

Trace Driven Driving Simulation:
Towards Integration of External Lab
with Simulator
and
The Integrated Study of Microscopic
and Macroscopic Problems in IVHS:
Emulation of the I-394 External
Laboratory in a Driving Environment

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Report Documentation Page

1. Report No. MN/RC - 94/23	2.	3. Recipient's Accession No.	
4. Title and Subtitle Trace Driven Driving Simulation: Towards Integration of External Lab With Simulator and The Integrated Study of Microscopic and Macroscopic Problems in IVHS: Emulation of the I-394 External Laboratory in a Driving Environment		5. Report Date June, 1994	
		6.	
7. Author(s) Shashi Shekhar and Peter A. Hancock		8. Performing Organization Report No.	
9. Performing Organization Name and Address Department of Computer Science and Human Factors Research Laboratory University of Minnesota Minneapolis, Mn 55455		10. Project/Task/Work Unit No.	
		11. Contract(C) or Grant(G) No. (C) Mn/DOT 70213 TOC 94	
12. Sponsoring Organization Name and Address Minnesota Department of Transportation Office of Research Administration 200 Ford Building-Mail Stop 330 117 University Avenue St. Paul, Mn. 55155		13. Type of Report and Period Covered Final Report 1993-1994	
		14. Sponsoring Agency Code	
15. Supplementary Notes			
16. Abstract (Limit: 200 words) <p>The research in traffic flow and safety has proceeded on two different tracks. The traffic flow research has focused on macroscopic aspects and aggregate behavior, while safety research has focused on the traveller's microscopic view of the transportation system. This dichotomy of research methodology has made it difficult to study many issues in intelligent vehicle highway systems in an integrated manner. In this project, we explore ways of facilitating research on problems which require integration of the two views of the transportation systems. In particular, we explore headup displays for conveying aggregate traffic information and exceptions to the drivers. We evaluate text based and graphic map based displays with fixed orientation as well as egocentric orientation. Our studies indicate that graphic displays are more effective than text based displays for the assimilation of information by drivers. Furthermore, our studies suggest that an egocentric map display allows drivers to assimilate and process information faster than a fixed orientation display.</p>			
17. Document Analysis/Descriptors IVHS Human factors Headup displays Integration Simulation		18. Availability Statement No restrictions. This document is available through the National Technical Information Services, Springfield, Va. 22161	
19. Security Class (this report) Unclassified	20. Security Class (this page) Unclassified	21. No. of Pages 26	22. Price

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Final Report

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The authors and the Minnesota Department of Transportation do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to this report.

Acknowledgments

This work was supported by the Undergraduate Research Opportunity Program, the Center for Transportation Studies and Minnesota Department of Transportation. The students from courses Csci 5504 and Csci 5106 developed many pieces of the software. The hardware and a small part of the software was acquired from American Honda, ESI, Ohio and XTAR, California. Mark Coyle, Meir Shargal, and Jeff Caird assisted in the implementation and analysis of this project.

Executive Summary

The research in traffic flow and safety has proceeded on two different tracks. The traffic flow research has focused on macroscopic aspects and aggregate behavior, while safety research has focused on the traveller's microscopic view of the transportation system. This dichotomy of research methodology has made it difficult to study many issues in intelligent vehicle highway systems in an integrated manner. In this project, we explore ways of facilitating research on problems which require integration of two views of the transportation systems. In particular, we explore headup displays for conveying aggregate traffic information and exceptions to the drivers. We evaluate text based and graphic map based displays with fixed orientation as well as egocentric orientation. Our studies indicate that graphic displays are more effective than text based displays for the assimilation of information by drivers. Furthermore, our studies suggest that an egocentric map display allows drivers to assimilate and process information faster than a fixed orientation display.

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1. Introduction

Intelligent Vehicle Highway Systems (IVHS) are being proposed to deal with traffic safety and congestion problems. Intelligent vehicles will aid drivers in various driving tasks such as routing, navigation, collision avoidance, vehicle monitoring and traffic status. IVHS will also manage global traffic information so that drivers and traffic controllers can make better decisions and reduce traffic congestion without expanding the capacity of the highways. To detect and predict congestion, the IVHS will collect the information about traffic on different highways to detect and predict congestion. The control algorithms for traffic lights and entrance ramps will utilize this information to manage traffic. Drivers will receive the information via electronic signboards on highways as well as via an onboard computer.

One approach to IVHS is to make all relevant information available to the driver. For example, traffic density on various highways could be broadcast to every vehicle. Information presentation interfaces are important to convey the relevant information to the drivers in a safe manner. The extra information presented to drivers to help them select the least congested routes greatly increases the volume of the information to be processed by the driver. This can lead to overloading of the drivers, resulting in increased time to gather information and respond to traffic events. The large volume of information also increases the time needed to detect driving events, due to the increased searching time to access relevant information. Thus the information-based approach to IVHS raises safety issues related to the delayed response by the drivers to the driving events.

1.1. Microscopic and Macroscopic Properties of IVHS

The research in IVHS can be divided into two categories, which we will call Microscopic and Macroscopic Research, respectively. Our research project focused on the integration of the two types of research to demonstrate that they can be used to aid each other, and that a stronger program will result if both are integrated together. The following subsections describe each of these types separately, and then we discuss a sample application that we use to show the integration of the two types of research.

