and (2) exploring what information drivers would like to have available when under automated control. This report will be of interest to engineers and researchers involved in Intelligent Transportation Systems and other Advanced Highway Systems.

Sufficient copies of the report are being distributed to provide a minimum of two copies to each FHWA regional and division office, and five copies to each State Highway Agency. Direct distribution is being made to division offices.

A. George Ostensen, Director
Office of Safety and Traffic Operations
Research and Development

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16. Abstract
These experiments investigated what drivers do when traveling under automated control, and what information they would like to have available during that time. Eighteen drivers ages 25 through 34 and 18 drivers age 65 or older participated in the first two experiments; 6 drivers participated in the third experiment. All experiments were conducted in the Iowa Driving Simulator. The driver drove the simulator vehicle onto a freeway and then moved to the center lane; following a period of manual driving, control was transferred to the AHS, and the driver traveled under automated control for at least 34 min. In the first two experiments, which were run together and consisted of a single trial for each driver, driver activities were videotaped for later analysis. In addition, a laptop computer was mounted near the driver that offered several types of information. Drivers were given a questionnaire after the experiment to allow ratings of and comments on the various information types. In the third experiment, each driver participated in eight trials, once each in the morning and afternoon on 4 days, simulating a commuter experience. Driver activities were again videotaped for later analysis, but there was no laptop computer available.

<u>Results</u>: In the two noncommuter experiments, drivers undertook a variety of activities, though despite pre-experiment encouragement to do so, almost no one brought any materials with them. Thus, the activities included such things as reading the strip map that was in the car, talking to the experimenter, adjusting the radio, and so on. The most frequent activity was using the laptop computer. A third of the drivers closed their eyes at least once for 5 or more consecutive seconds, with averages of 5.7 and 7.1 times for males and females, respectively. Regarding the information available on the laptop computer, drivers found information about the next exit to be least useful. Information about the driver's current location and the traffic ahead were more useful than next exit information. And information about time to the destination was selected significantly more frequently than the other three types of information. Drivers offered several suggestions for additional information they would like to have available during a trip on the AHS. In the commuter experiment, it was noted, however, that only two drivers brought something to do on the next-to-last trial, a somewhat surprising result in light of the fact that the drivers clearly knew by then that they would have almost half an hour during which they did not have any driving-related responsibilities.

17. Key Words
Automated Highway System, intelligent vehicles, human factors, observations of driver behavior, information during automated travel.

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# SI* (MODERN METRIC) CONVERSION FACTORS

## APPROXIMATE CONVERSIONS TO SI UNITS

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| in | inches | 25.4 | millimeters | mm |
| ft | feet | 0.305 | meters | m |
| yd | yards | 0.914 | meters | m |
| mi | miles | 1.61 | kilometers | km |
| | | **AREA** | | |
| $in^2$ | square inches | 645.2 | square millimeters | $mm^2$ |
| $ft^2$ | square feet | 0.093 | square meters | $m^2$ |
| $yd^2$ | square yards | 0.836 | square meters | $m^2$ |
| ac | acres | 0.405 | hectares | ha |
| $mi^2$ | square miles | 2.59 | square kilometers | $km^2$ |
| | | **VOLUME** | | |
| fl oz | fluid ounces | 29.57 | milliliters | mL |
| gal | gallons | 3.785 | liters | L |
| $ft^3$ | cubic feet | 0.028 | cubic meters | $m^3$ |
| $yd^3$ | cubic yards | 0.765 | cubic meters | $m^3$ |
| NOTE: Volumes greater than 1000 l shall be shown in $m^3$. | | | | |
| | | **MASS** | | |
| oz | ounces | 28.35 | grams | g |
| lb | pounds | 0.454 | kilograms | kg |
| T | short tons (2000 lb) | 0.907 | megagrams (or "metric ton") | Mg (or "t") |
| | | **TEMPERATURE (exact)** | | |
| °F | Fahrenheit temperature | 5(F-32)/9 or (F-32)/1.8 | Celcius temperature | °C |
| | | **ILLUMINATION** | | |
| fc | foot-candles | 10.76 | lux | lx |
| fl | foot-Lamberts | 3.426 | candela/$m^2$ | cd/$m^2$ |
| | | **FORCE and PRESSURE or STRESS** | | |
| lbf | poundforce | 4.45 | newtons | N |
| lbf/$in^2$ | poundforce per square inch | 6.89 | kilopascals | kPa |

## APPROXIMATE CONVERSIONS FROM SI UNITS

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| mm | millimeters | 0.039 | inches | in |
| m | meters | 3.28 | feet | ft |
| m | meters | 1.09 | yards | yd |
| km | kilometers | 0.621 | miles | mi |
| | | **AREA** | | |
| $mm^2$ | square millimeters | 0.0016 | square inches | $in^2$ |
| $m^2$ | square meters | 10.764 | square feet | $ft^2$ |
| $m^2$ | square meters | 1.195 | square yards | $yd^2$ |
| ha | hectares | 2.47 | acres | ac |
| $km^2$ | square kilometers | 0.386 | square miles | $mi^2$ |
| | | **VOLUME** | | |
| mL | milliliters | 0.034 | fluid ounces | fl oz |
| L | liters | 0.264 | gallons | gal |
| $m^3$ | cubic meters | 35.71 | cubic feet | $ft^3$ |
| $m^3$ | cubic meters | 1.307 | cubic yards | $yd^3$ |
| | | **MASS** | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.202 | pounds | lb |
| Mg (or "t") | megagrams (or "metric ton") | 1.103 | short tons (2000 lb) | T |
| | | **TEMPERATURE (exact)** | | |
| °C | Celcius temperature | 1.8C + 32 | Fahrenheit temperature | °F |
| | | **ILLUMINATION** | | |
| lx | lux | 0.0929 | foot-candles | fc |
| cd/$m^2$ | candela/$m^2$ | 0.2919 | foot-Lamberts | fl |
| | | **FORCE and PRESSURE or STRESS** | | |
| N | newtons | 0.225 | poundforce | lbf |
| kPa | kilopascals | 0.145 | poundforce per square inch | lbf/$in^2$ |

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised September 1993)

## TABLE OF CONTENTS

**TABLE OF CONTENTS (continued)**

## LIST OF FIGURES

## LIST OF TABLES

# INTRODUCTION

Currently, a great deal of attention is being focused on the possibility of using advanced technologies to develop an Automated Highway System (AHS), which would allow hands-off/feet-off travel in one's own vehicle. Human factors issues related to potential implementations of an AHS are being explored in an ongoing two-stage program that is being conducted for the Federal Highway Administration (FHWA). In the first stage of the program, seven experiments were conducted in the Iowa Driving Simulator. In the second stage, seven additional experiments were conducted, with the first five of them being run together. In this report are the results of the first two stage II experiments and part of the sixth. The other part of experiment 6 and the remaining four experiments will be reported on elsewhere.

The experiments reported here, like all those conducted in stage I, used an AHS configuration that would require little structural alteration to the roadways. This configuration consists of a three-lane expressway in which the left-most lane is reserved for automated traffic that travels in strings of one to four vehicles, while normal, unautomated traffic travels in the center and right lanes. With this configuration, the center lane is also used by vehicles that are in the process of transitioning into or out of the automated lane—there is no dedicated transition lane to and from that lane. Also, there are no barriers between the automated and unautomated lanes, nor between the unautomated lanes. This is one of several possible AHS configurations that would allow vehicles to enter the automated lane at a speed slower than the preferred AHS speed in that lane.

The experiments conducted in stage I of the program investigated:

- The transfer of control from the AHS to the driver of the simulator vehicle as the vehicle left the automated lane.(1)
- The transfer of control from the driver to the AHS as the simulator vehicle entered the automated lane.(2,3)
- The acceptability to a driver in the automated lane of decreasing vehicle separations as a vehicle enters the automated lane ahead of the driver.(4)
- The effectiveness of the driver when he/she was required to control the steering and/or speed when traveling through a segment of the expressway in which the capability of the AHS was reduced.(5)
- The effect on normal driving behavior of traveling under automated control for very brief periods of time.(6)

In the first five stage II experiments, which were run together, the following questions were investigated:

- Experiment 1: What do drivers do when traveling under automated control?
- Experiment 2: What information do drivers want when traveling under automated control?
- Experiment 3: What are the effects on normal driving behavior of traveling under automated control?
- Experiment 4: What is the effect of the distance between the driver's vehicle and the vehicle ahead on driver behavior when traveling under automated control and on normal driving behavior after automated travel?

- Experiment 5: How should control be transferred from the AHS to the driver after automated travel?

In these experiments, each driver participated in a single trial. It started with the driver's car positioned on the entry ramp of an expressway. The driver's task was to drive into the right lane of the expressway, move to the center lane, and, when instructed, transfer control of the car to the AHS. The AHS then drove the car into the automated (left) lane and moved it to the last position in a string. A period of travel under automated control then followed, during which the behavior of the driver was videotaped for later analysis. In addition, various types of information about the trip and of potential interest to the driver were made available on a laptop computer mounted in the car, and the frequency with which the driver requested each type of information was recorded. In this report, the results of experiments 1 and 2 are reported; the results of experiments 3 through 5 are reported elsewhere.

The sixth experiment, called the "commuter experiment," investigated the effects of commuting via the AHS, i.e., of repeatedly traveling under automated control to and from the same destinations at the same times of day. Each driver participated in eight trials—twice each day on a consecutive Wednesday, Thursday, Friday, and Monday. There was one trial each morning and one each afternoon: The objective was to simulate a commuter experience for the drivers. The eight trials were similar to the experimental trial in the first five experiments. Each trial started with the driver's car on the entry ramp of an expressway. The driver's task was to drive onto the expressway and transfer control of the car to the AHS; then, the AHS controlled the car for a period of time. While the simulator vehicle was under automated control, the behavior of the driver was videotaped for later analysis; however, the laptop computer was not available. The results of the videotape analysis are reported here; the effect on driving performance of commuting via the AHS, which was also investigated in this experiment, is reported elsewhere.

For the two noncommuter experiments, in which the driver traveled under automated control for a single period of time, the independent variables were age, gender, and the distance between the driver's car and the car ahead when it was in the automated lane (i.e., the intrastring gap). For the commuter experiment, in which the driver traveled under automated control several times, the only variable of interest for present purposes was trials. In all three studies reported here, the speed limit in the unautomated lanes was 88.6 km/h (55 mi/h), with the driver free to travel at whatever speed he/she chose; vehicles in the automated lane traveled at 104.7 km/h (65 mi/h).

## Objectives

In most visions of the AHS—including that of the National Automated Highway System Consortium—it has been assumed that when a vehicle was under automated control, the driver would be allowed to engage in any of a variety of activities not related to driving (e.g., working, reading, sleeping).[7] The objective of the first study reported here—one of the noncommuter studies—was to determine what drivers do when traveling under automated control, and whether the age and/or gender of the driver and/or the intrastring gap have an influence on those activities. One of the objectives of the commuter experiment—of relevance for this report—was to determine whether what drivers do when traveling under automated control changes as a function of experience with the AHS (i.e., across trials).

As conceptualization of the AHS proceeds, the details of the interface between the driver and the in-vehicle system will become more important. One part of that interface will be information supplied by the AHS to the driver, perhaps about such things as traffic conditions ahead, predicted trip time to the driver's selected exit, and so on. To maximize the utility of that information, it is important to determine what it is that drivers would like to know when traveling under automated control. The objective of the third study reported here—the second of the five noncommuter experiments—was to provide a first investigation of that issue.

