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EFFECT OF IN-VEHICLE DRIVER INFORMATION SYSTEMS ON DRIVING PERFORMANCE: SIMULATION STUDIES

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ABSTRACT

Driving simulation studies have been conducted to evaluate driver distraction for a range of in-vehicle route guidance devices. While the initial simulations showed generally improved driving performance with virtually all electronic devices in comparison to a paper map, the second set of simulation studies elicited even more lucid findings. Voice guidance and a revised heads-up display (compared to the first experiment) yielded shortest reaction times, lowest subjective workload and strongest user preferences. The electronic map also performed well but a heads-down guidance screen, identical to the heads-up display, performed worse among electronic devices.

1. INTRODUCTION

In-vehicle route guidance systems have been proposed as an IVHS system that could improve travel times and speeds by influencing drivers to avoid congested areas. There is a concern that providing guidance information in the vehicle could result in distraction from the driving task [1,2,3]. To address this concern, two sets of operator-in-the-loop simulation experiments have been conducted jointly by the University of California, Davis and the Hughes Aircraft Corporation.

The experiments were conducted in a high fidelity fixed base automotive simulator that has been developed by the Hughes Aircraft Corporation. This simulator is equipped with three screens for a total field of view of 170 degrees. On these screens computer generated images, such as roadway segments, traffic control devices, pedestrians and roadway traffic, are projected. The movement of these objects is synchronized with the vehicle movement generated by the subject (the driver).

The experiments used a within subject experimental design to evaluate the distraction, workload and perceptions associated with paper maps, visual electronic devices and audio route-guidance devices. In both the experiments, the order of presentation of the route-guidance devices was counterbalanced to reduce order effects. The objectives of the experiments were to determine if:

1. the mode of presentation of guidance information affects driver's workload, scanning behavior and response to normal traffic events,
2. the location and format of an in-vehicle visual display affects driver's workload, scanning behavior and response to normal traffic events.

This paper provides a description of the experimental design, driving environment, route guidance devices and the results obtained from each of the experiments. The paper concludes with a brief summary of on-going research including a set of rapid prototyping studies of guidance devices using table-top simulation.

2. EXPERIMENT 1

2.1. Subjects

The experiment was conducted with 9 males and 9 females between the age of 30 and 40, who were recruited by a market research firm from the Los Angeles area. The sample also had an equal number of subjects with low driving experience (defined as drivers who drove less than 12000 miles a year) and high driving experience (defined as drivers who drove more than 15000 miles a year) [4,5,6].

2.2. Driving Environment and Scenarios

Each of 8 driving scenarios, developed from a 2 mile by 2 mile section of central Los Angeles, represented an origin and a destination connected by a predetermined route. Subjects were asked to: drive safely, obey speed limits and respond to all traffic control devices, cars and pedestrians. Their secondary task was to monitor the route guidance display, navigating to the destination. The roadway network consisted of three road types: a four-lane divided Parkway with 12 foot lanes, shoulders and a 55 mph speed limit; urban four-lane undivided arterials with 12 foot lanes and a 40 mph speed limit; urban two-lane undivided arterials with 10 foot lanes and a 30 mph speed limit.

While the network was fixed, street names were changed between scenarios to reduce driver familiarity with the network. The traffic environment consisted of three types of vehicles: (a) vehicles from a side street that would intrude into the path of the test vehicle, (b) vehicles that traveled opposing lanes, some of which turned left in front of the subject, and (c) lead vehicles, speed of which varied from as low as 5 mph up to the speed limit. The average speed of the other vehicles in the driving scene were close to the speed limit of the particular section.

2.3. Route Guidance Devices

2.3.1. Heads-down-electronic route map

The electronic map was a six inch liquid-crystal display located in the instrument panel to the right of the driver. The map showed the network in green with the intended route highlighted in red. The thickness of the lines in the map was used to represent the 3 types of roadway segments. Before the subject started driving, the complete route network was shown (full scale). Once, the subject started driving, the display changed to a half-mile scale (Figure 1). The position of the driver's vehicle was shown by an icon (arrow) in the center of the map. The location of the destination was shown by a 'star'. The top left of the map showed the distance to the turn and the distance to the destination. The orientation of the map was always 'heading up' (i.e. the map rotated in such a way that the driver was always heading up the display).