1.1.1. Microscopic Analysis and Research

Microscopic analysis is concerned with the individual parts of a system. In IVHS, a microscopic analysis looks at the behavior of individual drivers in an attempt to improve the safety and efficiency of road travel. The Human Factors Research Laboratory (HFRL) makes use of a fixed-base driving simulator to study human performance in tasks related to driving. Examples of research performed at the HFRL in relation to IVHS include a study of left-turn driving performance with older drivers, and a study on the effect of tinted film on drivers' visibility. These studies look at the performance of drivers who have little or no information about the road or traffic conditions except for information gained by direct observation. For instance, information like traffic congestion, road accidents, and traffic flow are not available to the HFRL driving simulator subjects.

1.1.2. Macroscopic Analysis

In macroscopic analysis a system is viewed at an abstract level by a series of mathematical formulas. The goal is to predict the behavior of the collection of individual parts, rather than to predict the behavior of one of the individual parts. For example, the behavior of all of the cars traveling close to an accident would be viewed macroscopically as the flow of traffic slowing, while a microscopic view would attempt to understand why an individual driver slows down. Macroscopic analysis in IVHS is typically treated as a problem in fluid-flow analysis. In fluid-flow mechanics, the properties of a liquid flowing through a conduit or pipe are modeled by a series of equations. These equations are able to predict such phenomena as flow-rate changes. In IVHS, the highways are treated as the pipes, and the road traffic is treated as the fluid traveling through the pipe. Therefore, this type of analysis can predict traffic phenomena such as road congestion.

1.2. Need for Integration

This research was proposed at a time when there was no integration of the microscopic and macroscopic views of IVHS. Since this research was proposed, we have seen a number of examples of integration. For example, the HFRL conducted studies using the newest Delco radio systems, which are able to transmit congestion information to drivers. It is becoming increasingly apparent that both micro- and macroscopic analysis is necessary for a successful IVHS project. Further, these two types of analysis can be integrated to provide results superior to those achieved by either method. The next section describes a sample application that we have used to demonstrate the effectiveness of an integrated microscopic and macroscopic IVHS research program.

1.3. Headup Displays: A Problem Requiring Integration

Headup displays are being examined as a means to deliver IVHS information to drivers. Headup displays are being used in aircraft to present information to the pilot that is superimposed on his/her forward view of the external world. They are used to display two types of information in aircraft: (a) contact information about impending collisions, and (b) housekeeping information. Headup displays save a pilot time in acquiring the necessary information since they reduce head movements. In automobile driving, collision information may not be available in time to be useful. However, headup displays can help in simple navigational tasks that indicate the next routing decision (e.g. turn left/right, exit freeway). They can also be useful for displaying housekeeping information (e.g. speed), since they can reduce the drivers' eye movements, thereby reducing the time it takes to assimilate information. Cars operate at a lower speed than aircraft, but the distances involved are smaller also, yielding similar values for decision time in flying and driving. HUD technology makes it possible to display a wide range of information starting with the speedometer reading (simple) to a computer generated road-map (complex). Relevant questions in HUD design are the placement of displays, the priority scheme, and the method of presentation (i.e. alphanumeric vs. iconic headup displays).

The use of headup displays in aircraft has revealed safety hazards: occlusion of objects by the displays, cognitive capture, and information overload. These safety hazards become more critical in the driving world, due to a higher density of objects on the roads and a need for the driver to follow road signs and signals. A potential headup display design must be validated under realistic driving conditions to ensure safety. The driving simulator can be used as a design and validation tool for headup displays[1]. Driving simulators use graphic computers and display devices to produce pictures viewed by the driver. The driver sits in a car and can operate and feel the response of the actual steering mechanism, the accelerator pedal, the brake pedal and the other interfaces featured in the vehicle[2].

We have extended the driving simulator at the Human Factors Lab in Minnesota to create and validate arbitrary headup displays. The validation is of two types: effectiveness and safety. Effectiveness relates to the improvement of a driver's performance in driving tasks such as navigation. Safety relates to the reduction of drivers' mistakes. In this paper, we will describe the tool used to create headup displays and to design experiments to validate them.

2. Driving Simulator: The environment

The Simulation Hardware at the Human Factors Lab consists of a 1990 Accord which faces a large projection screen, as shown in Figure 1. The picture, consisting of road objects, is displayed on the screen by a high resolution projector. The accelerator, brake pedal, and steering wheel are connected to an Analog/Digital Converter (A/D Converter). Signals from the converter are used for real-time simulation in moving the driver through the environment. The computing system hardware uses Falcon Graphics to provide a real-time graphic system. The Falcon hardware contains three boards to be installed in the host PC. These boards are used for real-time calculation and projection of the simulation environment.

