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Development and Testing of Driver Interfaces for Navigation Displays

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16. Abstract
Several design reviews and two formal experiments examined driver responses to route guidance displays. In the design reviews, single and small groups of drivers were shown displays and asked to explain them. This resulted in interface revisions and design guidelines.

In a subsequent experiment, 60 drivers at a licensing office were shown plan, aerial, and perspective views of displays for 9 situations (T-turn left, etc.) and were asked to explain what they meant. There were few errors. Driver preferences were plan, aerial, and perspective view, in that order.

In a laboratory experiment, 12 additional drivers (6 age 30 or younger, 6 age 65 or older) in a vehicle mockup were simultaneously shown slides of intersections (photographed from the driver's viewpoint) and slides of a navigation display. Drivers indicated whether the two images were for the same or different type of intersection (cross, Y, T, etc.).

The response time data indicated head-up displays were better than console-mounted displays (1524 versus 1630 ms), and that aerial views were slightly but not significantly better than plan views (1501 versus 1523 ms), but significantly better than perspective views (1706 ms). Responses to intersections shown as solid objects were more rapid than to those shown as outlines (1557 versus 1597 ms). Error, eye-fixation, and preference data supported these results.

17. Key Words
IVHS, human factors engineering, ergonomics, navigation, driver information system, test methods

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PREFACE

The United States Department of Transportation (DOT), through its Intelligent Vehicle-Highway Systems (IVHS) program, is aiming to develop solutions to the most pressing problems of highway travel. The goal is to reduce congestion and improve traffic operations, reduce accidents, and reduce air pollution from vehicles by applying computer and communications technology to highway transportation. If these systems are to succeed in solving the nation's transportation problems, they must be safe and easy to use, with features that enhance the experience of driving. The University of Michigan Transportation Research Institute (UMTRI), under contract to DOT, has undertaken a project to help develop driver information systems for cars of the future, one aspect of IVHS. This project concerns the driver interface — the controls and displays that the driver interacts with, as well as their presentation logic and sequencing. This is 1 of 16 reports that documents that work.

The project had three objectives:

- Provide human factors guidelines for the design of in-vehicle information systems.
- Provide methods for testing the safety and ease of use of those systems.
- Develop a model that predicts driver performance in using those systems.

Although only passenger cars were considered in the study, the results apply to light trucks, minivans, and vans as well because the driver population and likely use are similar. Another constraint was that only able-bodied drivers were considered. Disabled drivers are likely to be the focus of future DOT research.

A complete list of the project reports and other publications is included in the final overview report.[1] To put this report in context, the project began with a literature review and focus groups examining driver reactions to advanced instrumentation.[2,3,4] Subsequently, the extent to which various driver information systems might reduce accidents, improve traffic operations, and satisfy driver needs and wants, was analyzed.[5,6,7] That analysis led to the selection of two systems for detailed examination (traffic information and cellular phones) and contractual requirements stipulated three others (navigation, road hazard warning, vehicle monitoring).

Each system was examined separately in a sequence of experiments. In a typical sequence, patrons at a local driver licensing office were shown mockups of interfaces, and driver understanding of the interfaces and preferences for them was investigated. Interface alternatives were then compared in laboratory experiments involving response time, driving simulation, and other methods. The results for each system are described in a separate report. (See references 8, 9,10,11,12,13, and 14) To check the validity of those results, several on-road experiments were conducted in which performance and preference data for the various interface designs were obtained.[15,16]

In parallel with that work, UMTRI developed test methods and evaluation protocols, UMTRI and Bolt Beranek and Newman (BBN) developed design guidelines, and BBN worked on the development of the driver model.[17,18,19]

Many of the reports from this project were originally dated May, 1993, the initial end date of the project. However, the reports were drafted when the research was conducted, over two years earlier for the literature review and feature evaluation, and a year earlier for the laboratory research and methodological evaluations. While some effort was made to reflect knowledge gained as part of this project, the contract plan did not call for re-writing reports to reflect recent findings.

This report describes several experiments designed to develop reasonable driver interfaces for a navigation system and compare format alternatives. A summary of the last experiment appears in a proceedings paper.[8]

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	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	l
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
psi	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	ac
ha	hectares	2.47	acres	mi^2
km^2	square kilometers	0.386	square miles	
		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	megagrams	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	psi

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

(Revised August 1992)

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INTRODUCTION

It is likely that many cars of the future will be equipped with navigation systems. These systems will inform drivers of their current location and heading, provide turn-by-turn directions to their destinations, and possibly provide trip statistics. It is important for these systems to be safe and ease to use. They should not distract drivers from their primary task of driving. Furthermore, their operation should be easy to learn and understand.

There is a growing body of literature on driver responses to navigation systems. (See references 20, 21, 22, 23, 24, and 25.) Key background materials are contained in the literature reviews conducted as part of this project.[2, 17]

This report examines several alternatives for turn-by-turn (individual intersection) displays and results in several design guidelines. Potential interface alternatives include electronic maps, arrows that indicate turns, voice guidance with varying levels of detail ("Turn right," versus "In 3.5 miles, at the stop sign at Plymouth Road, turn right"), text, etc. While there is still debate regarding whether information should be presented visually, auditorily, or both, it is evident that complex map displays are inappropriate for guidance. To examine alternatives based on visual displays, several design reviews were conducted, followed by a survey at a driver licensing office, and a laboratory, response-time experiment.

In designing navigation displays, two general issues need to be addressed:

- What information should be shown?
- How much information can be presented on a display before it becomes too cluttered and requires too much time to obtain the desired information?

Priorities for information elements were identified in a previous report and were used to guide the design of the interface examined here.[7]

In addition, this research considered several questions concerning specific aspects of map-type displays. Some of these issues were examined in detail in this report, others were examined in a cursory manner, and some were identified as needing further examination.

Questions examined in this report include

1. What angle of elevation should be used for the perspective of the map display?
2. How should some of the graphic details be implemented (with regard to color, shading, etc.)?
3. How should the town or neighborhood name for the display be presented?
4. How should the driver's heading be shown?

5. How should the current location be indicated?
6. How should the destination be shown?
7. How should street names be linked with map graphics?

INITIAL ITERATIVE DESIGN REVIEWS

The initial design phase of the navigation display involved the drawing of potential graphic representations, followed by discussion among project team members and presentation to a few naive subjects for comment. The initial interface concept was a "plan" view of an intersection with the street names (all horizontal) written on the graphic. (See figure 1a.) One alternative that was used represented the intersection from an "aerial" view (figure 1b), which had some advantages with regard to street name placement. (An "aerial view is the viewpoint from a tall building or low flying airplane.) The heading was shown in the upper left corner. Below the graphic was "On:" with the current street and "Intersection: 0.x mile," with "x" representing the distance in tenths of a mile. In some of the alternatives, the words "On" and "Intersection" were not included. Below were three touchscreen buttons, "show landmarks," "previous streets," and "upcoming streets." The two street buttons would show six streets and their distances from the current vehicle location. The landmarks button would toggle the display of present landmarks (e.g., stop signs, gas stations, etc.).

The next iteration of designs included route guidance instructions, which were thought to be an essential element of the navigation system. At issue was whether countdown bars to the next intersection should be provided and where they should appear (on the intersection graphic, adjacent to it, or integrated into it), and where turn arrows should appear (on or next to the intersection graphic). Figure 1 (c-f) shows some of the options.

One weakness of the concepts described above was that they did not provide much orienting information, resulting in display designs similar to those shown in figure 2. In those designs, the placement and identification of upcoming streets varied. The possibility that the display might be too cluttered resulted in the display shown in figure 3. This was the first design tested.