# METHOD

## Subjects

The following guidelines were used to select the drivers who participated in these experiments:

- The drivers had no licensing restrictions, other than wearing eyeglasses for vision correction during driving.
- The drivers did not require special driving devices—the simulator is not equipped for such devices.

All drivers who took part in this experiment were volunteers who had replied to advertisements in the Iowa City and The University of Iowa daily newspapers and who met the above selection criteria. None of the subjects had participated in other AHS experiments.

### *Subjects in the Noncommuter Experiments*

The same 36 drivers participated in these 2 experiments:

- Eighteen were between the ages of 25 and 34. Of these, half were male and half were female.
- Eighteen were age 65 or older. Again, half were female and half were male.

### *Subjects in the Commuter Experiment*

There were six drivers in this experiment, three males and three females. There was one driver from each of the following age groups: 25 through 34 years old, 35 through 44 years old, 45 through 54 years old, 55 through 64 years old, 65 through 74 years old, and 75 years old or older.

## The Iowa Driving Simulator

The Iowa Driving Simulator, located in the Center for Computer-Aided Design at the University of Iowa, Iowa City, is shown in figure 1.[8] The physical configuration of the simulator consists of a domed enclosure mounted on a six-degrees-of-freedom motion platform. The motion system, which uses hydraulic actuators, has a frequency bandwidth of 5 Hz and a special-effects channel for the production of high-frequency-vibration noise with a bandwidth of 8 Hz, and is capable of producing accelerations in excess of 1 g. For the current experiments, a midsize Ford sedan was placed on this platform and the simulator was controlled by a computer complex that included a Harris Nighthawk 5800 and an Evans and Sutherland ESIG 2000 Computer Image Generator. The Nighthawk was controlled by the ICON operating system and was responsible for arbitrating subsystem scheduling; for performing motion control, data collection operations, control loading, and audio cue control; and for performing the multibody vehicle dynamics and complex scenario control simulation.[9]

The inner walls of the dome act as a screen. For the current experiment, the ESIG 2000 projected correlated imagery onto two sections of these walls: the imagery for the first, a 3.32-rad (190°) section in front of the simulator vehicle, was provided by three, slightly overlapping projection systems, while the imagery for the second, a 1.13-rad (65°) section to the rear, was provided by a single projection system. The driver of the simulator vehicle viewed the imagery shown on the forward section through the windshield and side windows, and the imagery projected to the rear by turning around, or through an interior driving mirror, or through a left-hand

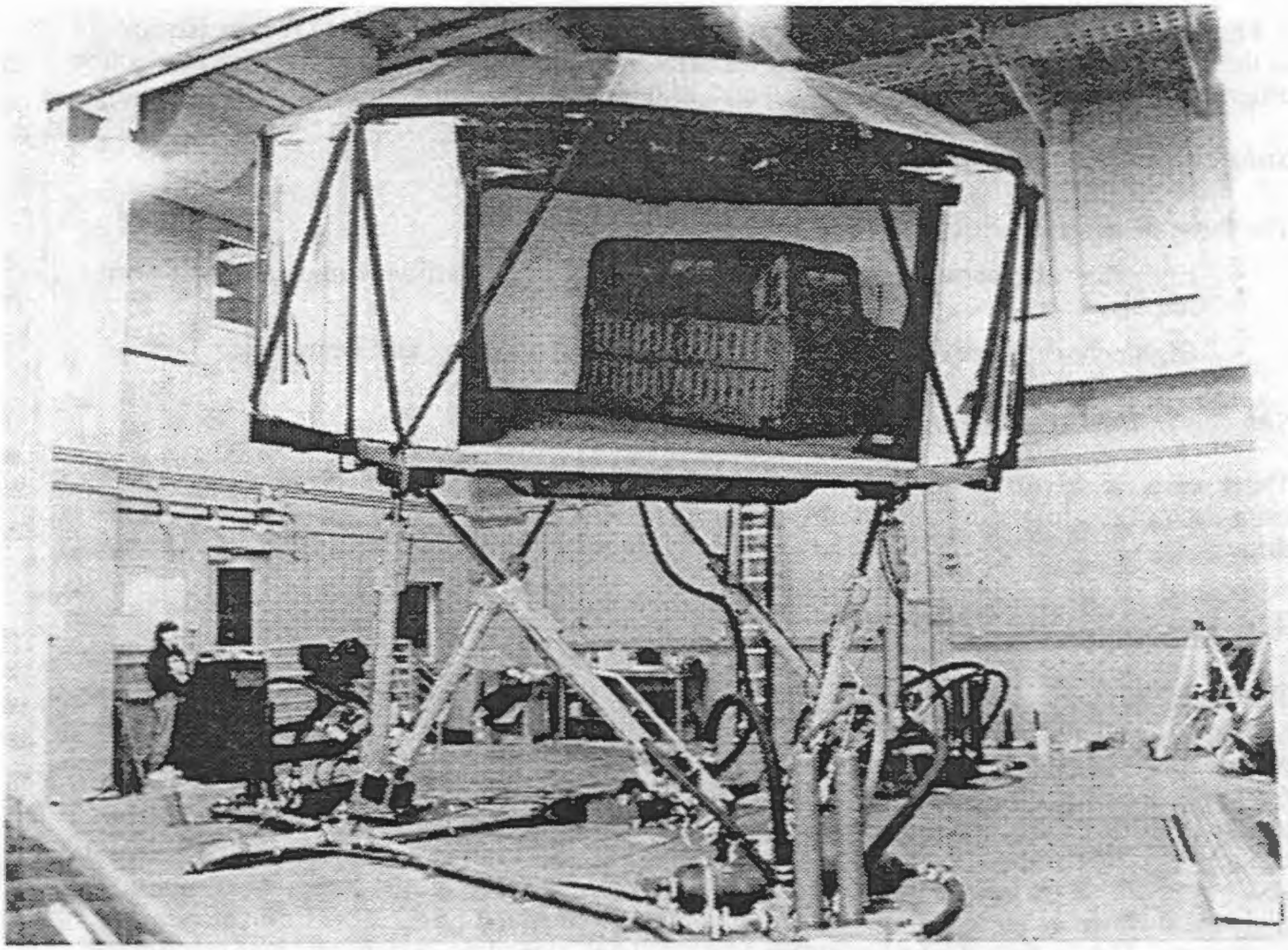

**Figure 1. The Iowa Driving Simulator.**

side driving mirror mounted outside the vehicle (the simulator vehicle did not have a right-side outside mirror).

A composite video image—consisting of four 1/4-screen images—was recorded throughout the experimental trials. The first two 1/4-screen images were provided by two small, infrared-sensitive cameras mounted unobtrusively inside the simulator vehicle. The infrared illumination provided for these two cameras was invisible to the drivers. The first of these images was a front view of the driver, showing his/her upper chest and head—the camera that provided this view was mounted on the dashboard just in front of the driver's side, forward stanchion of the simulator vehicle. The second 1/4-screen image showed a side view of the driver as well as the front half of the cab—this image was provided by a camera pointed toward the driver, and mounted on the passenger's side, central stanchion, above and slightly behind the far right upper corner of the passenger's seat. The third 1/4-screen of the recorded composite video image showed the imagery (provided by the ESIG 2000) that the driver could see on the central panel of the forward-view screen, while the fourth 1/4-screen image was an external view of the simulator provided by a camera mounted near the simulator operator's station.

## Driving Situation

The driving situation for all three experiments can be described using the taxonomy of interactions between the driver and the AHS developed by Bloomfield, Buck, Carroll, Booth, Romano, McGehee, and North.(1) Each driver drove in dry weather conditions, at midday, on a three-lane freeway that was 96.6 km (60 mi) long. The left lane was automated, the center and right lanes were unautomated, there was no transition lane, and there were no barriers between the automated and unautomated lanes or between the unautomated lanes. The lane widths were the current standard 3.66-m (12-ft) freeway width, and a standard road surface was used.

Table 1 shows the structure of the trials for three experiments. There was a single experimental trial for each driver who participated in the noncommuter experiments, preceded by 5 min of practice driving. In contrast, there were eight experimental trials for each driver who participated in the commuter experiment—and before the first of these trials there was also 5 min of practice driving. However, the single experimental trial in the noncommuter experiments and the eight experimental trials in the commuter experiment had similar structures—there were three sections to each of them. In the first section of each trial, the driver controlled the simulator vehicle and drove in the right and center lanes of the expressway; in the second section, the vehicle was under the control of the AHS and traveled in the automated lane; and in the third section, the driver again controlled the vehicle, and drove in the center and right lanes. In the two noncommuter studies, the length of the first section was at least 15 min, the length of the second section was at least 35 min, and the length of the third section was approximately 10 min. In the commuter study, in all eight experimental trials, the length of the first section was approximately 9.1 min, the length of the second section was at least 34 min, and the length of the third section was approximately 9.1 min.

**Table 1. Structure of the trials for the experiments reported in this paper.**

| Experiment | Practice | Section 1 | Section 2 | Section 3 |
|---|---|---|---|---|
| Commuter, trial 1 | 5 min | ~9.1 min<br>Driver controlled vehicle; drove in right and center lanes | ≥34 min<br>AHS controlled vehicle; traveled in left lane | ~9.1 min<br>Driver controlled vehicle; drove in center and right lanes |

**Table 1. Structure of the trials for the experiments reported in this paper (continued).**

| Experiment | Practice | Section 1 | Section 2 | Section 3 |
|---|---|---|---|---|
| Commuter, trials 2 through 8 | None | Same as for trial 1 | | |
| Noncommuter (one trial only) | Same as for commuter experiment, trial 1 | ≥15 min Driver controlled vehicle; drove in right and center lanes | ≥35 min AHS controlled vehicle; traveled in left lane | ≥10 min Driver controlled vehicle; drove in center and right lanes |

The posted speed limit in the unautomated lanes was 88.6 km/h (55 mi/h), but the driver was not specifically instructed to stay within that limit. The *average* speed of the other vehicles in the unautomated lanes was 88.6 km/h (55 mi/h)—their speeds were normally distributed around this mean value—and the density of those vehicles was 12.4 vehicles/km/lane (v/km/ln) [20 v/mi/ln]—a traffic density level at the upper boundary of the Transportation Research Board Level of Service B (LOS B).[10]

In the noncommuter and commuter experiments, the AHS presented one of two auditory messages to the driver approximately 14.5 min and 8.6 min, respectively, after the start of the trial:

- If he/she was in the right lane, the message was "Please move to the center lane and, when you get there, wait for further instructions." As soon as the driver was in the center lane, the message "Please remain in the center lane and wait for further instructions" was presented. If the driver did not comply with the "Please move to the center lane . . . ." message within 10 s, the message was repeated; if the driver did not comply with the message after three presentations, the message "Please pull over to the right shoulder and stop" was presented and the experiment was terminated.
- If he/she was in the center lane, the message was "Please remain in the center lane and wait for further instructions." If the subject did not comply, the message "Please move to the center lane and, when you get there, wait for further instructions" was presented as soon as the driver left the center lane. If the driver did not comply with the "Please move to the center lane . . . ." message within 10 s, it was repeated; if the driver did not comply with the message after three presentations, the message "Please pull over to the right shoulder and stop" was presented and the experiment was terminated.

It is to be noted that: (1) a tone preceded each presentation by the AHS of an auditory verbal message, and (2) whenever an auditory message was presented by the AHS, the car's radio speaker was silenced during the entire time the message was being presented.