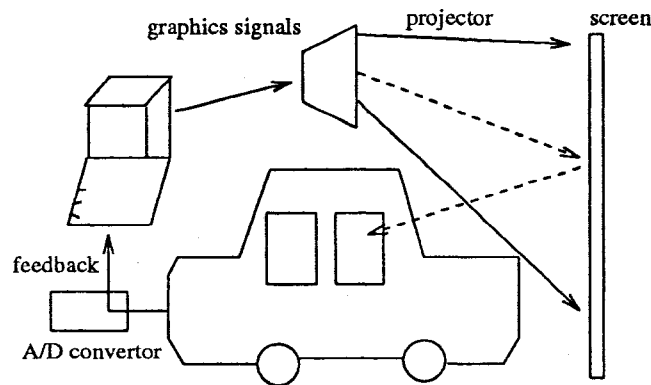


Figure 1. Driving Simulator Hardware

1. Get attributes for new trial
2. Get input (acceleration, brake, steering)
3. Find next position of the driver in the world
4. Find next positions for all moving objects
5. Calculate viewport (i.e. set of visible objects)
6. Update headsup displays
7. Position the driver
8. Draw the new frame
9. Loop back to step 1.

Figure 2. Simulation Algorithm

Figure 2 describes the main loop in the driving simulator software. A frame is created in each iteration of the loop. In each iteration, driver input (accelerator, brake, etc) is collected and analyzed. Based on the equation of motion for the car, the car's next position is calculated. Next, the positions of moving objects (cars) which move independently of the driver are calculated. The viewport of the driver is the area of the world visible to him. The next step calculates which objects are visible to him/her based on the new input, and a new frame is drawn. This completes one loop (frame), and this loop is executed approximately twenty times per second.

The roadview is generated from the current position of the driver and the graphic description of various objects in the world. Figure 3 shows the process used to create objects for use in the simulation world. These objects are created in a graphics package such as Autocad. They are then processed by 3DVIEWIII format conversion tools to transform them to a format usable by our graphics system. These objects are then stored in the database used by the driving simulator.

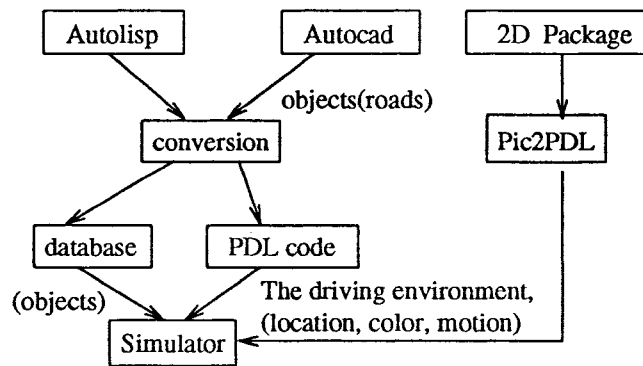


Figure 3. Process to create driving world

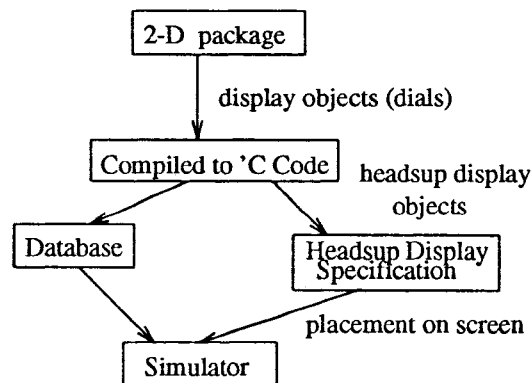


Figure 4. Process to create headup display

The design of Headup displays required a different approach from the method of designing real-world objects. Objects created in Autocad are placed into the database world according to three dimensional coordinates, whereas the headup displays in the flight simulator used the pixel locations of the screen to directly draw displays that are superimposed onto the screen. Figure 4 describes the additional processes used to design headup displays.

3. Design and Implementation

We have successfully extended the simulator at the Human Factors Research Lab to allow for validation and testing of Headup displays. The flight demonstration software provided the method to simulate headup displays, and to simplify the design process a translator has been written to convert drawings from Xfig to the 'C' code necessary in the simulator. The simulation world consists of additional objects modeled from Minneapolis highways and buildings to provide more realism. A new method of object design, Level of Detail (LOD) programming, allows complex designs to be used without subsequent processor slowdown.

The driving simulator module receives data from three sources, as shown in Figure 5. First, the driving world module specifies the location of objects in the world. Second, the database of basic objects contains the object descriptions described in the driving world specification module. Third, the headup display description, consisting of dials for speed, fuel, etc., is used by the driving simulator to create and display information based on driver inputs. The driving simulator calculates the next frame to be displayed and passes this to the PG2000 module, which draws the new frame. The PG2000 module consists of software and hardware used to render three-dimensional objects.

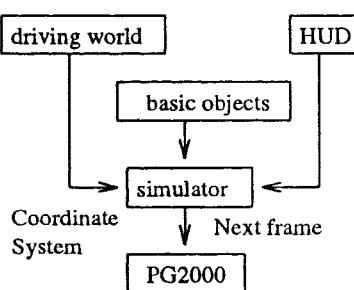


Figure 5. Block Diagram of Simulator

The headup displays represent housekeeping information (speed, fuel) and navigational information (compass and map). Two representations for each display have been designed, alphanumeric and iconic. The alphanumeric displays present the information as text, while the iconic displays capture the information graphically. Both display types are presented to the driver by superimposing them over the windshield. The headup display icons are specified by creating a drawing on a computer screen with the help of a drawing package. The drawing is then translated to a C program and linked to the simulation software. Figure 6 shows a driver's view with headup displays for navigation and speed superimposed on the windshield. Navigation displays specify the car's position and direction of travel, along with locations of traffic