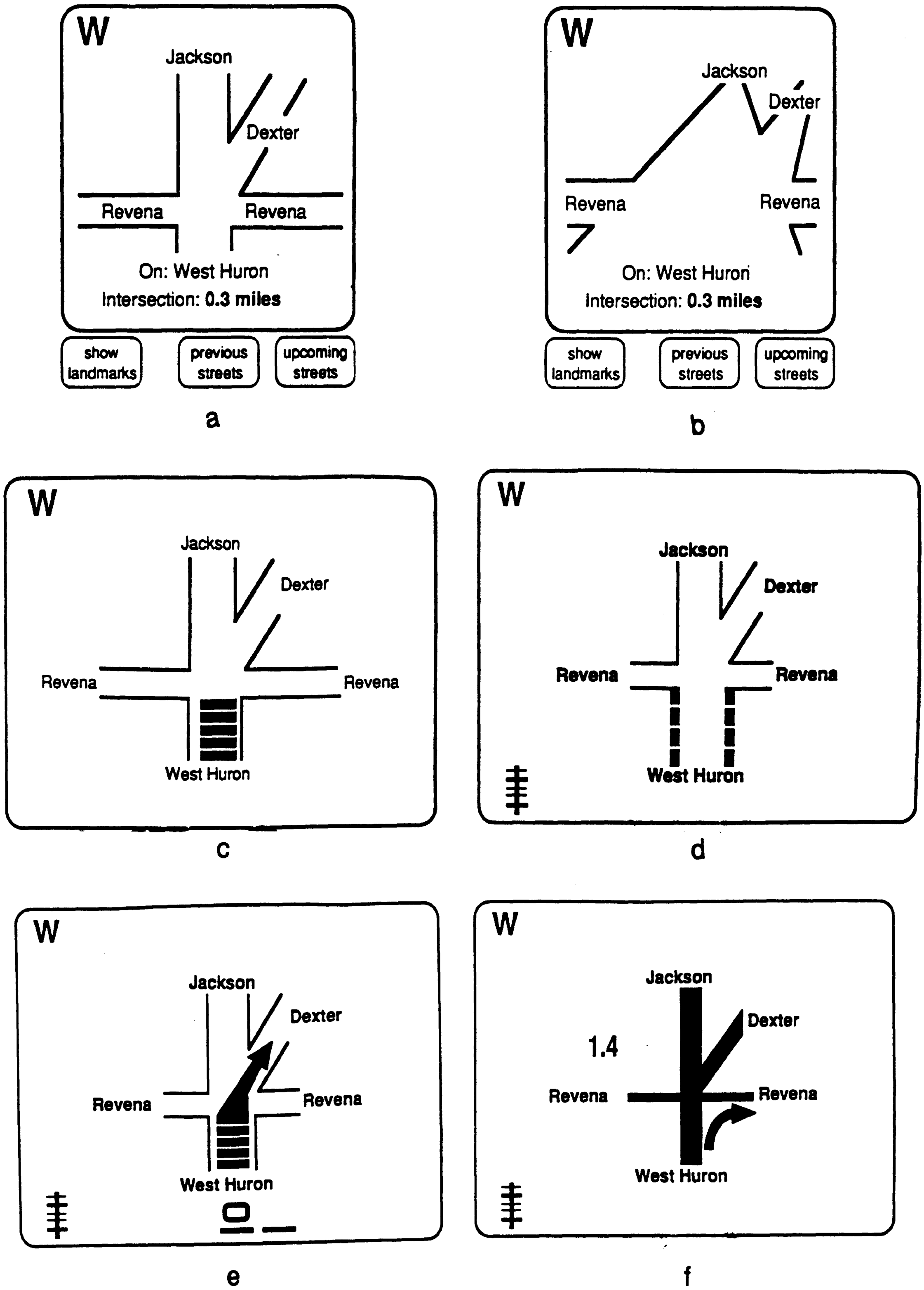


Figure 1. Initial ideas for navigation displays.

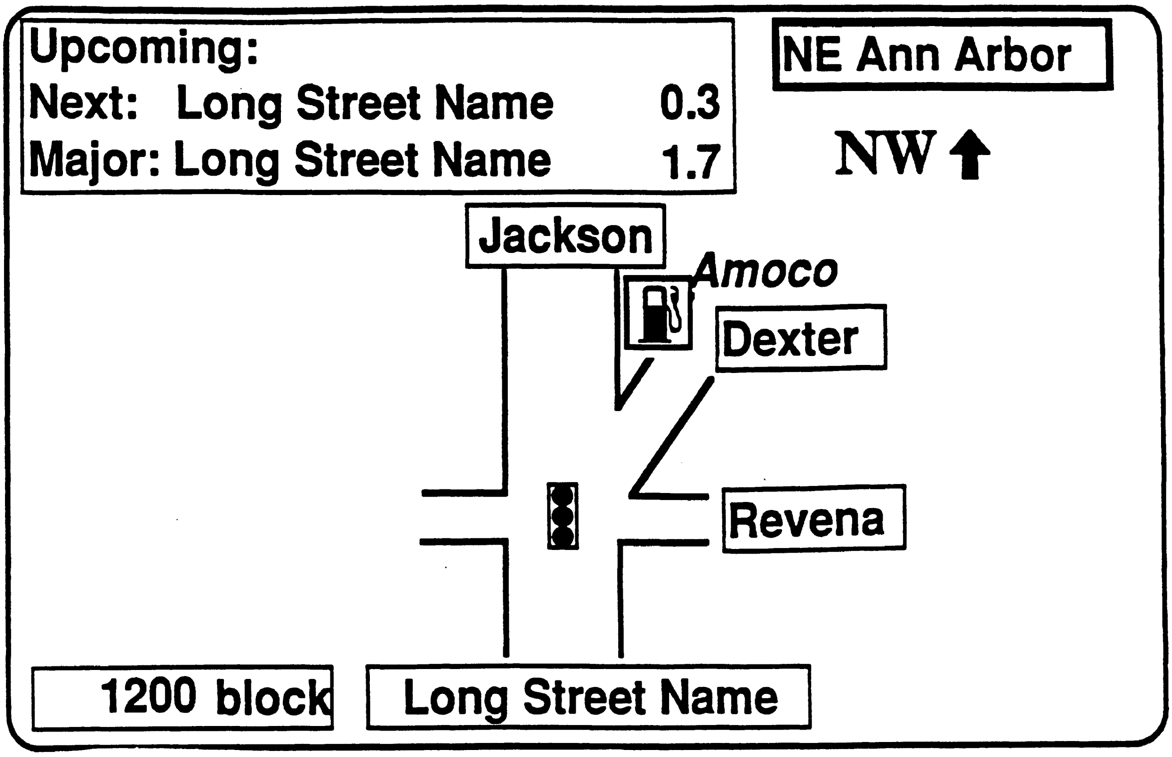


Figure 2. Intersection display with upcoming streets.

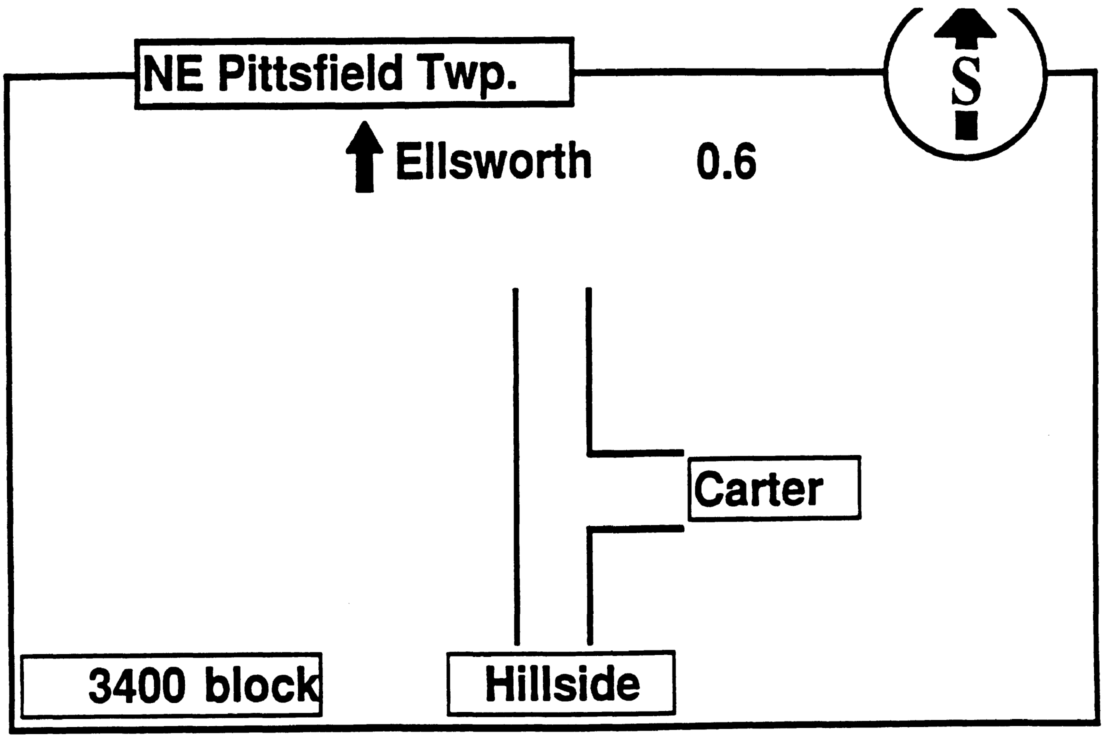


Figure 3. First design tested.

Informal evaluation then began. Displays were shown to nontechnical people (sometimes just one subject) at UMTRI who were not involved with the project. Each subject was never tested more than once. Subjects were told, "You are driving a car and you look at this display on the instrument panel. What is it telling you?" If a subject had difficulty understanding the interface, the misunderstanding seemed logical, and the misunderstanding could be eliminated by a simple change, the change was made before additional testing.

As an example of this process, in reacting to the first design (Figure 3), a participant initially thought she was driving on Ellsworth, heading to a destination 0.6 miles away. The subject said she was at Hillsdale and Carter, but did not understand what Ellsworth represented. A subsequent individual (seeing the same display with the arrow by Hillsdale removed) thought Hillsdale was her origin and did not know what "3400 block" meant.

In a re-design, the outline for the Ellsworth intersection (0.6 miles ahead) was shown as a dashed outline and an "X" was placed on the road next to 3400 Hillsdale (shown stacked and to the right of the X). The participant understood the X was for the current address but thought the street indicated by the dashed line was a rough road.

In another variation, the region name (NE Springfield) shown was placed at the top of the graphic in a box overlapping the graphic's border. For that design, one participant thought the region name was another street ahead.

These difficulties led to the following design guidelines:

1. To avoid confusion of region names and streets, give the state initials along with the place (NE Springfield, MI), and identify streets with abbreviations (St., Ave., etc.) This is particularly important for locations where there are similar names (e.g., in Atlanta, there is Peachtree Street, Peachtree Avenue, etc.).

2. When distances are presented, units (mi or km) will help to avoid misinterpretation.

3. To provide an indicator for upcoming towns or streets, use the word "ahead" with them.

Those guidelines resulted in the display shown in figure 4. Three drivers evaluated the display. All elements of the design were understood quickly, except for the "NE" as part of the Springfield location block. It was thought to represent compass headings, destination direction, or the part of Michigan in which the subject was located. "NE" was supposed to indicate that the map detail was for the northeast part of Springfield. Because of the resulting confusion, this information was deleted from future graphics.