In the noncommuter and commuter experiments, the transfer of control from the driver to the AHS was initiated approximately 15 min and 9.1 min, respectively, after the start of the experimental trial:

- If the driver was in the center lane, the AHS auditorily presented the message "To engage the automated system, push the *On* button now." If the driver complied—by pressing the *On* button on the steering wheel—the following message was presented auditorily: "Welcome to the Automated Highway System. Your vehicle is now controlled by the automated system. You will enter the automated lane in a moment." If the driver did not press the *On* button, the message was repeated up to two additional times at 5-s intervals. If the driver still failed to comply, the driver was instructed by the AHS to pull over to the right shoulder and stop, and the experiment was terminated.

- If the driver was not in the center lane, the "To engage the automated system, push the *On* button now" message was presented as soon as the driver entered the center lane. If the driver failed to press the *On* button after three messages given at 5-s intervals, the experiment was terminated.

As soon as the driver pressed the *On* button:

- The AHS took control of steering and speed and drove the car into an interstring gap in the automated lane that had been created by the AHS specifically for the driver's car. Once in the automated lane, the driver's car was accelerated to join the car ahead of it, making it the last car in a two-car string.
- In the noncommuter experiment, a laptop computer located to the driver's right and in a plane just below the vertical center of the steering wheel was automatically turned on. The computer presented a menu of information that the driver could access at his/her option throughout the time the driver was in the automated lane. The computer was automatically turned off after the period of automated travel.

  The laptop computer was not available in the commuter experiment.

Figure 2 shows the Main Menu of information for the laptop computer. The driver could see the information indicated by pressing the key corresponding to the menu item number for that information; the keys were located on a small keypad mounted in front of the computer screen. Figures 3 through 6 show examples of the information available. It is to be noted that all information of a dynamic nature (e.g., distance to the next exit) was continually updated throughout the period that the laptop computer was on. The formats shown in figures 2 through 6 are the same as those presented to subjects in the experiment. The information was presented on a black and white liquid crystal display that was 215.9 mm (8.5 in) wide by 139.7 mm (5.5 in) high.

Steering is controlled by: AHS
Speed is controlled by: AHS

MAIN MENU

1. Current location
2. Next exit
3. Time to destination
4. Traffic ahead

**Figure 2. Main menu of information available to drivers when traveling under automated control in the noncommuter experiment.**

| | |
|---|---|
| Steering is controlled by: | AHS |
| Speed is controlled by: | AHS |

CURRENT LOCATION

| | |
|---|---|
| Last exit: | Exit 24, County Road F |
| Distance past exit: | 2.5 miles |
| Next exit: | Exit 27, County Road V |
| Distance to exit: | 4.1 miles |

Press 0 to return to Main Menu

**Figure 3. Example of Current Location information available to drivers when traveling under automated control in the noncommuter experiment. (Exit designations and distances were updated continually throughout the period of automated travel.)**

| | |
|---|---|
| Steering is controlled by: | AHS |
| Speed is controlled by: | AHS |

NEXT EXIT

| | |
|---|---|
| Next exit: | Exit 27, County Road V |
| Distance to exit: | 4.1 miles |
| Travel time to exit: | 3 minutes 47 seconds |

Press 0 to return to Main Menu

**Figure 4. Example of Next Exit information available to drivers when traveling under automated control in the noncommuter experiment. (Exit designation, distance, and time were updated continually throughout the period of automated travel.)**

Steering is controlled by: AHS
Speed is controlled by: AHS

TIME TO DESTINATION

| | |
|---|---|
| Destination: | County Road Q<br>Exit 32 |
| Travel time to destination: | 26 minutes 57 seconds |

Press 0 to return to Main Menu

**Figure 5. Example of Time to Destination information available to drivers when traveling under automated control in the noncommuter experiment. (Destination and travel time were continually updated throughout the period of automated travel.)**

Steering is controlled by: AHS
Speed is controlled by: AHS

TRAFFIC AHEAD

| | |
|---|---|
| Distance to destination: | 32.5 miles |
| Traffic ahead: | Accident blocking far right lane at Exit 9, 43.5 miles ahead. Traffic congestion in center lane also at that exit. |

Press 0 to return to Main Menu

**Figure 6. Example of Traffic Ahead information available to drivers when traveling under automated control in the noncommuter experiment. (Distance was continually updated throughout the period of automated travel; the traffic description was changed as appropriate.)**

Speed in the automated lane was 104.7 km/h (65 mi/h), and vehicles were in strings of one, two, or three vehicles. The separation between strings of vehicles was 2.0 s (58.2 m [190.7 ft]).

- In the noncommuter experiments, the gap between vehicles within a string was varied (see "Independent Variables for the Noncommuter Experiments," below).

- In the commuter experiment, the intrastring gap was always 0.0625 s (which is 1.8 m [6 ft] at 104.7 km/h [65 mi/h]).

In all three experiments, when under automated control, the vehicle's steering wheel reflected any steering input from the AHS; the accelerator and brake pedals were functionally disconnected. There was a strip map of the roadway on the front passenger's seat of the car, which showed all exits by name (e.g., "County Road F") and number (e.g., "Exit 24"); distances between exits were not shown. No instructions were given regarding the map—the driver was free to use it if and when he/she wanted to.

## Experimental Design

### *Pre-Experiment Instructions for the Noncommuter Experiments*

During pre-experiment telephone conversations with potential subjects, people who were selected for participation in these experiments—based on: (1) their interest after having been told that the objective was to improve the quality of the driving simulator, and (2) their having passed a verbal health screening—were encouraged to bring something to do while they were waiting for the experiment to begin. During the experiment, drivers who brought things with them were told that they could not leave them in the training room, and would have to bring them into the simulator. The intent was to provide an opportunity for drivers to have something to occupy their time while under automated control without creating a mental set that they had to do anything.

### *Pre-Experiment Instructions for the Commuter Experiment*

People were selected for participation in this experiment as they had been for the others—based on: (1) their interest after having been told that the objective was to improve the quality of the driving simulator, and (2) their having passed a verbal health screening. However, subjects for this experiment were not given any instructions about bringing with them something to do. People who did bring things with them were allowed to take them into the simulator vehicle.

### *Independent Variables for the Noncommuter Experiments*

The same 36 drivers took part in each of the 2 experiments. For both experiments, the same three independent variables were investigated, and all were between-subjects variables:

- Age: Half the drivers were between the ages of 25 and 34; one-fourth were ages 65 through 69; and one-fourth were age 70 or older. Data from drivers in the two older age groups were analyzed together.
- Gap: For half of the drivers, the gap time between the front bumpers of their cars and the rear bumpers of the cars ahead of them was 0.0344 s, which is 1.0 m (3.3 ft) at the automated-lane speed of 104.7 km/h (65 mi/h). For the other half of the drivers, gap time was 0.0625 s, or 1.8 m (6.0 ft).
- Gender: Within each age-by-gap combination, the gender distribution was as shown in table 2.

**Table 2. Gender distribution for age-by-gap combinations.**

| | **Gap Time, seconds** | |
|---|---|---|
| **Age, years** | **0.0344** | **0.0625** |
| **25 through 34** | 5 males, 4 females | 4 males, 5 females |
| **65 or older** | 4 males, 5 females | 5 males, 4 females |

*Independent Variables for the Commuter Experiment*

The only variable of interest for present purposes was trials.

Table 3 shows a comparison of some of the variables for the noncommuter and commuter experiments.

**Table 3. Comparison of some variables for the noncommuter and commuter experiments.**

| Variable | Noncommuter Experiments | Commuter Experiment |
|---|---|---|
| **Number of trials per driver** | 1 | 8 |
| **Pre-AHS driving time** | 15 min | 14.1 min on trial 1; 9.1 min for each trial 2 through 8 |
| **Driver behavior videotaped?** | Yes | Yes |
| **Laptop computer available?** | Yes | No |
| **Posted speed limit in the unautomated lanes** | 88.6 km/h (55 mi/h) | 88.6 km/h (55 mi/h) |
| **Speed in the automated lane** | 104.7 km/h (65 mi/h) | 104.7 km/h (65 mi/h) |
| **Traffic density in the unautomated lanes** | 12.4 v/km/ln (20 v/mi/ln) | 12.4 v/km/ln (20 v/mi/ln) |
| **Independent variables** | • Age (25 through 34 years and ≥65 years).<br>• Gender.<br>• Intrastring gap (0.0344 s and 0.0625 s). | Trials (intrastring gap was constant at 0.0625 s) |

## Experimental Procedure

In this section are the procedures that were used in the various stages of the three experiments reported here.

*Introduction, Training, and Practice Procedure*

Before the start of the experiment, each driver watched a videotape that contained introductory material describing the research program and the AHS, and that provided some interactive practice with the AHS interface and protocol. The driver viewed the videotape while seated at a table on which was mounted a steering wheel that was positioned just in front of the driver. The driver was told that: (1) the experiment involved first driving in the simulator and then completing several vision tests and a questionnaire, and (2) this experiment was part of an ongoing FHWA program that was exploring ways of designing an AHS, determining how it might work, and determining how well drivers would handle their vehicles in such a system. It was made clear that the experiment was a test of the AHS, not a test of the driver. The video gave an explanation of what information would be available on the laptop computer and how to access it. Scripts of the narrations that accompanied the videotapes are shown in appendix A.

*Pre-Experimental Simulator Procedure*

The driver was taken to the Iowa Driving Simulator and seated in the driver's seat. The driver was asked to put on the seatbelt and to adjust the seat and mirrors, and then was given instructions on how to use the simulator emergency button.

*Experimental Simulator Procedure and Instructions for the Noncommuter Experiments*

Each driver took part in a single experimental trial. During the trial, an experimenter sat in the back seat of the car. The experimenter's primary responsibility was to monitor the driver for potential discomfort or other medical problems; there was a small, closed-circuit television monitor next to the experimenter in the back seat to allow him/her to better see the driver from that location. The experimenter was instructed not to initiate conversation with the driver once the trial began, though he/she could answer any questions that the driver had. After completing the trial, the driver returned to the subject preparation room, where he/she was debriefed and asked to complete a questionnaire that contained questions dealing with the driving simulator, the Automated Highway System, and the information that was made available on the laptop computer. A copy of the relevant parts of the questionnaire is presented in appendix B.

When the questionnaire was completed, the driver was taken to a vision testing room. The vision testing was divided into two sections. In the first section, a Titmus Vision Tester was used to test the following visual capabilities of the driver: far-foveal acuity, near-foveal acuity, stereo depth perception, color deficiencies, lateral misalignment, and vertical misalignment. In the second section, the spatial localization perimeter developed by Wall was used to determine the subject's reaction time and accuracy when detecting both static and dynamic peripheral stimuli.(11)

*Experimental Simulator Procedure and Instructions for the Commuter Experiment*

Each driver took part in eight trials, once each in the morning and afternoon on a consecutive Wednesday, Thursday, Friday, and Monday. During each trial, an experimenter sat in the back seat of the car. The experimenter's primary responsibility was to monitor the driver for potential discomfort or other medical problems; there was a small, closed-circuit television monitor next to the experimenter in the back seat to allow him/her to better see the driver from that location. The experimenter was instructed not to initiate conversation with the driver once the trial began, though he/she could answer any questions that the driver had. After the first and last trials (1 and 8, respectively), the driver returned to the subject preparation room, where he/she was debriefed and asked to complete a questionnaire that contained questions dealing with the driving simulator and the Automated Highway System. The questionnaire data are not presented in this report.