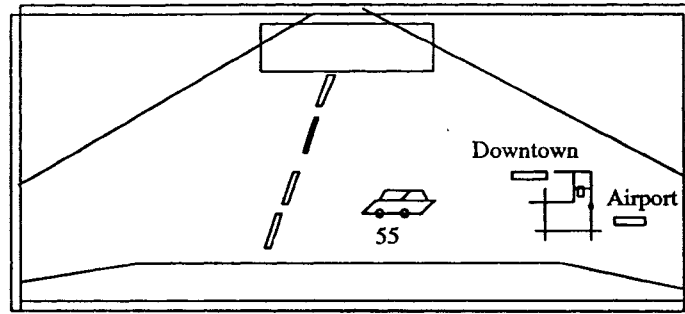


Figure 6. Drivers view

blockages. Speed is represented by three icons which represent a high, medium and low range of speed. The different HUD displays for speed are illustrated in Figure 7. This scheme allows the driver to obtain a quick estimate of speed. Actual speed can be read from the alphanumeric code below the icons.

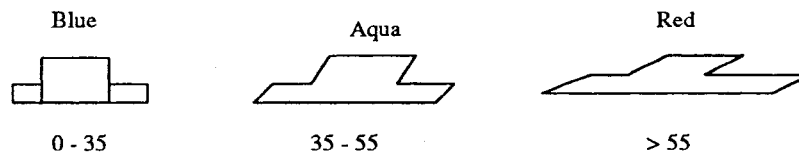


Figure 7. Three Speed Icons

A driving environment is designed by creating a library of 3-dimensional drawings and a 2-dimensional map which show the locations of the objects. A library of 3-dimensional primitives (e.g. road-segment, cubes, pyramids, prisms) are created using AutoLisp. Autolisp is a version of the Lisp programming language which is available in Autocad. Buildings, roads and other interesting 3-dimensional objects can be created by composing the primitives. The 2-dimensional map is specified on the computer screen using a picture drawing tool. To provide realism in the driving world, we created the skyline of Minneapolis with our software. The driving world in our environment consists of roads and buildings that represent the driving environment from the Minneapolis International Airport to downtown Minneapolis.

Level of Detail (LOD) programming was used to achieve real-time performance in a complex environment. A LOD object is actually a database of several objects with varying degrees of complexity. The parameters of the object dictate which version of the object will be visible from the driver's viewport. For example, if a house was designed as a LOD object, it might have three different drawings associated with it. The first would be the house in full detail, the second would be the house as a cubic block with windows only, and the final drawing would be a cubic shape alone. The first drawing might appear for distances less than 1000 feet, the second for distances 1000-2000 feet, etc. We divided the roads into a collection of 1/8 mile segments. Each

segment was designed as a level of detail object. Road segments more than 1/4 mile were not drawn to reduce the amount of drawing required by the graphics processor.

4. Using Simulator for Headup Display Design

The simulator is being used to create headup displays and to evaluate their safety and effectiveness. For example, using the simulator, the driver's assimilation and response time to new traffic blockage information from the radio broadcast and headup display was measured and compared. The parameters of the experiment included length of traffic blockage, driving speed, and distance between routing decision point and traffic blockage.

The experiment was set up in 3 steps. First, the driving environment and HUD's were created by the methods described earlier. Second, the experimenter specified the multiple trials to be used for each subject by specifying the values of the experiment parameters for each trial. This was accomplished by storing the experiment parameter values in a structure for each trial. The structure has the following information: control group, goal speed, traffic blocks with locations, and distance from rerouting decision point to present traffic blockage. Sixteen combinations were stored to represent sixteen trials. The experimenter accomplished this by choosing the attributes from the trial design menu (Figure 8).

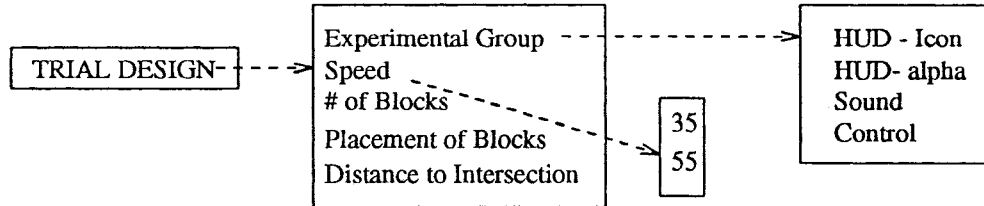


Figure 8. Menu to sample data

Finally, the experimenter specified the data to be collected from the experiments via a menu. The menu represents the entire state of simulation with the help of an entity-attribute model, listing each object with attributes. For our experiment, the data to be sampled include trial name and whether subjects had made the correct routing decisions. To record the correctness of rerouting decisions, the path followed by the subject is sampled and analyzed. To observe the trial for verification purposes, automatic replay of a trial is supported. The data collection menu (Figure 9) is used to provide a flexible user interface for the experimenter. For example, to store the subject's position the experimenter could select the "entities-cars-self-xpos-sample" path.