In parallel, preferences for road detail were obtained from seven drivers. (See table 1.) Figure 5 shows the alternatives examined.

In later research it was noted that including lane markings in the display made the images of four-lane roads too complex, so lane markings were not included.

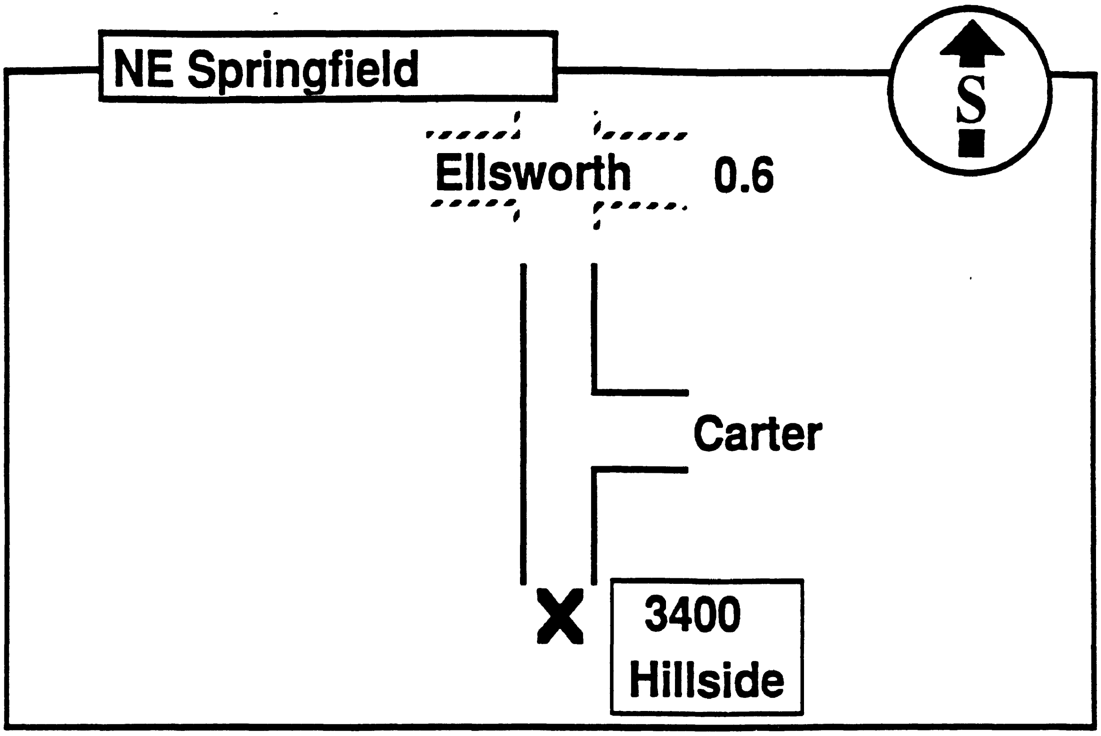


Figure 4. Interface used for examining area localizer.

Table 1. Driver preferences for road detail.

Road detail style	Number of subjects ranking as first choice	Typical subject comment
Outline without lane mark	1	"less cluttered"
Outline with lane mark	3	"markings could be useful"
Solid without lane mark	0	"does not look like a road"
Solid with lane mark	3	"looks like a real road and lane markings are easy to see"

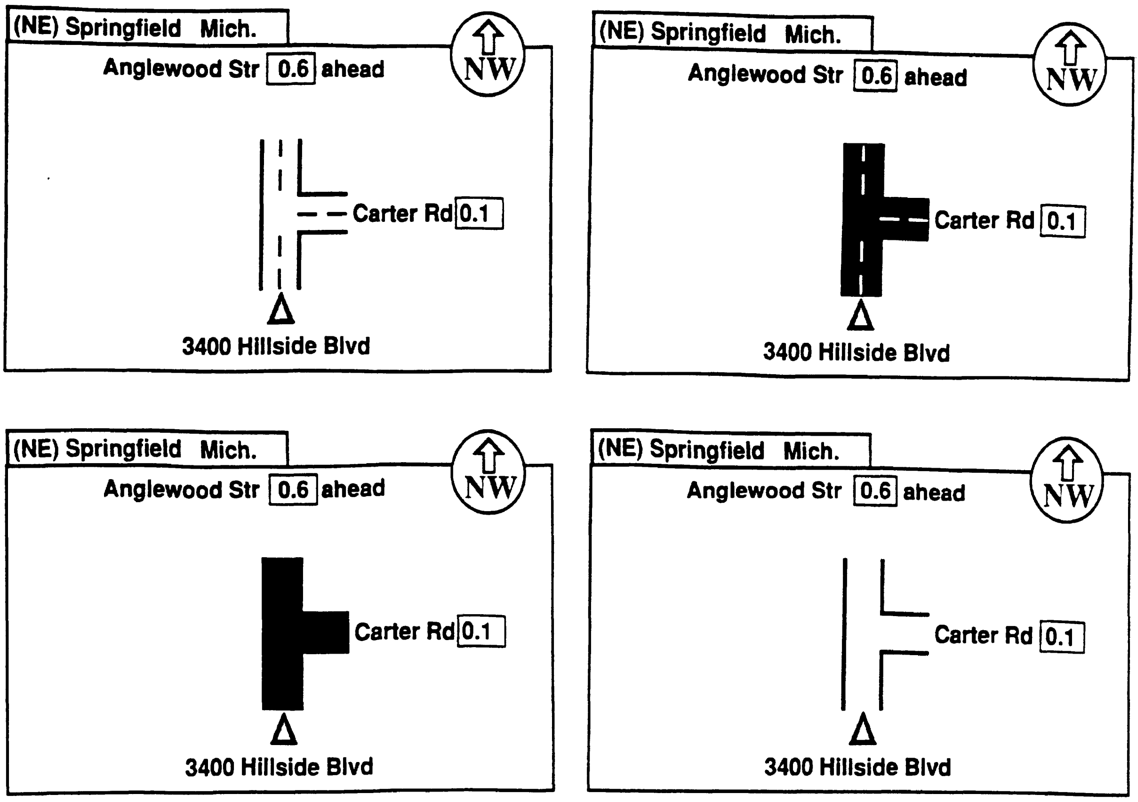


Figure 5. Lane marking test graphics.

These initial design studies were highly effective in eliciting drivers' ideas about the presentation of information elements on route guidance displays. Displays were laser-printed representations and often shown to single drivers typical of the user population. Misinterpretations by drivers that seemed logical to the design team were remedied wherever possible.

Admittedly, relying upon the feedback from a single driver can lead to selecting deficient design solutions. In real engineering projects, as was the case here, budgets and schedules do not permit an extensive review of each design nuance. In brief, no one can afford structured experiments with large numbers of subjects and statistical analysis to examine everything. This is particularly true during the early phases of design. Accordingly, the approach followed was to use feedback from a limited sample drivers to temper engineering judgment, eliminate weak ideas, and a later stages, to conduct well-controlled experiments to examine significant design and methodological issues.

DRIVER LICENSING OFFICE TESTS - MAP FORMAT

INTRODUCTION AND PURPOSE

In this experiment, the initial design of the driver interface for the navigation system was further refined. Given potential advantages of nonplan view displays for map label arrangement, the effect of observer viewpoint on comprehension of navigation displays was considered in detail. Most systems (e.g., TravTek) represented the world as a plan view--exactly what one would see on a map. This representation allowed the viewer to readily classify the geometry of the road network elements (cloverleafs, T-intersections, etc.).

A driver looking through a windshield sees a perspective view of the world, not a plan view. For orientation, drivers must match what they see on the navigation display with the outside scene. This suggests that the world should be represented in perspective on the navigation display since it is compatible with what drivers see. If plan and perspective views have advantages, then a compromise representation containing aspects of both (for example, the aerial view from a very low flying airplane) might be even better. Alternatively, an aerial display might be a poor choice, because it may contain the weaknesses of both plan and perspective displays.

Accordingly, this experiment examined the following questions:

- How well do drivers understand plan, aerial, and perspective displays?
- What are their preferences for the three formats?

METHOD

Test Participants

Three groups of 20 drivers (44 men and 16 women in total) waiting in line at a driver licensing office in Ann Arbor, Michigan participated. The drivers ranged in age from 16 to 77 years, with a mean age of 30. Participants drove from 1,700 to 40,000 miles per year with a mean of 17,100. None of the participants owned cars with a head -up display (HUD), but four had driven a car with a HUD. Four participants had a cellular phone in their vehicle and 29 participants had used one. All but seven participants had completed at least some college. (See table 2.) Most of the drivers were native English speakers, except for six people, each of whom spoke a different native language (Chinese, Arabic, Gujarati, Indonesian, Tagalog, and Persian).

Table 2. Highest education level of participants.

Level of Education	# of People
Some high school	2
Completed high school	7
Some college	24
College degree	11
Some graduate school	9
Graduate school degree	7

Test Materials and Equipment

There were 3 versions of the survey, each administered to a different group of 20 people. In each, drivers saw graphics depicting nine decision points with a guidance arrow. Those 9 consisted of 3 instances of a plan view display, 3 aerial, and 3 perspective. (See table 3.) The graphics (which filled a 6 cm by 6 cm area) were taped to index cards labeled on the back with a code. Roads were shown as black lines on a white background, while the guidance arrows were blue. Figure 6 shows graphics set 1. See the appendix for the complete graphics set.

Table 3. Guidance situations examined.