Following the last experimental trial, the driver returned for a post-experiment session, which was divided into two sections. In the first section, a Titmus Vision Tester was used to test the following visual capabilities of the driver: far-foveal acuity, near-foveal acuity, stereo depth perception, color deficiencies, lateral misalignment, and vertical misalignment. In the second section, the spatial localization perimeter developed by Wall was used to determine the subject's reaction time and accuracy when detecting both static and dynamic peripheral stimuli.(11)

# RESULTS

The results from the experiments are divided into two sections:

- Results of the observations of driver behavior.
- Results of the examination of what information drivers want when under automated control.

Vision testing was used to determine whether any subject's visual performance would suggest the need for a closer examination of their driving performance. No subject's vision indicated he/she would not be able to see the information displayed on the laptop computer or otherwise perform the tasks required in the experiments reported in this paper.

No subject was terminated for failure to comply with any instructions.

## Results of Observations of Driver Behavior When Traveling Under Automated Control

The question of interest is what drivers do when they are traveling under automated control. Given that these experiments are a first systematic look at this question, it was believed that the best approach would be to note all nondriving-related gross motor activities in which the drivers engaged and which could be seen (or heard) clearly. Thus, the videotape of each driver's trial was viewed and each discernible activity engaged in was recorded for the period between when the AHS assumed control of the vehicle until 1 min before the message indicating that the driver was about to leave the automated lane.

### *Observations for the Noncommuter Experiment*

Each occurrence of each activity was recorded; the duration of any occurrence was not noted during this time (except for eye closures, which were recorded only if they lasted for at least 5 s—even then, however, the specific duration was not recorded). During the time from 1 min before the message indicating the driver was about to leave the automated lane until the first message stating which function the driver was to take control of first, gross motor activities were recorded in chronological order along with their durations. These latter data were used as part of a separate experiment to determine whether there was any relationship between what drivers were doing just before the transfer of control from the AHS to the driver and their manual driving behavior after automated travel. The chronological data are not reported here.

**The Effect of Gender on Driver Activities**—Summary statistics for the activities in which drivers engaged are shown in table 4 as a function of driver gender.

Note that all drivers took their hands off the steering wheel. A one-way, unequal n's analysis of variance (ANOVA) on the frequency of laptop computer use compared with the next most frequent activity (talking to the experimenter) showed that for both males and females, the laptop computer was the most frequently engaged-in activity; for males, $F(1,27) = 10.6, p < 0.01$ (the complete ANOVA is shown in table 10 in appendix C); for females, $F(1,22) = 4.4, p < 0.05$ (the complete ANOVA is shown in table 11 in appendix C). There were no significant differences between female and male drivers in the numbers of times in which the various activities were engaged.

**The Effect of Age on Driver Activities**—Summary statistics for the activities in which drivers engaged are shown in table 5 as a function of driver age. There were no significant differences between age groups in the numbers of times in which any of the activities were engaged. For younger drivers, using the laptop computer was the most frequent activity, $F(1,23) = 6.0, p < 0.05$ compared with closing the eyes for 5 or more consecutive seconds (the complete ANOVA is shown in table 12 in appendix C). For older drivers, frequency of using the laptop computer was not statistically different from the next most frequent activity (talking to the experimenter).

**Table 4. Summary statistics for the various activities engaged in by male and female drivers in the non-commuter experiment from the time their vehicles were under automated control until 1 min before they received the message indicating they would leave the automated lane in 30 s.[1]**

| | Male | | | Female | | |
|---|---|---|---|---|---|---|
| **Activity** | **No. Drivers** | **Mean** | **Std. Deviation** | **No. Drivers** | **Mean** | **Std. Deviation** |
| **Use Laptop Computer[2]** | 14 | 14.4 | 8.1 | 14 | 16.1 | 12.3 |
| **Talk to Experimenter[3]** | 15 | 5.9 | 6.0 | 10 | 7.2 | 6.0 |
| **Read Map** | 12 | 4.3 | 2.2 | 13 | 3.9 | 2.6 |
| **Close Eyes for ≥5 Consecutive Seconds** | 6 | 5.7 | 4.3 | 7 | 7.1 | 5.6 |
| **Adjust Radio** | 9 | 2.9 | 2.0 | 7 | 2.0 | 1.3 |
| **Take Hands Off Steering Wheel** | 18 | 1.0 | 0.0 | 18 | 1.0 | 0.0 |
| **Turn to Look at Experimenter[3]** | 8 | 2.1 | 1.6 | 8 | 2.5 | 1.9 |
| **Turn On/Off Dome Light** | 7 | 2.0 | 1.2 | 5 | 1.8 | 0.4 |
| **Sing or Whistle** | 1 | (total = 7)[4] | n.a.[5] | 1 | (total = 1) | n.a. |
| **Look Toward Back Seat** | 2 | 1.5 | 0.7 | 0 | n.a. | n.a. |
| **Adjust Seat** | 2 | 1.5 | 0.7 | 1 | (total = 2) | n.a. |
| **Look at Cassette Tape Container** | 2 | 1.0 | 0.0 | 0 | n.a. | n.a. |
| **Touch Dashboard Instruments** | 1 | (total = 2) | n.a. | 0 | n.a. | n.a. |
| **Read Business Card** | 1 | (total = 1) | n.a. | 0 | n.a. | n.a. |

1 Except for "Use laptop computer," the total number of drivers possible for each activity was 18.
2 Due to computer failures, there were 14 drivers of each gender possible for this activity.
3 Excludes times when this activity was initiated by the experimenter.
4 When only one driver engaged in an activity, the total number of times the driver engaged in that activity is shown.
5 *n.a.* means not applicable.

**Table 4. Summary statistics for the various activities engaged in by male and female drivers in the noncommuter experiment from the time their vehicles were under automated control until 1 min before they received the message indicating they would leave the automated lane in 30 s (continued).**

| | Male | | | Female | | |
|---|---|---|---|---|---|---|
| Activity | No. Drivers | Mean | Std. Deviation | No. Drivers | Mean | Std. Deviation |
| Look Into Armrest Storage Compartment | 1 | (total = 1) | n.a. | 0 | n.a. | n.a. |
| Read Newspaper | 1 | (total = 1) | n.a. | 0 | n.a. | n.a. |
| Do Crossword Puzzles | 1 | (total = 1) | n.a. | 0 | n.a. | n.a. |
| Adjust Air Flow | 0 | n.a. | n.a. | 2 | 2.0 | 0.0 |
| Put In Eye Drops | 0 | n.a. | n.a. | 1 | (total = 2) | n.a. |
| Take Off Glasses | 0 | n.a. | n.a. | 1 | (total = 1) | n.a. |
| Adjust Sideview Mirror | 0 | n.a. | n.a. | 1 | (total = 1) | n.a. |

**Table 5. Summary statistics for the various activities engaged in by younger and older drivers in the noncommuter experiment from the time their vehicles were under automated control until 1 min before they received the message indicating they would leave the automated lane in 30 s.[1]**

| | 25 Through 34 Years Old | | | ≥65 Years Old | | |
|---|---|---|---|---|---|---|
| Activity | No. Drivers | Mean | Std. Deviation | No. Drivers | Mean | Std. Deviation |
| Use Laptop Computer[2] | 17 | 18.2 | 11.1 | 11 | 10.7 | 7.2 |
| Talk to Experimenter[3] | 11 | 4.2 | 6.0 | 14 | 8.1 | 5.4 |
| Read Map | 14 | 4.0 | 2.4 | 11 | 4.3 | 2.5 |
| Close Eyes for ≥5 Consecutive Seconds | 8 | 8.0 | 5.2 | 5 | 4.0 | 3.5 |
| Adjust Radio | 10 | 2.4 | 1.2 | 6 | 2.7 | 2.6 |
| Take Hands Off Steering Wheel | 18 | 1.0 | 0.0 | 18 | 1.0 | 0.0 |
| Turn to Look at Experimenter[3] | 7 | 2.3 | 1.7 | 9 | 2.3 | 1.8 |

1 Except for "Use laptop computer," the total number of drivers possible for each activity was 18.
2 Due to computer failures, there were 17 younger drivers and 11 older drivers possible for this activity.
3 Excludes times when this activity was initiated by the experimenter.

**Table 5. Summary statistics for the various activities engaged in by younger and older drivers in the noncommuter experiment from the time their vehicles were under automated control until 1 min before they received the message indicating they would leave the automated lane in 30 s (continued).**

| | 25 Through 34 Years Old | | | ≥65 Years Old | | |
|---|---|---|---|---|---|---|
| **Activity** | **No. Drivers** | **Mean** | **Std. Deviation** | **No. Drivers** | **Mean** | **Std. Deviation** |
| **Turn On/Off Dome Light** | 5 | 1.8 | 0.4 | 7 | 2.0 | 1.2 |
| **Sing or Whistle** | 2 | 4.0 | 4.2 | 0 | n.a.[4] | n.a. |
| **Look Toward Back Seat** | 1 | (total = 1)[5] | n.a. | 1 | (total = 2) | n.a. |
| **Adjust Seat** | 2 | 2.0 | 0.0 | 1 | (total = 1) | n.a. |
| **Look at Cassette Tape Container** | 2 | 1.0 | 0.0 | 0 | n.a. | n.a. |
| **Touch Dashboard Instruments** | 0 | n.a. | n.a. | 1 | (total = 2) | n.a. |
| **Read Business Card** | 0 | n.a. | n.a. | 1 | (total = 1) | n.a. |
| **Look Into Armrest Storage Compartment** | 0 | n.a. | n.a. | 1 | (total = 1) | n.a. |
| **Read Newspaper** | 1 | (total = 1) | n.a. | 0 | n.a. | n.a. |
| **Do Crossword Puzzles** | 0 | n.a. | n.a. | 1 | (total = 1) | n.a. |
| **Adjust Air Flow** | | | | 1 | (total = 2) | n.a. |
| **Put In Eye Drops** | 0 | n.a. | n.a. | 1 | (total = 2) | n.a. |
| **Take Off Glasses** | 0 | n.a. | n.a. | 1 | (total = 1) | n.a. |
| **Adjust Sideview Mirror** | 0 | n.a. | n.a. | 1 | (total = 1) | n.a. |

4 *n.a.* means not applicable.

5 When only one driver engaged in an activity, the total number of times the driver engaged in that activity is shown.

**The Effect of Gap on Driver Activities**—Summary statistics for the activities in which drivers engaged are shown in table 6 as a function of the intrastring gap experienced by the driver when the car was under automated control. The gap experienced by the driver while in the automated lane did not have a significant influence on the driver's activities. As with the previous data breakdowns, use of the laptop computer was apparently more frequent than was engaging in other activities.