An experimenter runs an experiment by first choosing the group type that will be tested. The trials have been created to reflect a random arrangement of the variables. The data collection has been done by recording correct and incorrect decisions for each trial. The entire

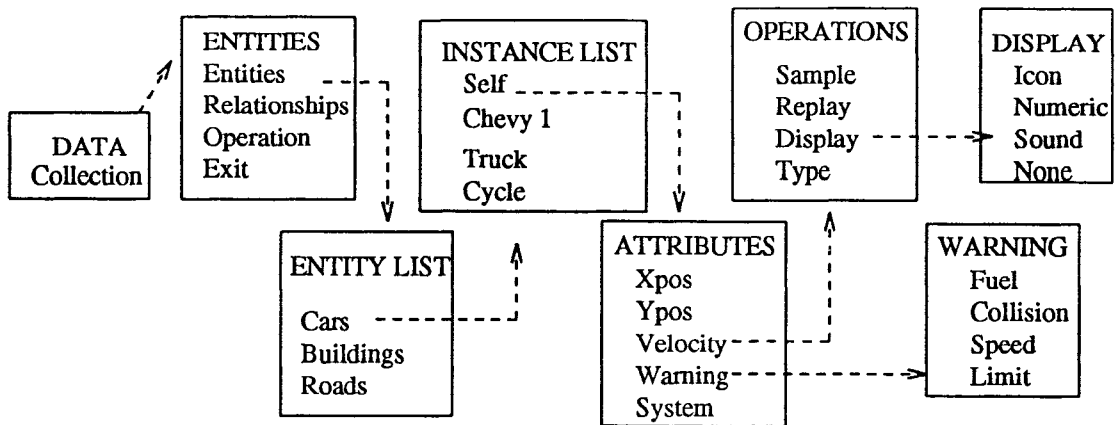


Figure 9. Menu to create experiment trials

experiment is saved to allow an automatic replay of the trials for each subject. This can be used to verify decisions or to analyze driver behavior.

5. Experimental Study

The use of HUD's in aircraft has demonstrated the need for human factors studies to determine their safety and effectiveness. Several questions on design principles remain open, including information overload, color, and type of display. The choice of color for the HUD's is also a question open for research, since wide variation in the color contrast of the external world has posed problems in the aviation world. In complex and changing driving environments, the situation becomes even more critical.

The type of display itself is an open question within automotive headup displays. HUD technology is able to support a wide variety of display options, from alphanumeric text to an iconic picture. IVHS technologies will provide even more information to the driver regarding routing and navigation, So concerns mentioned above are all pertinent when we consider the presentation of this information to drivers via HUD's. We have chosen to test two factors of a navigational HUD for routing information. First, the method of representation is examined by comparing alphanumeric and map icons. Second, we concentrated on iconic map representation and explored alternate ways of representing spatial knowledge.

5.1. General Task

For both experiments the driver's task was to make a left or right turn based on the information presented by a HUD. The independent variable was reaction time. The road map used for the experiments is shown in Figure 10. The first experiment compared response times with alphanumeric text versus a map icon. The second experiment compared reaction times when subjects had different orientations at the starting locations.

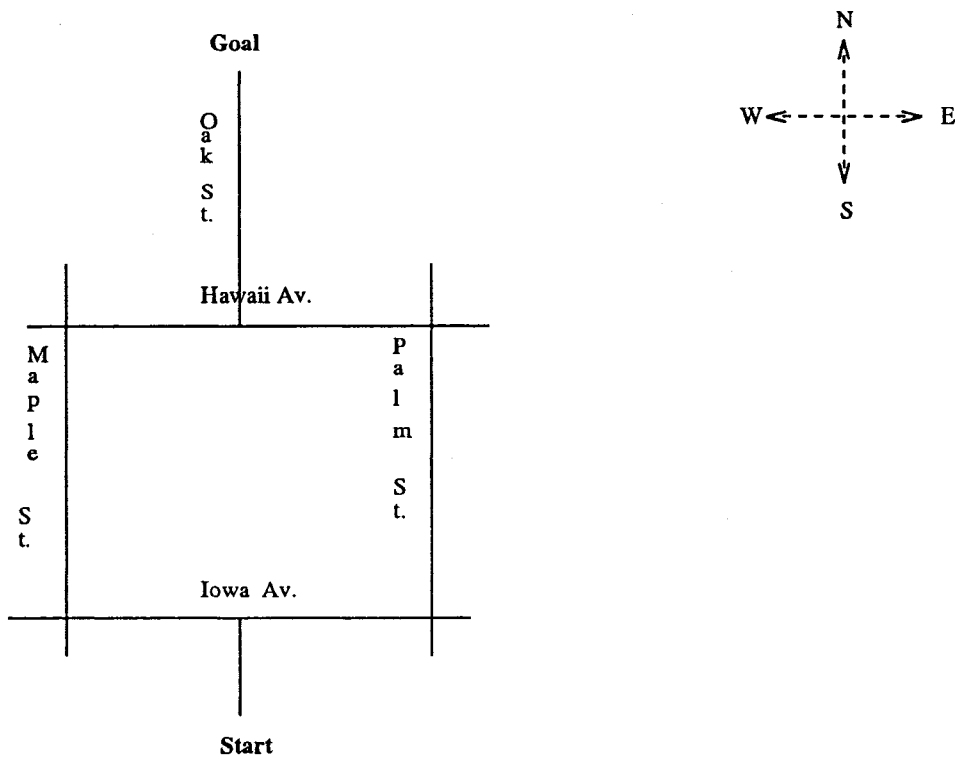


Figure 10. The road map of the driving environment.