2.3.2. Paper map

The basic design of the paper map was similar to the full scale electronic map, with the obvious difference being that the position of the driver was not tracked. The size of the map was 11" X 17". Each driver used the map in a way that was most convenient to them.

2.3.3. Heads-up-guidance display (HUD) with heads-down-electronic map

The HUD (Figure 2) was projected directly in front of the driver just above the hood of the car. It consisted of a vertical line which indicated the street on which the driver was traveling, and a horizontal line which indicated the street onto which the driver has to make a turn and the direction of turn. The distance to the decision point (shown in tenths of a mile till the driver is 500 feet from the intersection after which it is shown in feet) and the distance to the destination were also shown. The left side of the HUD showed the speed of the vehicle.

The horizontal bars on the vertical line indicated the distance to the decision point. The distance between two consecutive bars represented 25 percent of the distance between the decision point and the previous turn. Each of these bars disappeared after the driver crossed that particular point on the roadway. The vertical line thus represented a variable distance to the next distance point, the value of which was displayed numerically.

2.3.4. Voice guidance with heads-down-electronic map.

A pre-recorded female voice was used for providing guidance information. Two messages were given for each turn. The distance (from the next turn) at which the first message was given, depended on the type of road: 1200 feet for parkways, 700 feet for 4 lane undivided roads, and 400 feet for 2 lane roads. The second message (in all the three types of roads) was given 200 feet before the turn. An example of the content of the first message was:

"In 400 feet, turn right onto Zuma,"

An example of the content of the second message was:

"Turn right onto Zuma."

2.4. Dependent Variables

The dependent variables included: number of navigation errors, subjective workload, perception ratings, eye fixation data and reaction times to external events. Perception ratings were obtained on a scale of 1 to 5 for five system attributes: ease of use, clarity of information, quantity of information, preparation for turns and distraction from the driving task. Subjective workload was obtained using the NASA TLX method [7]. The workload and perception ratings were obtained after the subjects drove two scenarios in each of the four route-guidance systems [4,5,6].

Eye fixation data (obtained from an unobtrusive eye tracker) were used to obtain the percentage of time that the driver was looking at the road as opposed to the route-guidance system. Brake reaction times were recorded for each type of external event [4,5].

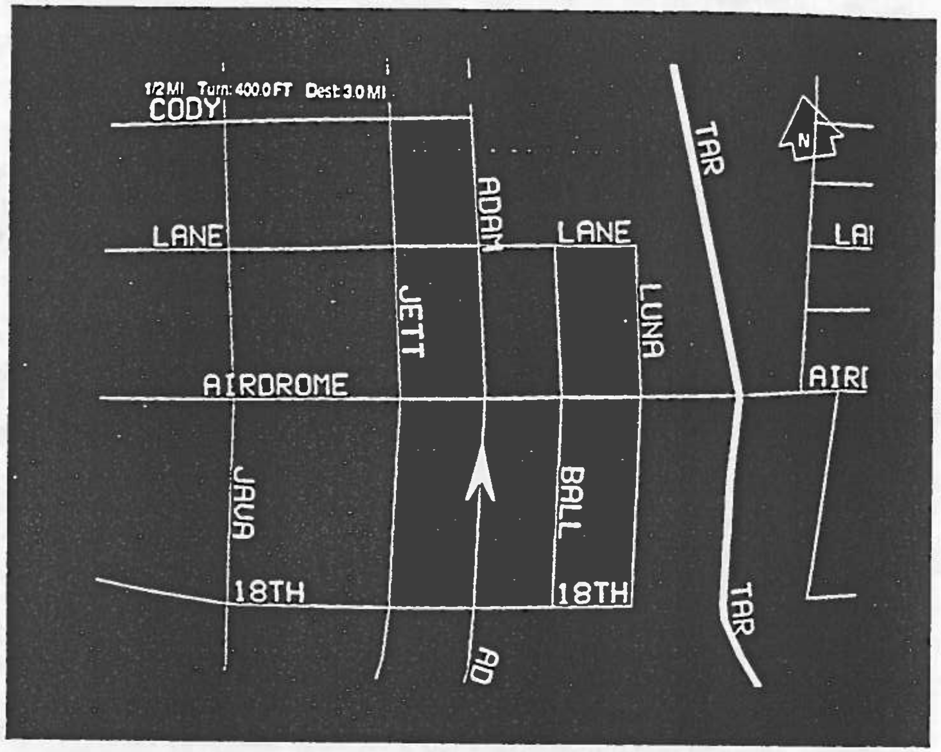

Figure 1 Electronic map (half-mile scale)