#	Guidance Situation	Instruction
1	T (end)	Turn left
2	Cross	Michigan left turn
3	Expressway ramp before underpass	Enter right
4	Expressway ramp after underpass	Enter left
5	Expressway ramp before overpass	Exit right
6	Expressway with parallel front road	Exit right
7	Traffic circle	Take third arm
8	Cross	Go straight
9	Five way intersection	Bear left

Participants were also shown a photograph of a person driving a car with a drawing of a generic example of a navigation display pasted to the center console. This helped participants visualize how the system would be implemented.

There was also a form for preference ranking of the three different views. There were two versions of each ranking form, with the order of the views switched to avoid location biases in ranking (e.g., ranking from left to right when participants were indifferent). See the appendix for a sample preference ranking form. Biographical information (participant age, education, type of car driven, experience with advanced displays, etc.) was also collected.

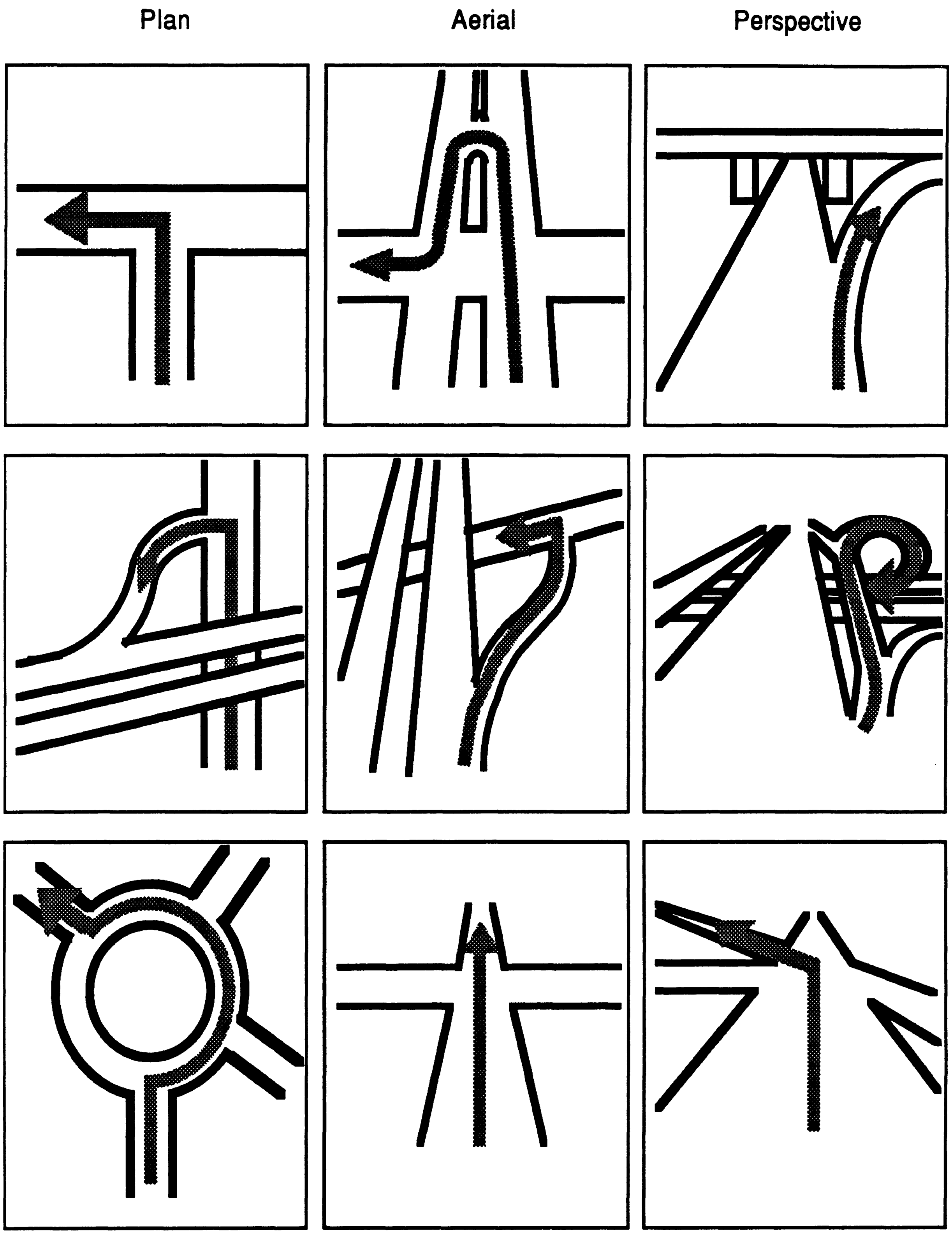


Figure 6. Navigation graphics set 1.
Note: The guidance arrow was blue when tested, not gray as shown here.

Test Activities and Their Sequence

Upon arriving at the driver licensing office, the experimenter determined whether the wait time appeared to be at least 10 to 15 minutes, which was necessary if the subject was to complete the experiment. Visits to the office were planned around peak service times of 12:00 noon and from 3:00 p.m. to 5:00 p.m.

The experimenter sat next to the participant and provided details about the experiment and filled out the biographical form. The experimenter then showed the participant 1 of the 3 sets of cards, 1 at a time. The participant described what he or she thought the navigation system was telling him or her to do and what the intersection was like. After all nine intersections were shown, the participant ranked the different views for each intersection type (1 = best, 3 = worst). A copy of the instructions and interview text is included in the appendix. Participants were not compensated for their time.

RESULTS

For each choice point, the experimenter recorded whether the participant understood the navigation display guidance (and if not, what they thought it meant), and how the participant described the intersection.

Driver Understanding

Responses to the comprehension questions were scored by the experimenters. For example, for the Michigan left turn, correct responses included "like Briarwood" (a local mall with a nearby intersection of the same geometry), "u-turn then right," etc. Responses such as "no clue," and "I don't know" were scored as errors. Table 4 shows the number of errors in responding to each of the three interface formats. The number of errors was quite low. From best to worst, there were 2 errors for the aerial format; 5 for the plan view; and 7 for the perspective, out of 180 responses to each format. By chance, the number of errors for the three test groups differed slightly (9 for group 1, 4 for group 2, and 1 for group 3). As a reminder, each group saw one third of the possible intersection-perspective combinations, groupings which presumably should have been of equal difficulty. Of the errors, three involved misunderstanding of examples showing frontage roads and four involved traffic circles, all complex decision points. There was no pattern to the errors, and since there were so few of them, responses to the other questions (where is the turn, what is the intersection like) were unrevealing.

Table 4. Number of errors for each format.

#	Plan	Perspective	Aerial
1	0	0	0
2	1	1	1
3	0	1	0
4	1	1	0
5	0	0	0
6	0	3	0
7	3	1	0
8	0	0	0
9	0	0	1
Total	5	7	2

Preferences

Table 5 shows the preference data for all participants. Overall, differences between the three views were significant (KW(2) = 552, $p < 0.0001$). Similarly, there were significant differences due to the view for each situation-decision combination, except for combination three (ramp before underpass, enter right).

Table 5. Mean rankings by format for each situation, and decision.

#	Situation and Decision	Plan	Perspective	Aerial
1	T (end), turn left	1.45	2.58	1.97
2	Cross, Michigan left turn	1.38	2.75	1.88
3	X-way ramp before underpass, enter right	1.95	2.13	1.92
4	Expressway ramp after underpass, enter left	1.43	2.65	1.92
5	Expressway ramp before overpass, exit right	1.42	2.88	1.70
6	Expressway with parallel front road, exit right	1.63	2.75	1.62
7	Traffic circle, take third arm	1.17	2.82	2.02
8	Cross, go straight	1.35	2.77	1.88
9	Five way intersection, bear left	1.37	2.75	1.88
	Mean	1.46	2.68	1.65

Note: 1 = first choice, 2 = second choice, 3 = third choice.

CONCLUSIONS

These data suggest that the format of an intersection graphic will only have minimal effect on driver comprehension. However, drivers preferred plan over aerial views, and strongly preferred aerial over perspective views. These conclusions must be viewed with some caution, because drivers never actually made any turn decisions and there was no limit on how long they could look at the graphics (as there would be when driving). Accordingly, an experimental verification was required. It is described in the next section.

RESPONSE TIME EXPERIMENT - DISPLAY FORMAT

INTRODUCTION AND PURPOSE

The initial driver licensing office experiment indicated that drivers comprehended the different views of route guidance displays. It was not known if they could do so quickly, as they would while driving. Further, the advantage of one format over another may depend on the location of the navigation display relative to the road scene. If the visual angle between the two was small, as for a HUD, a template match should be easy, thus favoring a perspective view. When the viewing angle was large, there might be time to abstract the road geometry from the scene, favoring a plan view.

Since these issues have not been considered in the literature and could not be resolved by argument, an experiment was conducted. A summary of this research was published earlier as a conference proceedings paper.[8] This section describes the experiment in greater detail and reports additional findings.

Of specific interest were:

- How long does it take a driver to interpret the intersection geometry of an orientation display
  - for a HUD versus on the instrument panel (IP)?
  - as a function of the navigation display viewpoint (plan, perspective, aerial)?
  - as a function of the road graphic design (solid or outline)?

- Which displays do drivers prefer?

- Do the preference and performance data agree?

- What is the sequence of driver eye fixations in making such decisions?

- What are typical eye fixation times?

In addition to evaluating design alternatives, this experiment was intended to explore response time experiments as a method for evaluating alternative display formats. The road graphic design was believed to affect performance, though not by very much.[26] If the method was sensitive to design differences, then the results should show a small, but statistically significant, effect for this factor.