Two factors contribute to the time it takes a driver to make a right or left turn. First, certain motor activities need to be performed, and second, time is needed to assimilate the information and to make a decision. We were interested only in the driver's assimilation and decision time, and therefore needed to filter out the motor activity time. This was done by using the appropriate verbal protocol for the subjects. The motor activities needed in this experiment were 1) moving the head and eyes to view the display, and 2) moving the foot to the accelerator and pressing it. Figure 11 illustrates the focus of our study with respect to the total measurement period. We attempted to control for the motor response times in the following manner. To make this time constant, we had subjects fixate upon the area where the display would be presented. To eliminate the foot response time as a variable, we required that subjects keep one foot on the brake when the trial began and that they move it to the accelerator only when they had made the decision to turn. We hoped that this would keep the time for motor activities negligible within each experiment.

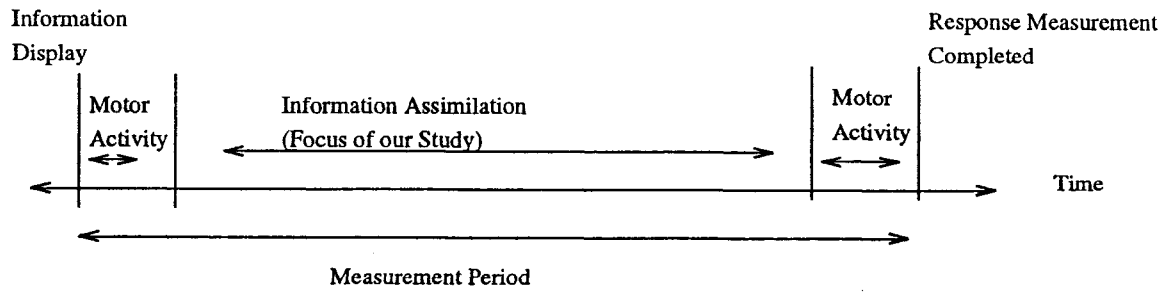


Figure 11. Time Response Diagram

5.2. Experiment 1

The first experiment was used to compare drivers' reaction times when making simple routing decisions which were presented using alphanumeric text displays and map icon displays. Ten subjects were involved with this study, all volunteers were from the University of Minnesota. Five subjects were in each alphanumeric group and map icon group.

Table 1. Text Message Used for Experiment 1

Block on Hawaii between Oak and Maple
Block on Palm between Hawaii and Iowa
Block on Maple between Hawaii and Iowa

For both groups, the task was to make a left or right turn based on the information presented. For the alphanumeric group, the information was presented as a textual message. Table 1 lists several examples of the textual messages that were used. The map group was given a headup display map showing the driver's location, destination, roads, and blockages. Seven block locations were chosen randomly. These seven blocks were presented five times, for a total of thirty five trials. Each subject was given one set of seven practice trials to become familiar with the simulator and experiment. In addition, the subjects were given the paper and pencil exercises shown in Figure 12 to get familiar with the tasks. These were also used to reduce learning effects, as pilot subjects showed dramatic time differences between the first and second sets of seven trials.

<p style="text-align: center;">N ↑ W ··· E ↓ S</p> <p style="text-align: center;">Block — road</p> <p>Circle one of the choices (RIGHT, LEFT) as your turning decision to reach goal in presence of given road block.</p>	1	2	3	
	<p>Goal</p> <p>O a k</p> <p>Hawaii Av.</p> <p>M a p l e P a l m</p> <p>Iowa Av.</p> <p>S t. S t.</p> <p>Start</p>	<p>Goal</p> <p>O a k</p> <p>Hawaii Av.</p> <p>M a p l e P a l m</p> <p>Iowa Av.</p> <p>S t. S t.</p> <p>Start</p>	<p>Goal</p> <p>O a k</p> <p>Hawaii Av.</p> <p>M a p l e P a l m</p> <p>Iowa Av.</p> <p>S t. S t.</p> <p>Start</p>	
	<p>Answer: LEFT RIGHT</p>	<p>Answer: LEFT RIGHT</p>	<p>Answer: LEFT RIGHT</p>	
	4	5	6	
	<p>Goal</p> <p>O a k</p> <p>Hawaii Av.</p> <p>M a p l e P a l m</p> <p>Iowa Av.</p> <p>S t. S t.</p> <p>Start</p>	<p>Goal</p> <p>O a k</p> <p>Hawaii Av.</p> <p>M a p l e P a l m</p> <p>Iowa Av.</p> <p>S t. S t.</p> <p>Start</p>	<p>Goal</p> <p>O a k</p> <p>Hawaii Av.</p> <p>M a p l e P a l m</p> <p>Iowa Av.</p> <p>S t. S t.</p> <p>Start</p>	<p>Goal</p> <p>O a k</p> <p>Hawaii Av.</p> <p>M a p l e P a l m</p> <p>Iowa Av.</p> <p>S t. S t.</p> <p>Start</p>
	<p>Answer: LEFT RIGHT</p>	<p>Answer: LEFT RIGHT</p>	<p>Answer: LEFT RIGHT</p>	<p>Answer: LEFT RIGHT</p>

Figure 12. Form to familiarize subjects with task.