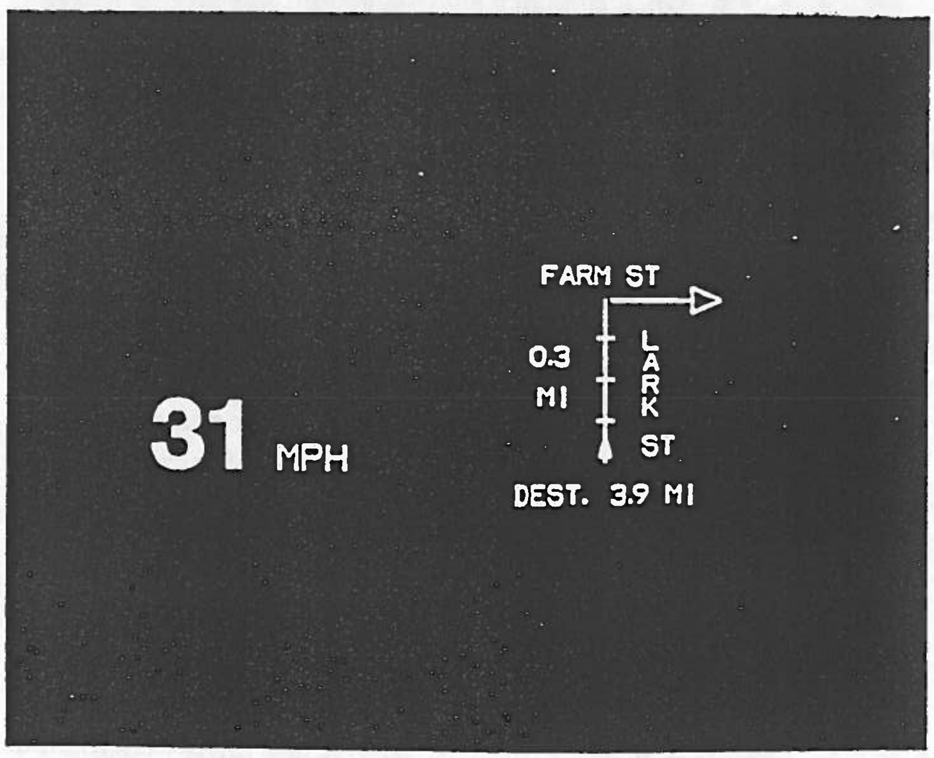

Figure 2 Heads up guidance display (experiment 1)

2.5. Results

A variety of statistical analyses were conducted using the data from the simulator and from the workload and perception ratings [4,5,6]. ANOVA models were developed for brake reaction time to external events. Linear regression models were developed for workload ratings and for the percentage of dwelling time on the road. Logit models were developed for the number of navigation errors. The models used route guidance type, subject category (based on gender and driving experience) and order effects as independent variables.

Subjective workload, user perceptions and navigation errors indicated the voice guidance/electronic map combination to be the best, and the paper map to be the worst. The electronic map was second best. Subjects performed worse in the HUD/electronic map combination than the electronic map. Based on the comments given by the subjects, there were two design issues which could have contributed to the relatively poor performance of the subjects with the HUD:

1. the variable distance displayed along the vertical line meant that the vehicle icon location and count down bars changed at a variable rate (more quickly on short segments, less quickly on longer ones),
2. when the driver reached the decision point (intersection stop line) the top of the cursor in the heads up display, was a fraction of an inch below the actual location of the intersection in the HUD.

Results from the reaction time models were less consistent. The best electronic device varied depending on the type of external event. For example, in the case of crossing vehicles, the electronic map came was the best (with the shortest reaction time). In the case of left turning vehicles, the HUD/electronic map combination was the best. In the case of traffic signal events, the HUD/electronic map combination and the voice guidance/electronic map combination were the best. The paper map was the worst (with longest reaction time).