METHOD

Test Participants

Participants were 12 licensed drivers, 6 younger (18-30 years old) and 6 older (65 years or older). Within each age bracket, there were three men and three women. The mean age for younger subjects was 22 and for older subjects was 69. The subjects were recruited from lists of previous UMTRI participants. They were each paid $15 for their participation.

Corrected visual acuity for the young subjects ranged from 20/13 to 20/22. For the older subjects, acuity ranged from 20/18 to 20/100. Participants drove 2,000 to 25,000 miles per year with a mean of 9,900 miles. Only 1 person had ever driven a car with a HUD, 4 had drafting experience, 2 indicated they had artistic skills, and 10 stated they could touch-type. When asked to rank themselves on a 5-point scale for their comfort level in using maps (very comfortable to very uncomfortable), 8 stated they were very comfortable and 4 stated they were moderately comfortable.

Test Materials and Equipment

The slides of intersections shown in the test blocks were photographed from approximately the driver's eye position in a car. There were five types of intersections shown (cross, Y, T, T-right, and T-left), with three examples of each type. Most were of residential areas in or near Ann Arbor, Michigan, photographed in the fall during the daytime. For the sake of simplicity, expressway interchanges were not considered. The displays were highly legible, with the instrument panel navigation displays having character heights of approximately 0.64 cm (1/4 in) viewed at a distance of just over 76.2 cm (30 in). The visual angle of the HUD display was identical to the instrument panel display, though the viewing distance was greater. Figure 7 shows an example road scene. Examples of navigation display slides are shown in figures 8, 9, and 10. (The actual displays were in color.)

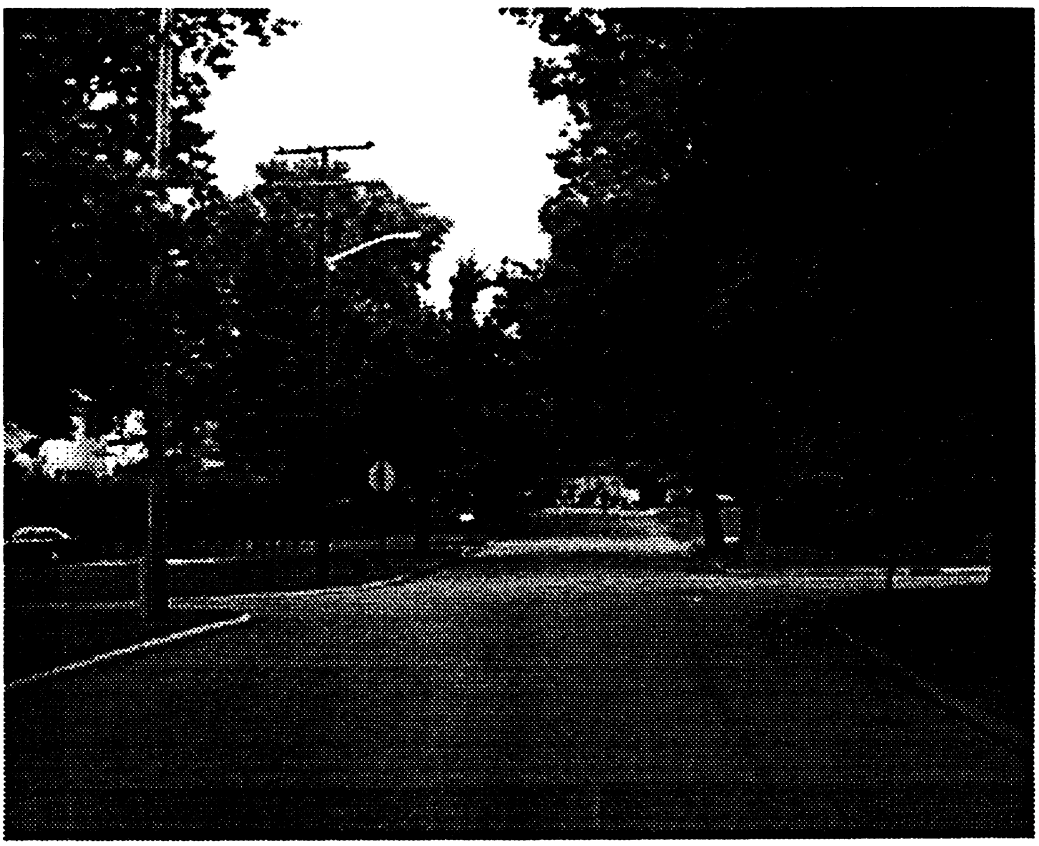


Figure 7. Example road scene.

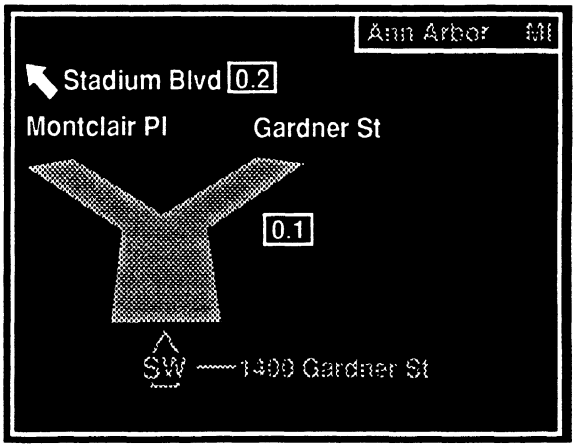


Figure 8. Aerial view of Y intersection.

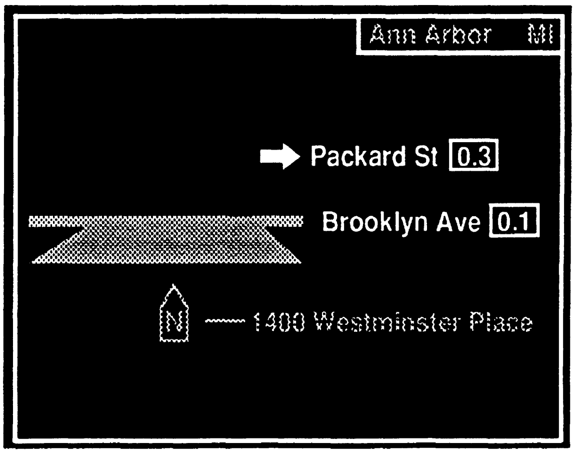


Figure 9. Perspective view of T-intersection.

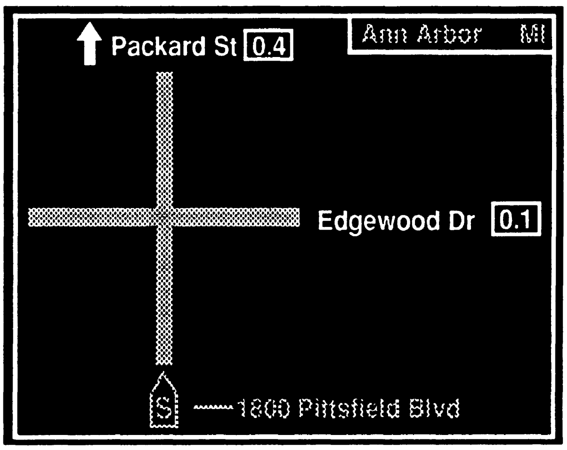


Figure 10. Plan view of cross intersection.

The overall arrangement of equipment is shown in figure 11. (Also see reference 27.) Three random-access slide projectors, fitted with Lafayette external shutters and custom controllers, presented the slides. An IBM XT computer fitted with a custom interface/timing board controlled the projectors. Input from participants was obtained from a custom keyboard with two piano-like keys mounted above microswitches. The keyboard was within easy reach on the center console.

All sessions were videotaped. A low-light-level video camera aimed at the participant's face recorded eye motions. A color camera, along with a time/date generator, special effects generator, and a VCR time-stamped, mixed, and recorded the road and navigation displays used for each trial.

Other miscellaneous equipment used included a Titmus Vision Tester. A Photo Research Spectra Pritchard digital spot photometer was used to set display lighting levels.

Forms (in the appendix) included a consent form, a biographical form, and a tabular form for recording drivers' display preferences.