Table 6. Summary statistics for the various activities engaged in by drivers who experienced 0.0344-s intervehicle gaps and drivers who experienced 0.0625-s intervehicle gaps in the noncommuter experiment, from the time their vehicles were under automated control until 1 min before they received the message indicating they would leave the automated lane in 30 s.[1]

| | 0.0344-s gap | | | 0.0625-s gap | | |
|---|---|---|---|---|---|---|
| Activity | No. Drivers | Mean | Std. Deviation | No. Drivers | Mean | Std. Deviation |
| Use Laptop Computer[2] | 12 | 19.6 | 13.1 | 16 | 12.0 | 6.2 |
| Talk to Experimenter[3] | 15 | 5.9 | 5.4 | 10 | 7.2 | 6.8 |
| Read Map | 11 | 3.2 | 1.8 | 14 | 4.9 | 2.6 |
| Close Eyes for ≥5 Consecutive Seconds | 7 | 6.3 | 4.1 | 6 | 6.7 | 6.1 |
| Adjust Radio | 7 | 2.1 | 1.2 | 9 | 2.8 | 2.1 |
| Take Hands Off Steering Wheel | 18 | 1.0 | 0.0 | 18 | 1.0 | 0.0 |
| Turn to Look at Experimenter[3] | 7 | 3.1 | 1.9 | 9 | 1.7 | 1.3 |
| Turn On/Off Dome Light | 5 | 2.2 | 1.1 | 7 | 1.7 | 0.8 |
| Sing or Whistle | 2 | 4.0 | 4.2 | 0 | n.a.[4] | n.a. |
| Look Toward Back Seat | 1 | (total = 2)[5] | n.a. | 1 | (total = 1) | n.a. |
| Adjust Seat | 1 | (total = 1) | n.a. | 2 | 2.0 | 0.0 |
| Look at Cassette Tape Container | 1 | (total = 1) | n.a. | 1 | (total = 1) | n.a. |
| Touch Dashboard Instruments | 1 | (total = 2) | n.a. | 0 | n.a. | n.a. |
| Read Business Card | 0 | n.a. | n.a. | 1 | (total = 1) | n.a. |
| Look Into Armrest Storage Compartment | 1 | (total = 1) | n.a. | 0 | n.a. | n.a. |
| Read Newspaper | 0 | n.a. | n.a. | 1 | (total = 1) | n.a. |

1 Except for "Use laptop computer," the total number of drivers possible for each activity was 18.

2 Due to computer failures, there were 12 drivers who experienced a 0.0344-s gap and 16 drivers who experienced a 0.0625-s gap for this activity.

3 Excludes times when this activity was initiated by the experimenter.

4 *n.a.* means not applicable.

5 When only one driver engaged in an activity, the total number of times the driver engaged in that activity is shown.

**Table 6. Summary statistics for the various activities engaged in by drivers who experienced 0.0344-s intervehicle gaps and drivers who experienced 0.0625-s intervehicle gaps in the noncommuter experiment, from the time their vehicles were under automated control until 1 min before they received the message indicating they would leave the automated lane in 30 s (continued).**

| | 0.0344-s gap | | | 0.0625-s gap | | |
|---|---|---|---|---|---|---|
| Activity | No. Drivers | Mean | Std. Deviation | No. Drivers | Mean | Std. Deviation |
| Do Crossword Puzzles | 0 | n.a. | n.a. | 1 | (total = 1) | n.a. |
| Adjust Air Flow | 1 | (total = 2) | n.a. | 1 | (total = 2) | n.a. |
| Put In Eye Drops | 1 | (total = 2) | n.a. | 0 | n.a. | n.a. |
| Take Off Glasses | 1 | (total = 1) | n.a. | 0 | n.a. | n.a. |
| Adjust Sideview Mirror | 1 | (total = 1) | n.a. | 0 | n.a. | n.a. |

### *Observations for the Commuter Experiment*

Do people change what they do when under automated travel after repeated exposure to the AHS? To explore that question, data from the first and seventh trial were examined—both morning sessions, thus eliminating any possible time-of-day effects that might have appeared had data from the eighth (last) trial been used. Each occurrence of each activity was recorded, as was the duration of each occurrence. As in the noncommuter experiment, eye closures were recorded only if they lasted for at least 5 s.

Due to a simulator failure, data for one driver for one of the trials could not be used. Thus, data from only five drivers are reported here. Recall that age, gender, and intrastring gap were not independent variables in this experiment, so the only breakdown of data is by trials.

Table 7 shows how many drivers engaged in each activity, how much time was spent in each activity across those drivers who engaged in it, and the percentage of the total time under automated control (up to 1 min before the "You will leave the automated lane in 30 seconds" message) in which the activity was engaged.

Because of the small number of drivers who engaged in each activity, the data in table 7 are not amenable to statistical analysis. Indeed, the small numbers make it difficult to make any statements about these data, except that it is interesting that more drivers did not bring something with which to occupy their time in trial 7, after several previous experiences with automated travel.

**Table 7. Number of drivers in the commuter experiment who engaged in each activity, the total time they were engaged in it, and the percentage of the total time in which the activity was engaged from the time their vehicles were under automated control until 1 min before they received the message indicating they would leave the automated lane in 30 s.[1]**

| | Trial 1 | | | Trial 7 | | |
|---|---|---|---|---|---|---|
| Activity | Number of Drivers Who Engaged in the Activity | Total Time Spent by Drivers Who Engaged in the Activity, seconds (Mean/ Standard Deviation) | Percentage of Total Time in Which Activity was Engaged[2] | Number of Drivers Who Engaged in the Activity | Total Time Spent by Drivers Who Engaged in the Activity, seconds (Mean/ Standard Deviation) | Percentage of Total Time in Which Activity was Engaged |
| Close Eyes for ≥5 Consecutive Seconds | 2 | 1018 (509.0/633.6) | 14.5 | 2 | 265 (132.5/183.1) | 3.6 |
| Talk to Experimenter[3] | 3 | 158 (52.7/63.6) | 2.2 | 1 | 17 (n.a.) | 0.2 |
| Read Map | 2 | 37 (18.5/6.4) | 0.5 | 0 | 0 (n.a.) | 0.0 |
| Look to Right Inside Cab | 1 | 16 (n.a.) | 0.2 | 0 | 0 (n.a.) | 0.0 |
| Read Magazine | 1 | 1269 (n.a.) | 18.0 | 2 | 2287 (1143.5/357.1) | 31.3 |
| Look in Direction of Steering Wheel/Instrument Panel | 1 | 12 (n.a.) | 0.2 | 0 | 0 (n.a.) | 0.0 |
| Adjust Sideview Mirror | 1 | 33 (n.a.) | 0.5 | 0 | 0 (n.a.) | 0.0 |
| Adjust Radio | 0 | 0 (n.a.) | 0.0 | 3 | 126 (42.0/44.4) | 0.6 |
| Read Label on Audio Tape | 0 | 0 (n.a.) | 0.0 | 1 | 36 (n.a.) | 0.5 |

[1] Due to a simulator problem, there were no usable data for one driver in trial 7. The data are based on five drivers.

[2] Based on the total time in which the activity was engaged, from the preceding cell. Percentages do not add up to 100 because not all activities in which the drivers engaged are shown.

[3] Excludes times when this activity was initiated by the experimenter.

## Results of an Investigation of What Information Drivers Want When Traveling Under Automated Control

To determine what information drivers might want when on the AHS, four information screens were made available on a laptop computer during the period of automated travel in the noncommuter experiments (see figures 7(a) through 7(d), which were shown earlier in the report as figures 3 through 6).

| | |
|---|---|
| Steering is controlled by: | AHS |
| Speed is controlled by: | AHS |

CURRENT LOCATION

| | |
|---|---|
| Last exit: | Exit 24, County Road F |
| Distance past exit: | 2.5 miles |
| Next exit: | Exit 27, County Road V |
| Distance to exit: | 4.1 miles |

Press 0 to return to Main Menu

(a)

| | |
|---|---|
| Steering is controlled by: | AHS |
| Speed is controlled by: | AHS |

NEXT EXIT

| | |
|---|---|
| Next exit: | Exit 27, County Road V |
| Distance to exit: | 4.1 miles |
| Travel time to exit: | 3 minutes 47 seconds |

Press 0 to return to Main Menu

(b)

| | |
|---|---|
| Steering is controlled by: | AHS |
| Speed is controlled by: | AHS |

TIME TO DESTINATION

| | |
|---|---|
| Destination: | County Road Q<br>Exit 32 |
| Travel time to destination: | 9 minutes 15 seconds |

Press 0 to return to Main Menu

(c)

| | |
|---|---|
| Steering is controlled by: | AHS |
| Speed is controlled by: | AHS |

TRAFFIC AHEAD

| | |
|---|---|
| Distance to destination: | 32.5 miles |
| Traffic ahead: | Accident blocking far right lane at Exit 9, 43.5 miles ahead. Traffic congestion in center lane also at that exit. |

Press 0 to return to Main Menu

(d)

**Figure 7. Examples of the four information types presented on the laptop computer in the noncommuter experiment: (a) Current Location, (b) Next Exit, (c) Time to Destination, and (d) Traffic Ahead. (Dynamic information was continually updated throughout the period of automated travel.)**

Access to each screen was via a Main Menu, which listed each of the information types by name (e.g., Current Location).

To determine drivers' responses to the various information types, two methods were used:

- Analysis of the percentages of times drivers requested each type.
- Analysis of driver ratings of the information types. Each driver who used the laptop computer was asked to rate, on a scale from 0 to 100, whichever of the four information types he/she requested during the experiment, where 0 meant "not useful" and 100 meant

"very useful." In addition, the driver was given an opportunity to respond to the following questions regarding each information type:

- "What did you especially like or not like about the [information type] information? How would you change it to make it more *useful?*"
- "Are there other kinds of information you would find useful during an actual trip on an Automated Highway System?"

### *Analysis of Percentages of Times Information Types Were Requested*

First, the percentage of time that each driver selected each of the four types of information was calculated; the average percentages are shown in figure 8. Then, a one-way ANOVA was run on these percentages, collapsing them across age and gender. Due to computer failures, there were data from only 28 drivers for this analysis. There was a significant effect of information type, $F(3,81) = 11.6, p < 0.05$ (the complete ANOVA is shown in table 13 in appendix C). To determine which information types were chosen more often than others, a Newman-Keuls test was run on the data, with the following results (shown also in table 8; all at $p < 0.05$):

- Time to Destination, Current Location, and Traffic Ahead were each selected more often than Next Exit.
- Time to Destination was selected more often than Traffic Ahead and Current Location.

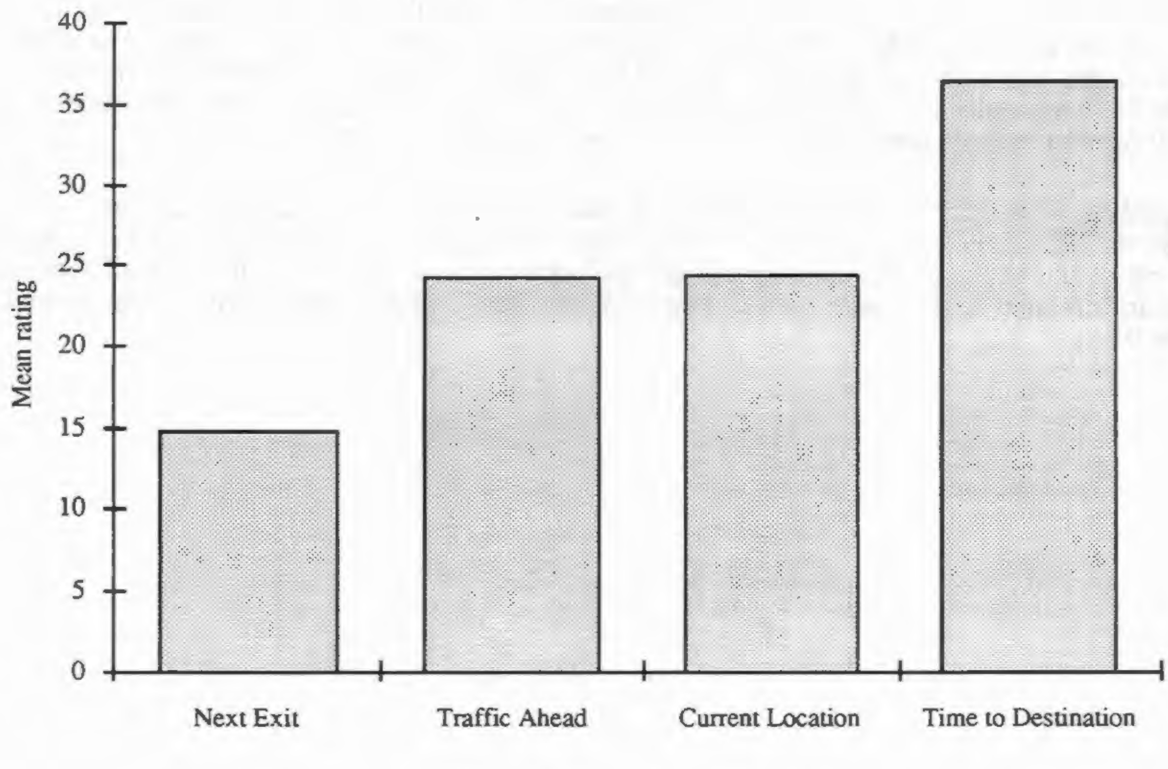


**Figure 8. Average percentage of time each information type was selected.**

**Table 8. Results of the Newman-Keuls test on the percentage of time information choices were selected.**[1]

| | Next Exit | Traffic Ahead | Current Location | Time to Destination |
|---|---|---|---|---|
| **Next Exit** | – | * | * | * |
| **Traffic Ahead** | – | – | n.s.[2] | * |
| **Current Location** | – | – | – | * |
| **Time to Destination** | – | – | – | – |

[1] n = 28
[2] *n.s.* means not significant
* $p < 0.05$

To determine whether age and/or gender made a significant difference in driver selection of the various information types, age and gender were used as the variables in independent unweighted means ANOVA's on each information type. There were data from 28 drivers for each of these analyses. There were no significant results in any of the analyses: neither age nor gender had a significant effect on the percentage of times drivers chose each of the four information types, nor were there any interactions between age and gender.