3. EXPERIMENT 2

Experiment 2 was conducted to address additional issues regarding the design of route-guidance systems that arose as a result of findings from experiment 1. The questions to be addressed included:

1. will audio-guidance alone perform as well and be perceived as favorably as the audio-guidance in combination with electronic map,
2. is a heads-up-guidance display superior to a heads-down-guidance display, given the same display format,
3. will a modified guidance display (compared to the one used in experiment 1) perform better and be perceived more favorably,

To address these issues, five route guidance systems were tested: (i) paper map; (ii) heads-down-electronic map; (iii) heads-up-guidance display alone (iv) heads-down-guidance display alone; and (v) voice guidance alone. The paper map, the heads-down-electronic map and the voice guidance messages were identical to those that were used in experiment 1. The guidance display retained the vehicle speed indication but used a different display compared to the first experiment (see figure 3) [8].

The display showed speed in miles per hour, the name of the street on which the vehicle was currently traveling, the name of the next decision street and the distance in tenths of miles or feet to the decision point. There were several cues to indicate closure distance to the decision point. A vehicle icon (amber in color) moved up the currently traveled street (a vertical green line with an arrow at the top). As the vehicle approached the decision point, the distance to this maneuver changed to indicate closing distance. When the driver was more than 400 feet from the turn, an amber triangle indicated whether the driver should turn right or left at the next decision point. The units of this distance value changed from tenths of miles to feet within 400 feet of the decision point. When this change occurred, a large green arrow with an elongated tail replaced the small amber triangle previously displayed. The geometry of the decision intersection was maintained in that both variations of 'T' and fully crossed intersections were indicated. When the vehicle icon reached the intersection point and the vehicle made a turn, a new display was presented [8].

3.1 Subjects

Seventeen male subjects between the age of 19 and 35 participated in the experiment. Three of the subjects were college students and the remainder were volunteers from Hughes Aircraft Company.

3.2 Driving Environment and Tasks

The same simulated roadway network used in the first experiment was employed in the second experiment. However, changes to the driving scenarios included removal of the lead vehicle and the addition of two tasks.

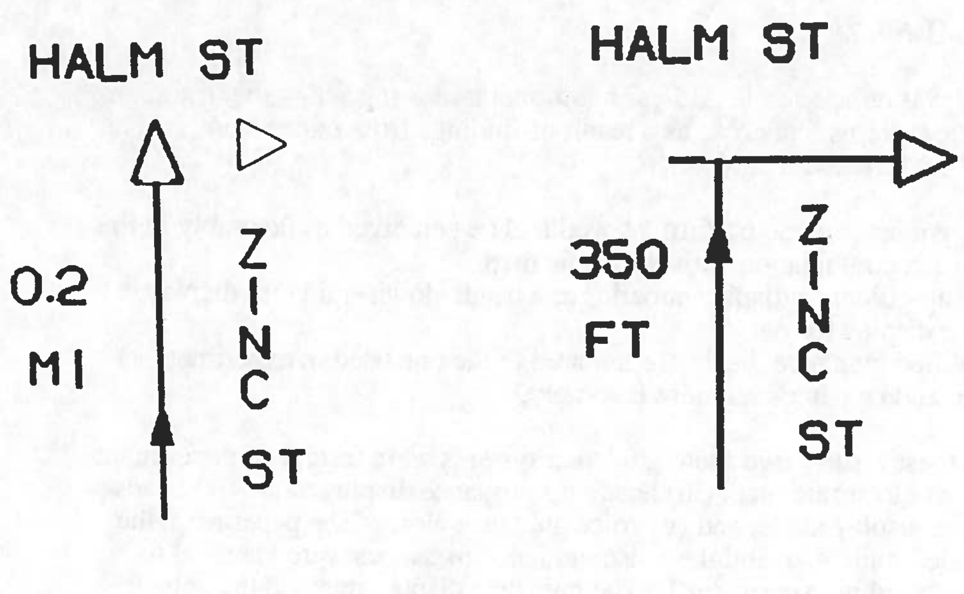

Figure 3 Guidance display (experiment 2)

The first additional task was a scanning task of the external visual scene. Coral colored squares of an outline form were presented on the left and right edges of the roadway. Subjects were asked to monitor these squares for a change in shape - the squares rotated 45 degrees - to become diamonds. As soon as drivers detected the change, they were asked to push a button on the left or right of the steering wheel hub depending on whether the diamond appeared on the left or right side of the roadway. The occurrence of this rotation was random for both squares within an interval of five to 20 seconds, and this rotation never happened when drivers were turning corners. Diamonds remained on the screen for a duration of five seconds, or shorter if the subjects responded more quickly by the pushing the appropriate button [8].