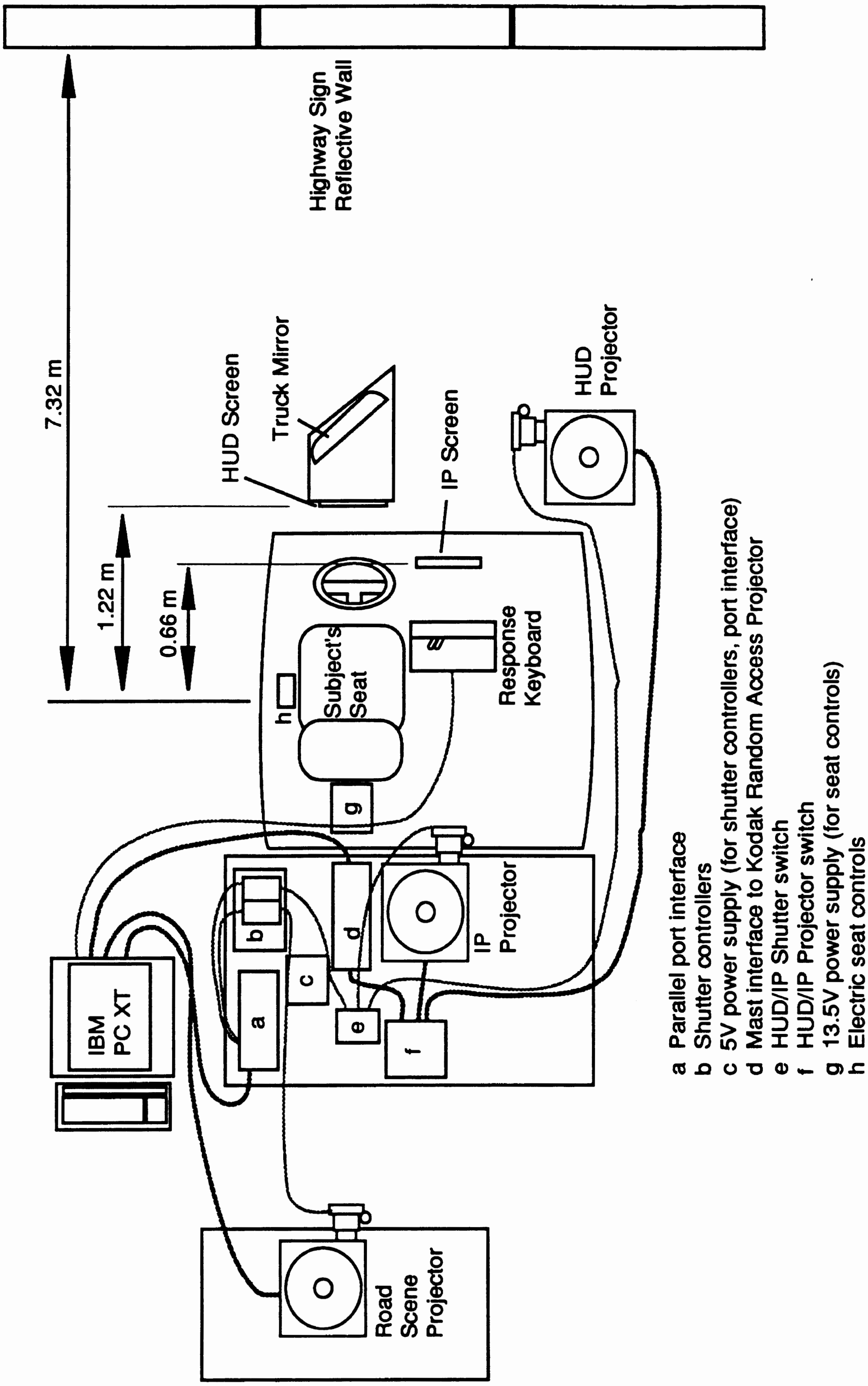


Figure 11. Laboratory equipment arrangement.

Equipment model numbers

- Random access slide projectors (3 total)
  - 1 Mast System 2
  - 2 Kodak Ektagraphic RA-960s
- Video camera — low-light level, RCA model TC1030/H10
- Color camera — JVC S100U
- Time/date generator — Thalner TD426P
- Special effects generator — JVC KM-1200
- VCR — time-stamped, Panasonic AG-6200
- Vision Tester — Titmus model OV-7M.
- Digital spot photometer — Photo Research Spectra Pritchard model PR-1980A CD

Test Activities and Their Sequence

After completing a biographical form, answering questions about their use of maps, and having their vision tested, participants were seated in an A-to-B pillar mock-up of a 1985 Chrysler Laser. The test protocol was then explained. (See the appendix for the complete listing of the procedure.) On each trial a slide of a road scene was shown on a retroreflective wall approximately 7.3 m in front of the driver. At the same time, a slide of a navigation system display (or a geometric shape in practice trials) was shown either on the center console of the instrument panel (IP) or where a HUD would be located. The navigation display location was fixed for each block. Drivers compared the two images (road scene and navigation display) and pressed either a "same" or "different" key on the center console. Response times (to the nearest millisecond) and errors were recorded. After a delay of three seconds, the projector displayed the next randomly-ordered slide. See the appendix for a listing of the slides in all carousels.

Each participant responded to 15 trial blocks. The first 2 blocks of 56 trials each were for practice to avoid confounding of learning the button-pressing task with learning to use the navigation display. Participants were shown slides of 7 geometric shapes (squares, circles, etc.) on the wall and at 1 of the 2 test locations (HUD or IP). The probability of "same" and "different" responses was equal. This task helped participants learn the same-different response-time task without specific practice with the stimuli of interest.

Subsequently, participants responded to six blocks of test trials. For those blocks, the location (HUD or IP) was fixed, though the location sequence was counterbalanced across subjects. Across blocks, the view (perspective, aerial, plan) and road format (solid, outline) were varied in a counterbalanced order. After a break, participants were given an additional practice block of 56 trials requiring responses to geometric shapes at the second location, followed by 6 blocks of test trials at that location (for a total of 12 test blocks per subject). The order of blocks for each subject appears in the appendix. Figure 12 shows the manner in which the test conditions were combined.

More specifically, in each test trial, participants were shown 1 of 15 randomly ordered, life-size images of intersections and, simultaneously, a slide of a navigation display. Within each test block, each slide appeared at least four times, twice as a "same" response and twice as "different." For the "different" trials, navigation displays were shown with road scenes with which confusion was likely (e.g., a T-left with a cross). Thus, the number of trials per block was at least 60 (4 by 15). All trials with exceptionally fast responses (under 300 ms) or slow responses (over 4 s) were automatically repeated at the end of each block. Response times under 300 ms were not physically possible given the test materials; hence, they represented guesses by subjects. Times in excess of 4 s represented breakdowns of the decision-making process. Error trials were also repeated. Consequently, each block contained an equal number of correct responses with reasonable response times.

After completing the response time portion of the experiment, participants rated the 12 designs from best to worst. Sessions averaged 1 hour and 45 minutes per person during which each participant typically responded to slightly less than 1,000 trials.

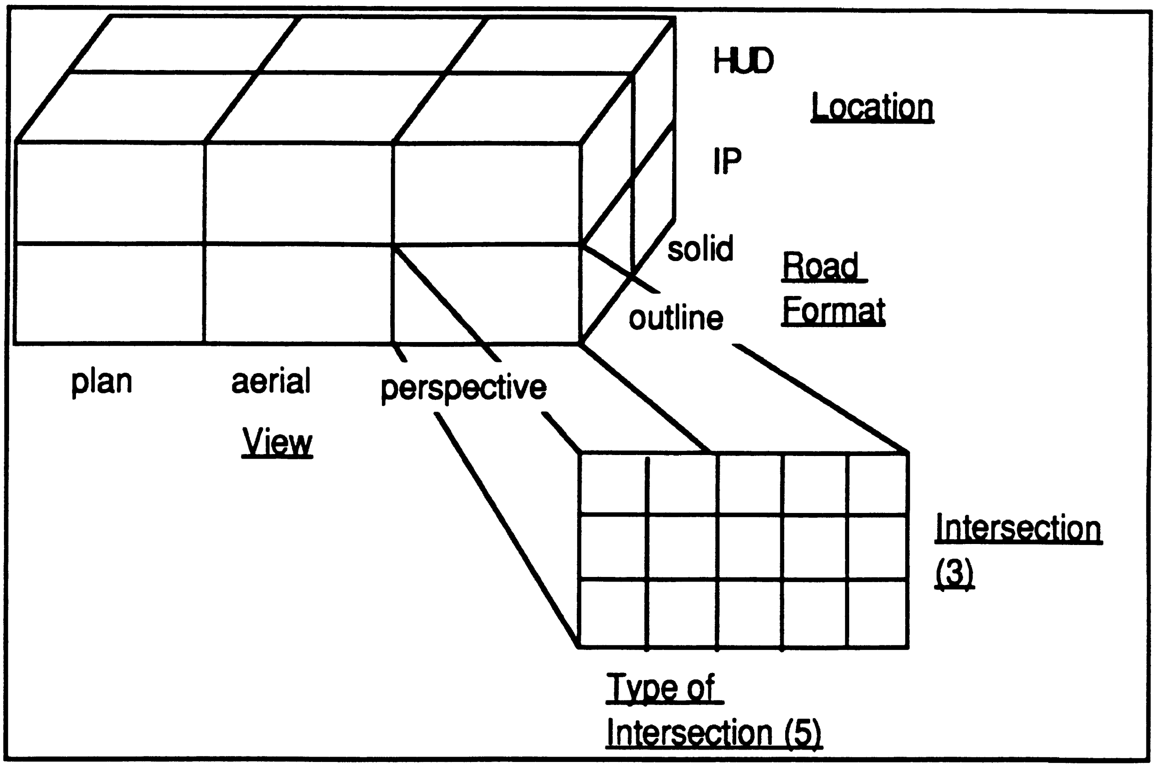


Figure 12. Design of the navigation experiment.

RESULTS

Errors

Some 11,848 key presses were recorded, of which 8,640 were correct responses to slides on test trials within the time deadlines. The remaining trials ("repeats") resulted from pressing the wrong key within the time deadlines, pressing either key under the minimum time, pressing either key after the maximum time, or not pressing any key.

Error rates were low, varying from 1.5 to 5.5 percent for younger drivers and 5.5 to 14.3 percent for older drivers. (See table 6.) For responses within the time limits, the error rates were 2.9 percent for younger drivers and 8.6 percent for older drivers. The older drivers had much more difficulty keeping their responses within the time limits; most key presses that exceeded the time limit were correct responses that occurred too late. (A maximum time of 5.5 s should be considered in future studies.) These errors occurred mostly during the first block of the actual system test, as older subjects needed more time to acquaint themselves with the protocol. Some of the older subjects, when the first screen appeared, sat and studied the display for a long time before responding. Subject 4 had a particularly difficult time responding quickly. Since all of these trials were repeated, the older subjects had more practice than younger subjects in responding to the system.