*Analysis of Driver Ratings of the Information Types*

As indicated above, each driver was asked to rate, on a 100-point scale, the usefulness of each information type he/she selected during the experiment. To determine whether there were overall differences in the ratings, a one-way, repeated measures ANOVA was done, collapsing the results across age and gender. Data from 30 drivers were available for this analysis. The effect of information type was significant, $F(3,87) = 3.0$, $p < 0.05$ (the complete ANOVA is shown in table 14 in appendix C). A Newman-Keuls test on the data failed to show any differences among the information types considered singly; the means are shown in figure 9.

Regarding what information drivers especially liked or disliked, what they would change to make the information more useful, and what other information they would like to have available during an actual trip on an Automated Highway System, there were many different answers for each information type. Those answers that were provided by two or more drivers are shown in table 9.

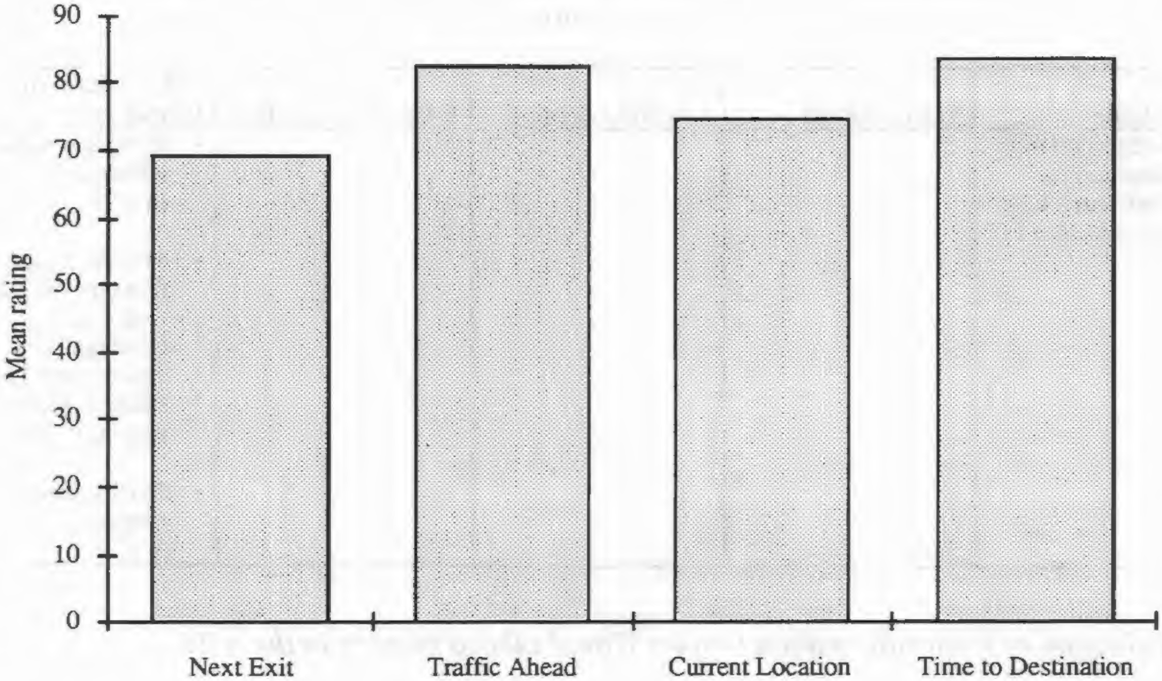


**Figure 9. Mean ratings of information types.**

**Table 9. Suggestions from drivers regarding the information types shown on the laptop computer.** [1]

| Next Exit | Traffic Ahead | Current Location | Time to Destination | Other Useful Information |
|---|---|---|---|---|
| • The information shown here was not much different from that shown for Current Location. (n = 6)<br>• Although the information was not much different from Current Location, the time element was nice to have. (n = 2) | • Add an estimate of how long congestion ahead will last. (n = 2) | • Add a simple map. (n = 6)<br>• Show distance to the destination. (n = 2) | • Make this information available when driving manually. (n = 2)<br>• Add distance to the destination. (n = 2)<br>• Add a map. (n = 2) | • Provide a timer or alarm clock (some said to allow the driver to sleep while under automated control). (n = 2)<br>• Provide a map (some said like the [strip] map that was in the vehicle in the experiment). (n = 3) |

[1] Only suggestions made by at least two drivers are shown. Numbers in parentheses indicate how many drivers made each suggestion.

Table 9. Suggestions from drivers regarding the information types shown on the laptop computer (continued).[1]

| Next Exit | Traffic Ahead | Current Location | Time to Destination | Other Useful Information |
|---|---|---|---|---|
| • Add information about gas stations, food, lodging, etc. (n = 5) | | | | • Provide weather information. (n = 7)<br>• Provide information on what's at each exit (e.g., other highway connections, gas stations, food, lodging). (n = 3)<br>• Provide road information. (n = 2) |

### *Examination of What Information Drivers Would Like to Provide to the AHS*

Since drivers had been given several types of information that they might find useful during automated travel, the stage was set for asking drivers if there was any information they would like to be able provide *to* the Automated Highway System. To that end, the questionnaire contained the following question: "What kinds of information would you like to be able to provide *to* the Automated Highway System? (For example, if there is some disturbance on the road ahead, would you like to be able to tell that to the System?)"

The following types of information were suggested by at least two drivers:

- Information about weather conditions (or problems). This was suggested by seven drivers.
- Information about accidents and other disturbances. This was suggested by five drivers.
- Information about construction areas.
- Information about obstructions on the road.
- Information about road conditions (of an unspecified nature).

In addition, three drivers simply indicated agreement with the example concerning disturbances on the road ahead, which was given in the question.

# DISCUSSION

## Observations of Driver Behavior When Traveling Under Automated Control

What can be said first is that the types of activities in which the drivers engaged in both the noncommuter and commuter experiments may have been influenced by the presence of the experimenter, which may have had an inhibiting effect on some people. (Of course, the experimenter's presence also led some people to talk to him/her and to turn to look at him/her, activities that otherwise would not have occurred.) Alternatively, if the experimenter had acted more like a passenger, initiating and otherwise playing a role in social conversation, there may have been still a different distribution of activities.

Use of the laptop computer was relatively high, considering that four uses per driver would have been sufficient to allow him/her to examine each type of information once. What might account for the higher use? (Averages were 14.4 times per male and 16.1 times per female, and 18.2 times per younger driver and 10.7 times per older driver.) There are at least two possibilities: (1) Drivers found at least some of the information to be useful and/or interesting, or (2) they were bored—recall that almost no one brought anything with them to do, despite the pre-experiment encouragement to do so. One might speculate that with repeated exposures to automated travel, drivers would learn to bring things with them to occupy their time. But in the commuter experiment, where drivers *did* have repeated exposures, only two drivers brought something with them (magazines) for trial 7 (as compared with one driver in trial 1). This result is somewhat surprising, and again may be related to the presence of the experimenter. Or, it may be due to the relatively dark environment inside the car. (Although the forward view was of a sunny day at midday, the brightness inside the car did not correspond to that view [recall that the cab was mounted inside a dome].) This lack of illumination may have discouraged reading and related activities. Perhaps true commuters will find other ways to occupy their time, e.g., by doing work, reading, talking on a cellular telephone, and perhaps AHS travelers, in general, will find ways to improve the illumination inside their vehicles (if this is not provided as part of the AHS in-vehicle package).

Regarding eye closures, the criterion of 5 or more consecutive seconds was admittedly arbitrary. The intent was to try to capture a behavior that drivers who are manually controlling their vehicles would not be likely to do—at the automated lane speed of 104.7 km/h (65 mi/h), a vehicle travels 145.3 m (476.7 ft) in 5 s, which is a significant distance. And, in the noncommuter experiment, about one-third of both males and females, 44 percent of younger drivers, and 28 percent of older drivers met the criterion for eye closures at least once during the approximately 33.5 min of automated travel (up to 1 min before the "You will leave the automated lane in 30 seconds" message) (see tables 3 and 4). Because exact durations were not determined for activities in the noncommuter experiment, it is not possible to say what percentage of time drivers who did meet the criterion actually spent with their eyes closed. In the commuter experiment, where durations were measured, there were only two drivers in each of trials 1 and 7 who met the criterion, and it is difficult to say anything meaningful based on such small numbers (those data are in table 7). The fact that several drivers closed their eyes for at least 5 consecutive seconds in the noncommuter experiment can perhaps be taken to indicate a certain comfort level with the conditions of automated travel they experienced (a speed of 104.7 km/h [65 mi/h] and an intrastring gap of 0.0344 s or 0.0625 s).

As was stated in the Objectives, some people have suggested that the driver's attention may have to be maintained during automated travel so that he/she will be prepared to resume control when needed.(7) Nothing in these data bear directly on whether a driver's attention can be maintained for up to 33.5 min (the length of automated travel in the noncommuter experiment covered by the data reported here). First, a clear definition of *maintained attention* is needed: does this mean simply "not sleeping?" Or does it mean that the driver must attend to the road ahead? Or does it mean something else? In any case, it is assumed that on the real AHS, instructions to drivers would be quite different if it were important for their attention to be maintained as compared with those instructions that were given in these experiments, in which drivers were implicitly given carte blanche to do whatever they liked during the period of automated travel (within, of course, certain limits). Furthermore, certain measures might be taken to try to ensure that drivers at least do not go to sleep—though such measures might be so annoying as to severely limit the utility of automated travel, and thus dissuade people from using the AHS, a clearly undesirable outcome. No such measures were attempted during these experiments.

## An Investigation of What Information Drivers Want When Traveling Under Automated Control

As shown in the results, the following preferences were shown by drivers for the various types of information available on the laptop computer during the period of automated travel:

- Time to Destination, Current Location, and Traffic Ahead were each selected more frequently than Next Exit.
- Time to Destination was selected more frequently than Traffic Ahead and Current Location.