The second additional task was monitoring vehicles that started to move into intersections (crossing vehicles). The subjects were instructed to push the appropriate steering wheel button if they detected this motion. Vehicles started to move at a headway of six seconds from the driver's vehicle. Intersections were populated with both stationary and moving vehicles on the side streets [8].

It was hypothesized that drivers' performance in these additional tasks would be a good measure of the attentional demand associated with the different route-guidance devices.

3.3 Dependent Variables

As in experiment 1, workload and perception ratings were collected after the subjects completed trials in each route-guidance system. Response time data were also recorded for the scanning and vehicle crossing tasks.

3.4 Results

A variety of statistical analyses were conducted with the data obtained from the experiments [8]. A within subject Multivariate Analysis of Variance (MANOVA) was performed on the response time data with navigation type as an independent variable. Nonparametric Kruskal-Wallis tests were used to analyze workload and perception data.

Voice guidance was associated with the shortest response times, followed closely by the heads-up-guidance display and the heads-down-electronic map. The paper map was associated with the longest response times. Response times while using the voice-guidance system, the heads-up-guidance display and the heads-down-electronic map were significantly shorter than when using the paper map and the heads down guidance display ($p < 0.01$). The data from workload and perception ratings showed similar results. The voice-guidance system, the heads-up-guidance display and heads-down-electronic map were associated with lower workload and were more preferred in comparison to paper map and heads down guidance display.

The results indicate that there is no optimal navigation device. Display location seems to be an important factor, however, it interacts with display format: subjects performed significantly worse with the heads-down-guidance display in comparison to heads-up-guidance display, although they performed quite well with the heads-down-electronic map. Despite its complexity, some subjects expressed preferences for the map because it indicated the number of blocks to the decision point unlike the guidance display and the voice-guidance system.

4. DISCUSSION AND CONCLUSIONS

The results from the two simulation experiments can be summarized as follows:

1. There is no optimal navigation device. Although it is obvious that the voice guidance system competes the least with the busy visual system, some subjects found it annoying and wanted to have the option of shutting it off [4,5,6,8]. Another difficulty with audio systems is that the information provided is 'discrete' (i.e. it is provided only at specific points in time unlike visual systems which update information continuously). Provision of some sort of a 'repeat button' could mitigate this problem somewhat.

2. It seems clear that reasonably well designed electronic systems, outperform the paper map.

3. The format of a guidance display plays an important role in the acceptability of a device: the modified heads-up-guidance display (used in experiment 2) performed better and was preferred over the format used in experiment 1 (which contained the variable distance problem).

4. The location of a visual display can have a significant effect on driving performance. Heads-up displays seem to perform better than heads-down displays.

5. In spite of their complexity, electronic maps were received quite favorably and performed consistently well. The subjects liked knowing the number of blocks to a decision point. It is important to note that the scale and direction (heading up) of the map were fixed so subjects did not have to contend with the additional distraction of changing map scale while in motion.

Further research is being conducted in a table top simulator at the University of California, Davis. A Silicon Graphics Indigo-Extreme computer system is used in conjunction with Designer's Workbench software from Corypheaus, Inc. to provide real-time simulation with device rapid prototyping. Subjects undertake a tracking task using a mouse, and also display their decision to turn left, turn right or go straight through an intersection by pressing different mouse buttons. The experiments are intended to study mode of voice generation (synthesized voice in comparison to female / male digitized voice), format of visual displays (4 different formats of turn by turn guidance displays and 2 different formats of electronic maps) and user generated designs through rapid prototyping.

Further research needs to be conducted using older subject populations. Both experiments 1 and 2 used relatively young subjects (between 30 and 40 years old in experiment 1 and between 19 and 35 in experiment 2). Research is also needed to study the safety and usability aspects of electronic maps that could be displayed heads up. Comparisons with findings from field operational tests (e.g. Pathfinder, TravTek) will also be important.

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