One older subject could not comprehend the perspective and aerial displays, and completed most of those blocks by rote. This subject required two sessions to complete all of the blocks. Two of the older subjects had difficulty understanding the geometry of several of the road scene slides. It was necessary for the experimenter to stand in front of the road scene screen and point out road features to these subjects. The most common problems occurred when participants thought they could see the "T" intersection continuing as if it were a cross, or seeing a driveway as the right or left leg of an intersection.

Table 6. Errors by subject, type, and age.

Age Group	Subj Num	Correct	Incorrect	Repeats: Short Cor	Repeats: Short Incorr	Repeats: Long Cor	Repeats: Long Incorr	Repeats: No Respns	% Repeated
young	1	720	21	---	---	---	---	2*	3.1
	3	720	10	---	---	---	1	---	1.5
	5	720	19	---	---	---	---	---	2.6
	7	720	12	---	---	---	---	---	1.6
	9	720	19	---	---	---	---	---	2.6
	11	720	40	---	---	1	---	---	5.4
Younger Total Repeat %:									2.8
older	2	720	97	---	2	20	2	---	14.4
	4	720	75	2	3	134	35	---	25.7
	6	720	50	2	2	10	1	---	8.3
	8	720	41	---	---	2	1	---	5.8
	10	720	103	---	---	1	---	---	12.6
	12	720	38	---	1	17	5	---	7.8
Older Total Repeat %:									12.4

Note: Cor = Correct , Incorr = Incorrect, Respns = Responses
* software error, RT system was set up to wait until a response was given

Table 7 shows the errors and repetition data by display location. For responses within the time deadlines, there were only eight more errors for the IP location. However, there was a large difference in percentage repeated because of the many correct IP responses that exceeded the time limit (156 versus 29).

Table 7. Errors by display location.

Location	Correct	Incorrect	Repeats: Short Cor	Repeats: Short Incorr	Repeats: Long Cor	Repeats: Long Incorr	Repeats: No Respns	% Repeated
IP	4320	267	3	5	156	37	---	9.8
HUD	4320	258	1	3	29	8	2	6.5

Note: Cor = Correct , Incorr = Incorrect, Respns = Responses

Table 8 shows the error and repetition data for the three view types. The aerial view generated the fewest errors. The plan view had slightly more, though it had fewer correct responses exceeding the maximum time. The perspective view had considerably more errors overall than the other designs.

Table 8. Errors by view type.

View	Correct	Incorrect	Repeats: Short Cor	Repeats: Short Incorr	Repeats: Long Cor	Repeats: Long Incorr	Repeats: No Respns	% Repeated
Aerial	2880	98	---	1	45	3	---	4.9
Plan	2880	141	---	4	24	6	2	5.8
Perspect	2880	286	4	3	116	36	---	13.4

Note: Cor = Correct , Incorr = Incorrect, Respns = Responses, perspect = Perspective

Table 9 shows the repetitions for each road format. The solid design, which was graphically simpler, had a significantly lower repeat rate than the outline, and had fewer errors.

Table 9. Errors by road format.

Road Format	Correct	Incorrect	Repeats: Short Cor	Repeats: Short Incorr	Repeats: Long Cor	Repeats: Long Incorr	Repeats: No Respns	% Repeated
Solid	4320	238	---	3	43	11	2	6.4
Outline	4320	287	4	5	142	34	---	9.8

Note: Cor = Correct , Incorr = Incorrect, Respns = Responses

Repetition and error data for the five different intersection types are given in table 10. Subjects, especially older ones, experienced significant difficulty with Y intersections.

Table 10. Errors by intersection type.

Intersection Type	Correct	Incorrect	Repeats: Short Cor	Repeats: Short Incorr	Repeats: Long Cor	Repeats: Long Incorr	Repeats: No Respns	% Repeated
T Left	1728	80	---	1	27	1	---	5.9
Cross	1728	87	1	1	32	3	2	6.8
T Right	1728	105	---	1	25	5	---	7.3
T	1728	134	1	2	28	7	---	9.1
Y	1728	119	2	3	73	29	---	11.6

Note: Cor = Correct , Incorr = Incorrect, Respns = Responses

Additional tables for combinations of view, road format, and location appear in the appendix.

Response Times

The practice condition presented no difficulties for any subjects. Only 2.9 percent of the trials were repeated. Most errors or times exceeding the maximum response time occurred within the first few trials.

Analysis of variance (ANOVA) was used to examine correct responses for the test data within the time deadlines. Histograms revealed that the distributions were log normal and there was little censuring of the responses due to the floor and ceiling constraints. For two of the older female participants, however, the response time ceiling could have been 500 ms or so longer. There were 11 factors considered in the ANOVA, compiled into 3 groups: participants, display factors, and test protocol. The three participant-related factors included sex, age (younger and older), and subjects nested within age and sex. The five display factors were location (IP or HUD), view (plan, aerial, or perspective), road format (solid, outline), type of intersection (cross, Y, T, T-left, T-right), and intersection shown (three examples of each type). The protocol factors included, the order in which conditions were presented (12 counterbalanced blocks), the response type (same or different), and the repetition of slides within blocks (2 levels). These data were analyzed using both MIDAS and BMDP8V.[28,29] P8V was used to compute a full factorial model of the data with all factors except for the blocks. MIDAS was used to check the Sums of Squares and examine block effects. The two computer programs gave values that agreed to five significant figures.

The full model yielded more than 500 terms, most of which were high-order interactions uninterpretable in a practical sense (e.g., the sex-by-age-by-location-by-type-by-repetition interaction). Accordingly, all interactions involving 3 or more factors that were thought to be unimportant or insignificant, were pooled. Furthermore, many of the Mean Squares were small and unlikely to be significant. It appeared that age, sex, and location were the likely sources of interaction.

Consequently, the resulting model included all main effects, most one-way interactions (except for those with blocks and subjects), and the one two-way display interaction of interest (location-by-view-by-road format). All other terms were combined to form a pooled error term for all F tests. While some of the interactions with test blocks could have been significant, they were deemed of secondary importance and therefore pooled. When not pooled, the Mean Squares for subject-by-location, subject-by-view, and subject-by-road format were sufficiently large to be significant. The complete ANOVA table is in the appendix.

Of the factors related to people (sex, age, and subjects nested with age and sex), all were highly significant ($p < 0.001$). Table 11 shows the mean response times. Differences due to age were very large (about 600 ms). Older drivers were 50 percent slower in responding. Differences due to sex were also large. Men were about 10 percent (186 ms) faster. The range of response times within age-sex categories was 200 to 300 ms; though it was 800 ms for the older women category. The interaction between age and sex was not significant.

All of the test protocol factors, blocks, keys (same/different), repetitions, were highly significant ($p < 0.001$). Figure 13 shows the improvement in performance as a function of practice (test block), emphasizing the need for control over block differences (achieved here by counterbalancing). The function is a smoothly decaying exponential until test block 9, with minor unexplained variability thereafter.

Table 11. Mean response times (ms) by participant.

		Sex		
		Men	Women	Mean
Age	Younger	1148 1398 875	1391 1322 1525	1276
	Mean	1140	1412	
	Older	1945 1758 1777	2408 1755 1618	1877
	Mean	1826	1927	
	Grand Mean	1483	1669	

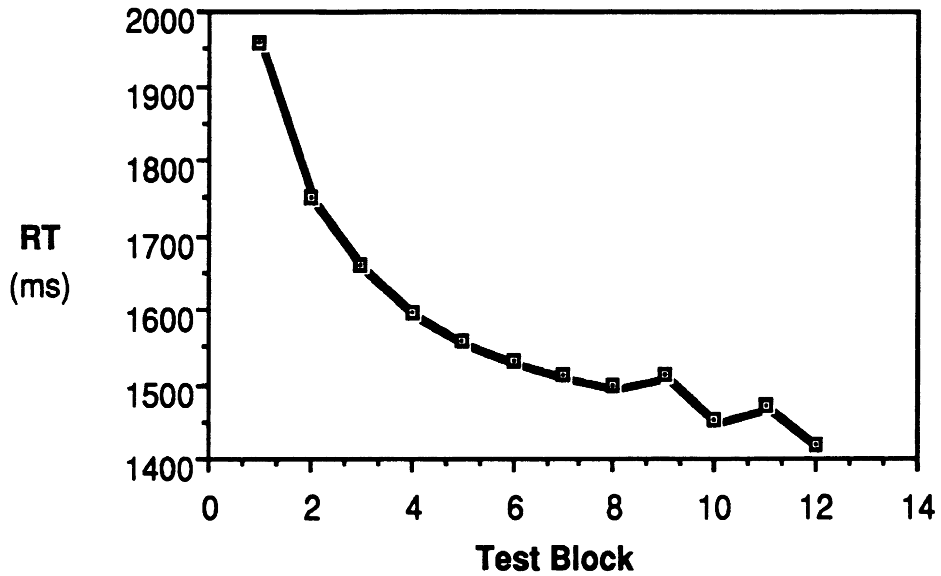


Figure 13. Response Time (RT) versus test block.

Response times to "sames" were faster than "differents" (1537 versus 1616 ms), as is typically the case. In a manner similar to Sternberg letter-matching tasks "same" responses involve a serial self-terminating search. The geometry observed is compared with a mental list of geometries until a match is encountered, which stops the comparison process. (Is it a "Y?" No, then go on. Is it a "T?" Yes, then stop.) "Different" responses are usually longer because they involve an exhaustive comparison of all options.