There were no age or gender effects on the frequencies with which the various types were selected.

Next Exit—which told what exit it was and both the distance and time to it, and which was selected 14.8 percent of the time—was apparently not very useful to drivers (though it still got a rating of 69.2 on the 100-point scale). Indeed, it would seem that information about the next exit would be useful only if it were possible to get off there—and this was, of course, not possible for the drivers in this experiment. As an aside, it might be worth noting that drivers on the real AHS may also not be able to simply get off at the next exit. If they must demonstrate their readiness to drive manually after a period of automated travel before they are given back control—still an open issue at this time—then the amount of time such a demonstration might take could preclude "quick" exits (as compared with manual driving, where one can decide a very short distance before an exit to get off there). Also, on the questionnaire, some drivers indicated they would like to have information about gas stations, food, and lodging at each exit. If there is a readiness demonstration requirement, the possibility of which the drivers in our experiment would almost certainly not have known, then such information will have real utility only if it is provided for several upcoming exits, to allow drivers sufficient time to plan in advance where they would like to exit (if it is at some exit other than their original one).

Traffic Ahead—which provided a 96.6-km (60-mi) moving look at traffic ahead of the vehicle's current location and told the distance to the driver's destination, and which was selected 24.3 percent of the time—and Current Location—which indicated the last exit and distance past it, and the next exit and distance to it, and which was selected 24.4 percent of the time—were both selected more frequently than Next Exit. On the questionnaire, at least six drivers wanted a simple map added to the Current Location display. This would have the advantage of showing location in relation to the destination on a single display. And two people wanted distance to the destination shown on the display. Regarding the Traffic Ahead display, the traffic information changed only one time during the period of automated travel (the distance to the destination was continually updated), and the accident that was indicated was located beyond the driver's destination (so there was no need to simulate it). Perhaps drivers were curious as to whether the traffic information would change, or perhaps the primary utility of this display was its showing distance to the destination. Driver responses to both Traffic Ahead and Current Location indicate that where one is in relation to the destination appears to be have been useful to the drivers in this experiment.

Time to Destination—which showed the destination and the travel time to it—was selected more frequently than any of the other types of information (more than 33 percent of the selections) and had the nominally highest rating (83.7). Again, drivers in this experiment apparently wanted to know where they were in relation to their destination. Recalling that virtually none of the drivers brought anything with them to do, this interest may have reflected boredom on their part. On a real AHS, though, such information might prove useful for another reason—it will tell the driver how long he/she is able to continue whatever activity in which he/she is engaged.

Finally, drivers had an opportunity to state whether there was any other information not specific to one of the four information types that they would like to have available (see table 9). Weather information was mentioned by seven of the drivers, but none said why they would find it useful. (It could be because it would allow rerouting around bad weather ahead, or it would give the driver some idea that his/her trip is going to be delayed.) At any rate, the ideas suggested by the drivers in this experiment—both those associated with a specific information type and those in the "other useful information" category—provide a useful starting point for AHS designers, who should continue to ask drivers what information they would like to have available and what services they would find most useful on an Automated Highway System.

## An Examination of What Information Drivers Would Like to Provide *to* the AHS

The types of information the drivers in this experiment wanted to be able to provide to the AHS (see "Examination of What Information Drivers Would Like to Provide *to* the AHS" in the *Results* section) indicate an apparent concern for travel delays. All types of information mentioned by two or more drivers dealt with weather (seven drivers), accidents (five drivers), road construction, obstructions, or general road conditions. Perhaps drivers believe that making such information available will allow the system to do a better job of routing vehicles around congested or otherwise slow-traffic areas, and this will, in turn, make their trips more efficient. Of course, one should also think about the notion that drivers may believe that the AHS will, in fact, need their assistance to find out the types of information they mentioned. Coupled with the already-discussed idea that information from the AHS about gas, food, lodging, etc. at each exit has limited utility if drivers cannot exit relatively quickly, this may have implications for the need to begin providing a basic education to a larger audience about what the AHS might and might not be able to do, and to solicit input from this larger audience on a variety of topics that will help determine the marketability of the Automated Highway System. At any rate, the information mentioned by the drivers in this experiment, including what they would like the AHS to provide to them, can be used by AHS designers as a useful starting point in helping determine what capabilities the AHS should have.

# APPENDIX A: SCRIPTS OF THE NARRATIONS THAT ACCOMPANIED THE VIDEOTAPES

## Introduction for the Noncommuter Experiments Script

The drivers whose data are reported in this paper were divided into three groups based on how control was transferred back to them after automated travel. The videotapes shown to the drivers in the three groups, and the accompanying narrations, differed in the instructions regarding control transfer. However, since that variable was not relevant until after the period of interest for the data reported here, there was no discussion of the various methods in the report. Likewise, narration from only one version of the videotape is shown in this appendix, since it contains all details of importance for this paper. In addition, only those parts of the narration that are relevant for present purposes are included (i.e., only those parts through the period of automated travel).

## Text of the Videotape Narration for the Noncommuter Experiments

**[A. Introducing the AHS]**

Passage A.1: The study in which you are about to participate is part of an ongoing investigation of Automated Highway Systems. We are conducting the investigation for the FHWA, the Federal Highway Administration. The FHWA is responsible for safety and travel effectiveness on our highways. In this investigation, the FHWA is trying to determine how to design an Automated Highway System in order to reduce congestion and to increase highway safety. We are conducting a series of studies using the Iowa Driving Simulator. We will explore how an Automated Highway System might work, and how well drivers would handle their vehicles in such a system. The data provided by you, and others, will aid us in making accurate and responsible recommendations about how to design and operate the Automated Highway System. This is a test of the Automated Highway System, not a test of you or your driving skills. We will maintain your privacy—your data will never be presented with your name attached.

Passage A.2: The Automated Highway System could be designed in a number of ways. The version that you will drive in the simulator today has been installed on a freeway with three lanes in each direction. In this freeway, the left-most lane is reserved for automated traffic only. All the vehicles in this lane are under the control of the Automated System. They will be arranged in strings—there may be one, two, three, or four vehicles traveling together in each string. The vehicles in the automated lane will be traveling at 65 miles per hour, faster than the traffic in the other two lanes. The right and center lanes are not automated—the vehicles in them will be controlled manually by their drivers.

**[B. Driving on the Freeway]**

Passage B.1: At the start of the drive, your car will be parked on a freeway entrance ramp. You will drive from the entrance ramp into the right lane. For about fifteen minutes, you will drive on the freeway.

Passage B.2: You will be able to drive in the right lane and the center lane, but not in the left lane—that is reserved for automated vehicles. If you start to move into the left lane, you will hear the following warning:
["You've entered the left lane.
You're not authorized to be in the left lane.
Return to the center lane immediately."]

Passage B.3: While you are in the right or center lanes, you will drive among vehicles that are not under automated control—these vehicles will behave in the way that traffic usually behaves on a freeway. The speed limit in the right and center lanes is 55 miles per hour.

**[C. Entering the Automated Lane]**

Passage C.1: Now, I will describe how you enter the automated lane and join one of the strings of automated vehicles.

Passage C.2: After driving your car for fifteen minutes, you will hear a message. If you are in the center lane, the message will be:
["Please remain in the center lane and wait for further instructions."]

Passage C.3: When you hear this message, you should remain in the center lane. You will soon hear further instructions.

Passage C.4: If, at the end of the fifteen minutes, you are not in the center lane, but are in the right lane instead, you will hear this message:
["Please move to the center lane and, when you get there, wait for further instructions."]

Passage C.5: You should move to the center lane as soon as it is safe to do so.

Passage C.6: After you have been in the center lane a few moments, you will hear the following message:
["To engage the automated system, push the *On* button now."]

Passage C.7: When you push the *On* button, you will hear this message:
["Welcome to the Automated Highway System. Your vehicle is now controlled by the automated system. You will enter the automated lane in a moment."]

Passage C.8: The Automated System will take control. It will keep your car in the center lane, controlling your speed and steering while it waits for a suitable gap in the automated lane. When it finds a suitable gap between two strings of automated vehicles, the System will move your car into the automated lane. Then, it will increase your speed gradually, until the gap between your car and the string of vehicles ahead narrows and you become the last vehicle in that string.

Passage C.9: Let me review the entry procedure. You will be driving in the right or center lane. If you are in the right lane, you will be asked to move to the center lane—if you are already in the center lane, you will be asked to stay there. After a few moments, you will be asked to press the *On* button to let the system know that you are ready to enter the automated lane. When you press the *On* button, you will hear a message informing you that the system has taken control of your car. It will move you from the center lane to the automated lane, and increase the speed of your car until you join the string of automated vehicles ahead of you.

**[D. Traveling in the Automated Lane]**

Passage D.1: For the next thirty minutes, the Automated Highway System will move you along rapidly in the automated lane, steering your car and controlling its speed automatically.

Passage D.2: As you travel along under automated control, the steering wheel will move as the car steers itself. You will notice the steering wheel movement most when the car goes around a curve.

**[E. Using the Information Display]**

Passage E.1: When you are in the automated lane, you will be able to obtain current information about your journey. This information will be presented on the laptop computer that will be mounted to your right in the vehicle. You will be able to obtain information about your current location or the next exit on the freeway; you will be able to learn the time to your destination; and you will be able to obtain information about the state of the traffic ahead.

Passage E.2: You will be able to obtain this information by pressing the keys on a key pad. To discover your current location, you will press 1 on this key pad—you will then be able to see how far you have traveled since the last exit, and how far away you are from the next exit.

Passage E.3: By pressing zero on the key pad, you will return to the main menu. Then, if you press 2, you will receive information about the next exit—you will see how far away it is, and how long it will take to get to it while you are traveling in the automated lane.

Passage E.4: To return to the main menu again, you press zero. Now if you press 3, you will receive information about your destination—how far away it is and how long it will take to get to it.

Passage E.5: You press zero to return to the main menu again. Then, by pressing 4 on the key pad, you can obtain information about the state of the traffic ahead.

Passage E.6: You can obtain this information—about your current location, the next exit, your destination, or the state of the traffic—by pressing the appropriate key at any time while you are in the automated lane.

Passage E.7: This information will not be available to you before you enter the automated lane or after you leave it and take control of your car again.

**[F. Leaving the Automated Lane]**

Passage F.1: After you have traveled in the automated lane for about half an hour, you will hear a message informing you that you are about to leave the automated lane. This is what you will hear:
["You will leave the automated lane in thirty seconds. Once in the center lane, you will be asked to resume control of your vehicle."]

## Introduction for the Commuter Experiment Script

All drivers in this experiment were shown the same videotape. Only those parts of the narration that are relevant for present purposes are included (i.e., only those parts through the period of automated travel).

## Text of the Videotape Narration for the Commuter Experiment

**[A. Introducing the AHS]**

Passage A.1: The study in which you are about to participate is part of an on-going investigation of Automated Highway Systems. We are conducting the investigation for the FHWA, the Federal Highway Administration. The FHWA is responsible for safety and travel effectiveness on our highways. In this investigation, the FHWA is trying to determine how to design an Automated Highway System in order to reduce congestion and to increase highway safety. We are conducting a series of studies using the Iowa Driving Simulator. We will explore how an Automated Highway System might work, and how well drivers would handle their vehicles in such a system. The data provided by you, and others, will aid us in making accurate and responsible recommendations about how to design and operate the Automated Highway System. This is a test of the Automated Highway System, not a test of you or your driving skills. We will maintain your privacy—your data will never be presented with your name attached.