5.3. Experiment 2

The second experiment was used to compare drivers' reaction times for making simple routing decisions that were presented using the map icon from experiment one. This experiment varied the starting location of the driver in the world. The map used for both experiments was fixed base. As mentioned earlier, previous work demonstrated that a fixed orientation map can cause orientation problems due to inconsistent mapping. We wanted to see how dramatic these effects would be when using our map.

The experiment compared egocentric and fixed orientation maps for their effectiveness in conveying macroscopic traffic incident information to drivers. In a fixed orientation map, the icon representing the self vehicle changes orientation in the map display, while the map orientation remains fixed. In an egocentric display, the map display changes orientation while the icon representing the self vehicle remains facing up at the center of the display. We simulated an egocentric display by having the starting position facing north. Since we measured only the reaction time needed to decide whether to turn left or right, we did not need to simulate the map rotation that would be expected in a true egocentric display.

For this experiment, the independent variable was the starting position of the driver. Four positions were varied: northsouth, southnorth, eastwest, and westeast (see below). The block locations were randomized also, but data obtained from experiment 1 indicates that the block locations did not affect reaction times. Our feeling was that the southnorth (starting from south and moving north) group would be quickest, as there is a one to one mapping between stimulus and response. That is, if the subjects saw a block on the right hand side of the (displayed) map they would need to turn left (in the real world) to avoid it. The opposite is true for the northsouth orientation. A block seen on the left side of the (displayed) map would require a left turn in the real world. This is not intuitive and thus may produce longer reaction times. Twenty subjects, all volunteers, were used in this study.

5.4. Observations and Analysis

Our observations for experiment 1 are summarized in Figure 13. The iconic display leads to a shorter response time by a factor of 3. The age of the subjects varied from 21 to 39. The mean age of the subject pool was 28.8 and the standard deviation was 5 years. We used the t-test for the hypothesis as it is related to individual blocks, as well as to the aggregate overall blocks. There is a significant difference in response times for the two types of displays. The response times for the map icon are, in general, at least 3 times faster than for the textual displays. These results confirm that iconic displays are able to deliver more information that the driver can assimilate faster. The observations for experiment 2 are summarized in Figure 14. Also, the

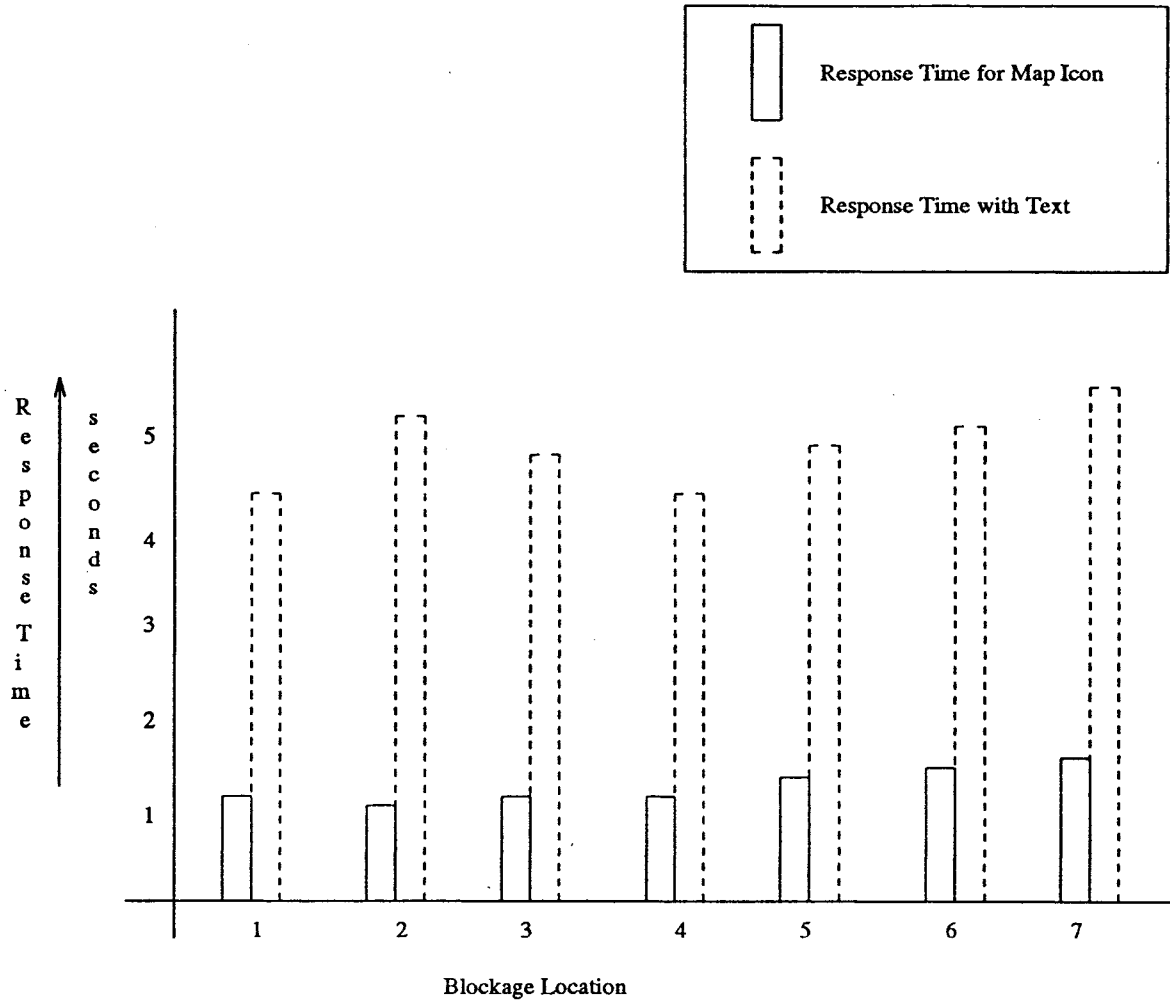


Figure 13. Response time for Iconic and Text HUD

subjects seem to prefer the ego centered orientation. For Figure 14, the age of the subjects varied from 21 to 39. The mean age of the subject pool was 28.8 and the standard deviation was 5 years. We tested the hypothesis on individual subjects using the t-test. For the total, the F-test was used. Egocentric headup displays convey information faster than fixed orientation headup displays.

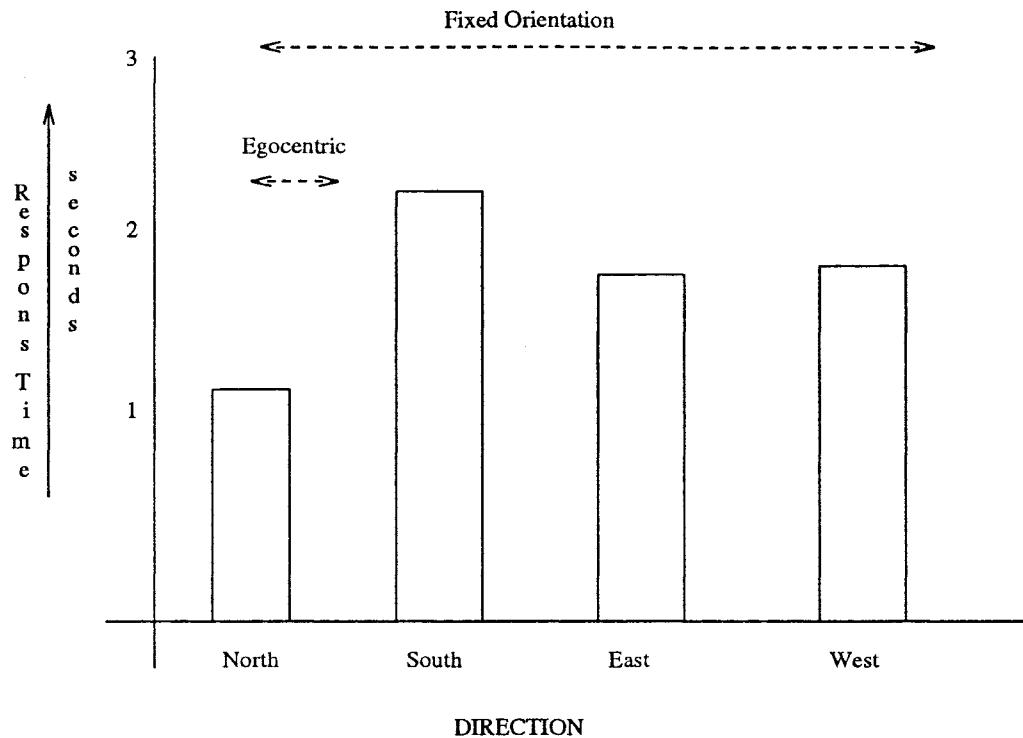


Figure 14. Comparison of navigation map orientations

5.5. Discussion

These results may not apply to real-world driving directly, because of the motor activities and secondary tasks in actual driving and navigation. The experiments were designed to control the effect of the motor activities of moving the head, eyes, hand or leg to gather information or to execute the selected response. The response time for navigation decisions for each headup display will increase to account for these motor activities. Furthermore, the experiments were designed to eliminate the secondary tasks in driving and navigation of watching cross traffic, signal and signs, since the driver may not look at the navigation information while performing the secondary tasks. Furthermore, due to the headup displays, the driver will be able to view the road during navigation information gathering, to be able to react to unanticipated traffic events. The secondary tasks may also increase the driver's reaction time or require him/her to look at the information more than once to grasp the navigation information completely. Under the assumption of a uniform increase in response time for all three navigation information displays, we can make comparative statements. We can extend the conclusions that drivers' reaction time for maps is less than their reaction time for textual information. The reaction time for drivers with headup maps is less than their reaction time with absolute North direction-up maps.

6. Results and Impact

We have developed a system that can be used to study alternative methods of information presentation, including headup displays. We have designed iconic and alphanumeric-based HUD's for navigation and speed. The simulator is now being used for several experiments in the human factors laboratory.

References

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