Passage A.2: In this study, we are interested in whether the Automated Highway System might help a driver who has to travel to work every day by car. We will ask you to drive in the simulator vehicle as if you were going to work in the morning and returning home at night for the next four days—that is today, tomorrow, and on Friday of this week, and then on Monday of next week.

Passage A.3: The Automated Highway System could be designed in a number of ways. The version that you will drive in today and in the next few days, has been installed on a freeway with three lanes in each direction. In this freeway, the left-most lane is reserved for automated traffic only. All the vehicles in this lane are under the control of the Automated System. They will be arranged in strings—there may be one, two, three, or four vehicles traveling together in each string. The vehicles in the automated lane will be traveling at 65 miles per hour, faster than the traffic in the other two lanes. The right and center lanes are not automated—the vehicles in them will be controlled manually by their drivers.

**[A1. Practice]**

Passage A1.1: When you first get into the simulator today, you will be asked to drive on the freeway for five minutes. This is to give you a chance to get used to the car and the way that it handles before you drive to work. This will be the only time there will be a practice drive.

**[B. Driving on the Freeway]**

Passage B.1: At the start of your drive to work, your car will be parked on a freeway entrance ramp. You will drive from the entrance ramp into the right lane and then, for about ten minutes, you will drive on the freeway.

Passage B.2: You will be able to drive in the right lane and the center lane, but not in the left lane—that is reserved for automated vehicles. If you start to move into the left lane, you will hear the following warning:
["You've entered the left lane.
You're not authorized to be in the left lane.
Return to the center lane immediately."]

Passage B.3: While you are in the right or center lanes, you will drive among vehicles that are not under automated control—these vehicles will behave in the way that traffic usually behaves on a freeway. The speed limit in the right and center lanes is 55 miles per hour.

**[C. Entering the Automated Lane]**

Passage C.1: Now, I will describe how you enter the automated lane and join one of the strings of automated vehicles.

Passage C.2: After driving your car for about ten minutes, you will hear a message. If you are in the center lane, the message will be:
["Please remain in the center lane and wait for further instructions."]

Passage C.3: When you hear this message, you should remain in the center lane. You will soon hear further instructions.

Passage C.4: If, at the end of the ten minutes, you are not in the center lane, but are in the right lane instead, you will hear this message:
["Please move to the center lane and, when you get there, wait for further instructions."]

Passage C.5: You should move to the center lane as soon as it is safe to do so.

Passage C.6: After you have been in the center lane a few moments, you will hear the following message:
["To engage the automated system, push the *On* button now."]

Passage C.7: When you push the *On* button, you will hear this message:
["Welcome to the Automated Highway System. Your vehicle is now controlled by the automated system. You will enter the automated lane in a moment."]

Passage C.8: The Automated System will take control. It will keep your car in the center lane, controlling your speed and steering, while it waits for a suitable gap in the automated lane. When it finds a suitable gap between two strings of automated vehicles, the System will move your car into the automated lane. Then, it will increase your speed gradually until the gap between your car and the string of vehicles ahead narrows and you become the last vehicle in that string.

Passage C.9: Let me review the entry procedure. You will be driving in the right or center lane. If you are in the right lane, you will be asked to move to the center lane—if you are already in the center lane, you will be asked to stay there. After a few moments, you will be asked to press the *On* button to let the system know that you are ready to enter the automated lane. When you press the *On* button, you will hear a message informing you that the system has taken control of your car. It will move you from the center lane to the automated lane, and increase the speed of your car until you join the string of automated vehicles ahead of you.

**[D. Traveling in the Automated Lane]**

Passage D.1: For the next twenty-five minutes, the Automated Highway System will move you along rapidly in the automated lane, steering your car and controlling its speed automatically.

**[E. Leaving the Automated Lane]**

Passage E.1: After you have traveled in the automated lane for about twenty-five minutes, you will hear a message informing you that you are about to leave the automated lane. This is what you will hear:

["You will leave the automated lane in thirty seconds. Once in the center lane, you will be asked to resume control of your vehicle."]

# APPENDIX B: QUESTIONNAIRE FOR THE NON-COMMUTER EXPERIMENTS

## Introduction

There were four versions of the questionnaire used in this experiment—one for each method of transferring control to the driver after automated travel (a variable that was not relevant for the purposes of this report) and one for a control group (who drove manually throughout the entire trial, and who also were not relevant for present purposes). What is shown below are only those questions that were reported on in this paper. The results of the remaining questions for all four groups are being reported elsewhere.

## Questionnaire

The questionnaire is presented with the instructions first, as it was for drivers in the experiment.

# Instructions

The following series of questions deals with the driving simulator, the experiment that you just took part in, and the Automated Highway System. For most of the questions, you will be asked to provide a rating from 0 to 100. The meanings of the two endpoints of the scale are provided for each question. Your answer can be any whole number between 0 and 100; do not use fractions or decimals. A space is provided for you to write your answer in.

Example:

| **Question** | **Scale** | **Your Rating** |
|---|---|---|
| How would you rate the importance of airbags in driver safety? | 0 = Very unimportant<br>100 = Very important | ____________ |

If you think that airbags are pretty important in driver safety, you would provide a rating of over 50; the more important you think they are, the closer your rating would be to 100. If you think that airbags are not too important, you would provide a rating of less than 50; the more *un*important you think they are, the closer your rating would be to 0.

---

# Questions

9–12. During the experiment, when your car was under automated control, you were given an opportunity to request various kinds of information. An example of each kind of information is shown below. For each kind of information, you are asked to tell whether you looked at it during the experiment and to rate its *usefulness*. You are then given an opportunity to tell what you especially liked or did not like about the information presented and how you would change it.

9a. Did you look at the CURRENT LOCATION information (shown below) during the experiment?

- ❑ Yes (Please go to question 9b.)
- ❑ No (Please go to question 10a.)

| Question | Scale | Your Rating |
|---|---|---|
| 9b. How useful did you find the CURRENT LOCATION information? | 0 = Not useful<br>100 = Very useful | ________ |

| CURRENT LOCATION | |
|---|---|
| Last exit: | Exit 14, County Road N |
| Distance past exit: | 8.1 miles |
| Next exit: | Exit 17, County Road I |
| Distance to exit: | 0.3 miles |

What did you especially like or not like about the CURRENT LOCATION information? How would you change it to make it more *useful*?

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

10a. Did you look at the NEXT EXIT information (shown on the next page) during the experiment?

- ❑ Yes (Please go to question 10b.)
- ❑ No (Please go to question 11a.)

| Question | Scale | Your Rating |
|---|---|---|
| 10b. How useful did you find the NEXT EXIT information? | 0 = Not useful<br>100 = Very useful | ________ |

| NEXT EXIT | |
|---|---|
| Next exit: | Exit 17, County Road I |
| Distance to exit: | 0.3 miles |
| Travel time to exit: | 0 minutes 18 seconds |

What did you especially like or not like about the NEXT EXIT information? How would you change it to make it more *useful*?

______________________________

______________________________

______________________________

______________________________

______________________________

11a. Did you look at the TIME TO DESTINATION information (shown below) during the experiment?

- ☐ Yes (Please go to question 11b.)
- ☐ No (Please go to question 12a.)

| Question | Scale | Your Rating |
|---|---|---|
| 11b. How useful did you find the TIME TO DESTINATION information? | 0 = Not useful<br>100 = Very useful | ________ |

| TIME TO DESTINATION | |
|---|---|
| Destination: | County Road Q<br>Exit 32 |
| Travel time to destination: | 43 minutes 22 seconds |

What did you especially like or not like about the TIME TO DESTINATION information? How would you change it to make it more *useful*?

____________________________________________________________________

____________________________________________________________________

____________________________________________________________________

____________________________________________________________________

____________________________________________________________________

12a. Did you look at the TRAFFIC AHEAD information (shown below) during the experiment?

- ❑ Yes (Please go to question 12b.)
- ❑ No (Please go to question 13.)

| **Question** | **Scale** | **Your Rating** |
|---|---|---|
| 12b. How useful did you find the TRAFFIC AHEAD information? | 0 = Not useful<br>100 = Very useful | __________ |

TRAFFIC AHEAD

| | |
|---|---|
| Distance to destination: | 28.4 miles |
| Traffic ahead: | Accident blocking far right lane at Exit 9, 42.7 miles ahead. Traffic congestion in center lane at that exit also. |

What did you especially like or not like about the TRAFFIC AHEAD information? How would you change it to make it more *useful*?

__________________________________________________________________________

__________________________________________________________________________

__________________________________________________________________________

__________________________________________________________________________

__________________________________________________________________________

13. Are there other kinds of information you would find useful during an actual trip on an Automated Highway System?

__________________________________________________________________________

__________________________________________________________________________

__________________________________________________________________________

__________________________________________________________________________

__________________________________________________________________________

(Questions 14 through 25 are not relevant for the present experiment.)

26. What kinds of information would you like to be able to provide *to* the Automated Highway System? (For example, if there is some disturbance on the road ahead, would you like to be able to tell that to the System?)

__________________________________________________________________________

__________________________________________________________________________

__________________________________________________________________________

__________________________________________________________________________

__________________________________________________________________________

# APPENDIX C: ANALYSIS OF VARIANCE TABLES

**Table 10. ANOVA on the frequency that using the laptop computer and talking to the experimenter were engaged in by male drivers.**[1]

| Source of Variation | SS | df | MS | *F* |
|---|---|---|---|---|
| Treatment | 530.9 | 1 | 530.9 | 10.6* |
| Error | 1359.1 | 27 | 50.3 | |
| Total | 1890.0 | 28 | | |

[1] n = 14 for using the laptop computer; n = 15 for talking to the experimenter
* $p < 0.01$

**Table 11. ANOVA on the frequency that using the laptop computer and talking to the experimenter were engaged in by female drivers.**[1]

| Source of Variation | SS | df | MS | *F* |
|---|---|---|---|---|
| Treatment | 459.1 | 1 | 459.1 | 4.4* |
| Error | 2302.5 | 22 | 104.7 | |
| Total | 2761.6 | 23 | | |

[1] n = 14 for using the laptop computer; n = 10 for talking to the experimenter
* $p < 0.05$

**Table 12. ANOVA on the frequency that using the laptop computer and closing the eyes for 5 or more consecutive seconds were engaged in by younger drivers.**[1]

| Source of Variation | SS | df | MS | *F* |
|---|---|---|---|---|
| Treatment | 563.3 | 1 | 563.3 | 6.0* |
| Error | 2160.5 | 23 | 93.9 | |
| Total | 2723.8 | 24 | | |

[1] n = 17 for using the laptop computer; n = 8 for talking to the experimenter
* $p < 0.05$

**Table 13. ANOVA on the percentage of times each information type was selected across drivers, collapsed across age and gender.**[1]

| Source of Variation | SS | df | MS | *F* |
|---|---|---|---|---|
| Between drivers | 0.0 | 27 | | |
| Within drivers | 22,218.1 | 84 | | |
| Information type | 6,678.9 | 3 | 2,226.3 | 11.6* |
| Residual | 15,539.2 | 81 | 191.8 | |
| Total | 22,218.1 | 111 | | |

[1] n = 28
* $p < 0.05$

**Table 14. ANOVA on the ratings of the four information types.**[1]

| Source of Variation | SS | df | MS | $F$ |
|---|---|---|---|---|
| Between subjects | 48,822.2 | 29 | | |
| Within subjects | 45,391.7 | 90 | | |
| Information type | 4,232.2 | 3 | 1,410.7 | 3.0* |
| Residual | 41,159.5 | 87 | 473.1 | |
| Total | 94,213.9 | 119 | | |

1 The data are based on 30 drivers.

* $p < 0.05$

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