Just as performance improved across blocks, it also improved within blocks for the repetition of slides (1631 versus 1522 ms). Except for the first test block, drivers had seen each of the road scenes in a previous block. In each block, almost half of the trials were situations where the driver had viewed a particular scene with a particular display in a particular location, so large practice effects were expected. The navigation displays were quite different from anything test participants had seen before (outside of the laboratory).

With regard to displays, the effects of location and view were very highly significant ($p < 0.001$). The effect of road format was also significant, but at a lower level ($p < 0.05$). Response times to HUD displays were about 100 ms less than those on the IP (1524 versus 1630 ms). Response times to aerial views (1501 ms) were less (but not significantly) than those to plan views (1523 ms). Both were significantly less than those for perspective views (1706 ms). To date, all navigation systems based on map formats have used plan views. These data suggest there may be other equally good alternatives. While the perspective view is a direct analog of the scene, the authors believe drivers did not respond well to it because many of the key details (e.g., cross streets) are thinner lines and more difficult to see in perspective. The perspective format seemed to be more sensitive to minor perturbations in the actual view of the road, hence the difficulties with the perspective "Y"s.

Driver response times for navigation displays with roads shown as solid lines were lower than those in outline form (1557 versus 1597 ms). As noted in the introduction, road format was included to determine the sensitivity of the experimental protocol. Road format was hypothesized to have a small but significant effect on performance, which is what the experiment indicated. Table 12 shows the response times for all 12 combinations tested.

Table 12. Mean response times (ms).

System	Road Format	Location	RT
Aerial	Outline	HUD	1443
Plan	Solid	HUD	1447
Aerial	Solid	HUD	1459
Plan	Outline	HUD	1497
Plan	Solid	IP	1524
Aerial	Solid	IP	1547
Aerial	Outline	IP	1557
Plan	Outline	IP	1623
Perspective	Outline	HUD	1646
Perspective	Outline	HUD	1651
Perspective	Solid	IP	1714
Perspective	Outline	IP	1811

Of these display factors, only the interaction of location with road format approached significance ($p = 0.12$). The use of outline road images was relatively more detrimental on the IP (1595 versus 1664 ms) than on the HUD (1519 versus 1528 ms).

Also noted was a highly significant interaction between sex and location ($p < 0.001$) and a significant interaction between age and location ($p < 0.05$). Men did relatively better in using the head-up display (HUD = 1415 ms, IP = 1552 ms) than did women (HUD = 1632 ms, IP = 1707 ms). In terms of age, the HUD location was relatively more beneficial to older drivers (HUD = 1807 ms, IP = 1945 ms) than to younger drivers (HUD = 1240 ms, IP = 1312 ms).

As expected, there were highly significant differences between intersection types and intersections within type (both $p < 0.001$). Table 13 shows the mean times for the 15 intersections examined. The authors do not believe that a complete theory of how drivers view intersections can be developed from these data. For example, if the time required for a decision was proportional to the number of "arms" in the intersection, then response times for crosses should be longer than those for other intersection geometries (which involved fewer arms). Most likely these differences reflect unique properties of the particular intersections chosen. In photographing intersections, it was evident that Ys were difficult to discriminate from Ts, hence most of the Ys were photographed facing uphill, making those intersections relatively easier to discriminate. Other factors influencing response time were patches of black top that broke continuity, paved driveways that resembled streets, tree shadows, and cars stopped on cross streets. In spite of these intrusions, there were no interactions between display factors (location, view, road format), simplifying the analysis.

Table 13. Mean response times (ms) for each intersection.

Example	Cross	Y	T	T-Right	T-Left	
a	1714	1377	1503	1665	1469	
b	1581	1569	1594	1566	1694	
c	1604	1493	1494	1745	1582	Grand Mean
Mean	1633	1480	1530	1659	1582	1577

Subjective Rankings

At the end of the trials, the drivers were asked to rank the 12 design-location combinations from best to worst. The results are shown in table 14, and a graphic summary appears in figure 14. The differences in ranks were significant ($H(11) = 75.264$, $p < 0.001$) with the HUD location being preferred overwhelmingly over the IP location. The plan view was preferred over aerial in both locations, and plan view and aerial were preferred over perspective in either location. There was no significant difference between solid and outline formats for the road, except for perspective where solid ranked higher. The mean ranks were highly correlated with the mean response times ($r = 0.948$, $p < 0.001$).

Table 14. Design-location combination ranks (n=12).

	Best											Worst			
	1	2	3	4	5	6	7	8	9	10	11	12	Mean Rank	Mean RT (ms)	Total Number of errors
1	4	1	3	1	1	1	0	0	0	0	1	0	3.42	1447	39
2	1	6	1	0	1	2	0	0	1	0	0	0	3.50	1497	36
3	2	0	5	0	1	2	1	0	1	0	0	0	4.17	1459	43
4	3	1	0	3	2	0	1	2	0	0	0	0	4.17	1443	34
5	1	0	2	2	1	1	2	1	1	0	0	1	5.75	1524	35
6	1	1	0	2	1	1	2	3	0	1	0	0	5.83	1623	22
7	0	3	0	1	0	1	3	1	1	1	1	0	6.25	1557	33
8	0	0	1	2	2	1	1	3	1	1	0	0	6.42	1547	63
9	0	0	0	1	3	0	0	0	5	2	1	0	7.92	1651	20
10	0	0	0	0	0	2	2	0	1	2	4	1	9.25	1646	86
11	0	0	0	0	0	1	0	0	1	5	3	2	10.17	1714	20
12	0	0	0	0	0	0	0	2	0	0	2	8	11.17	1811	94

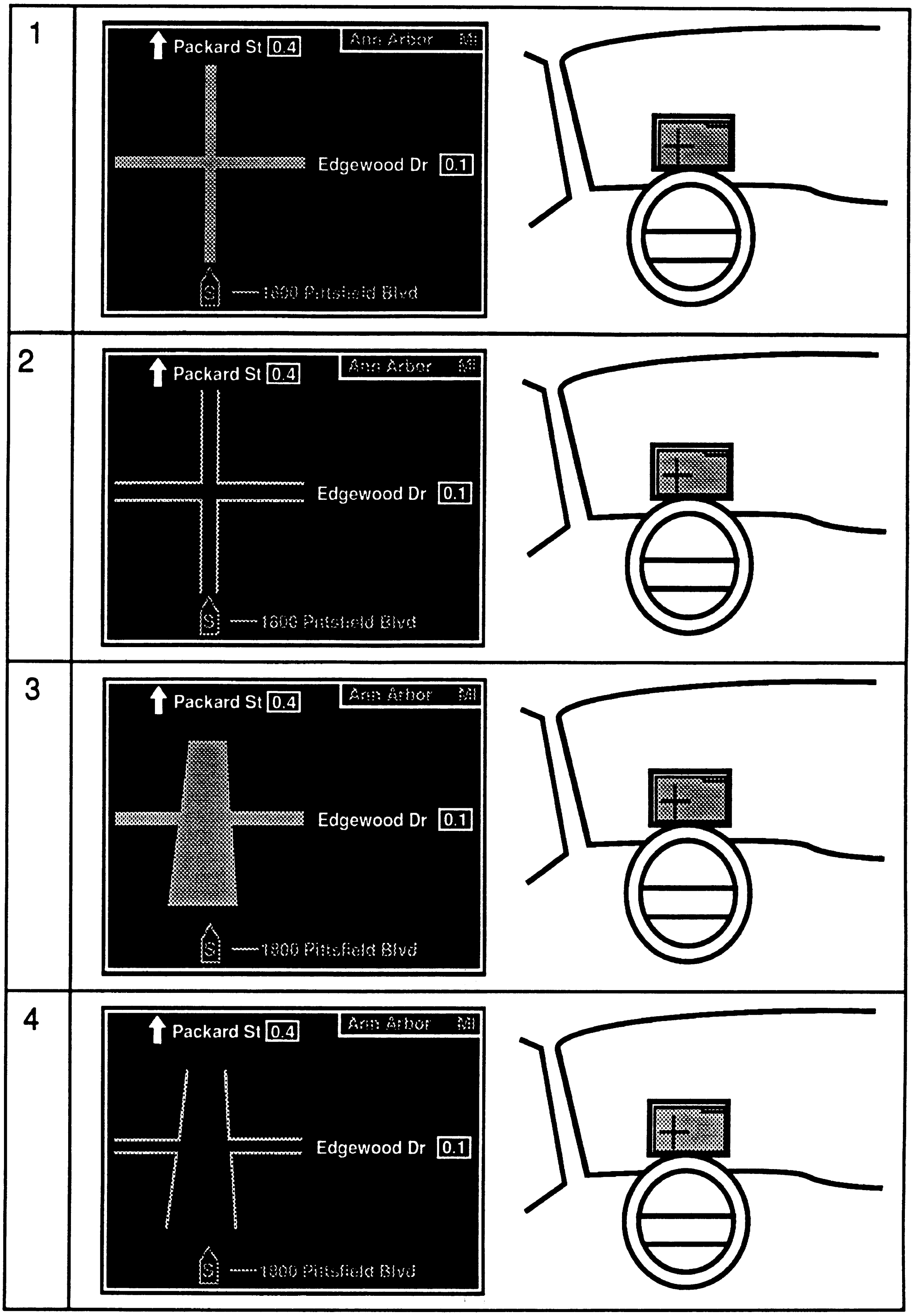


Figure 14. Ranking of designs.

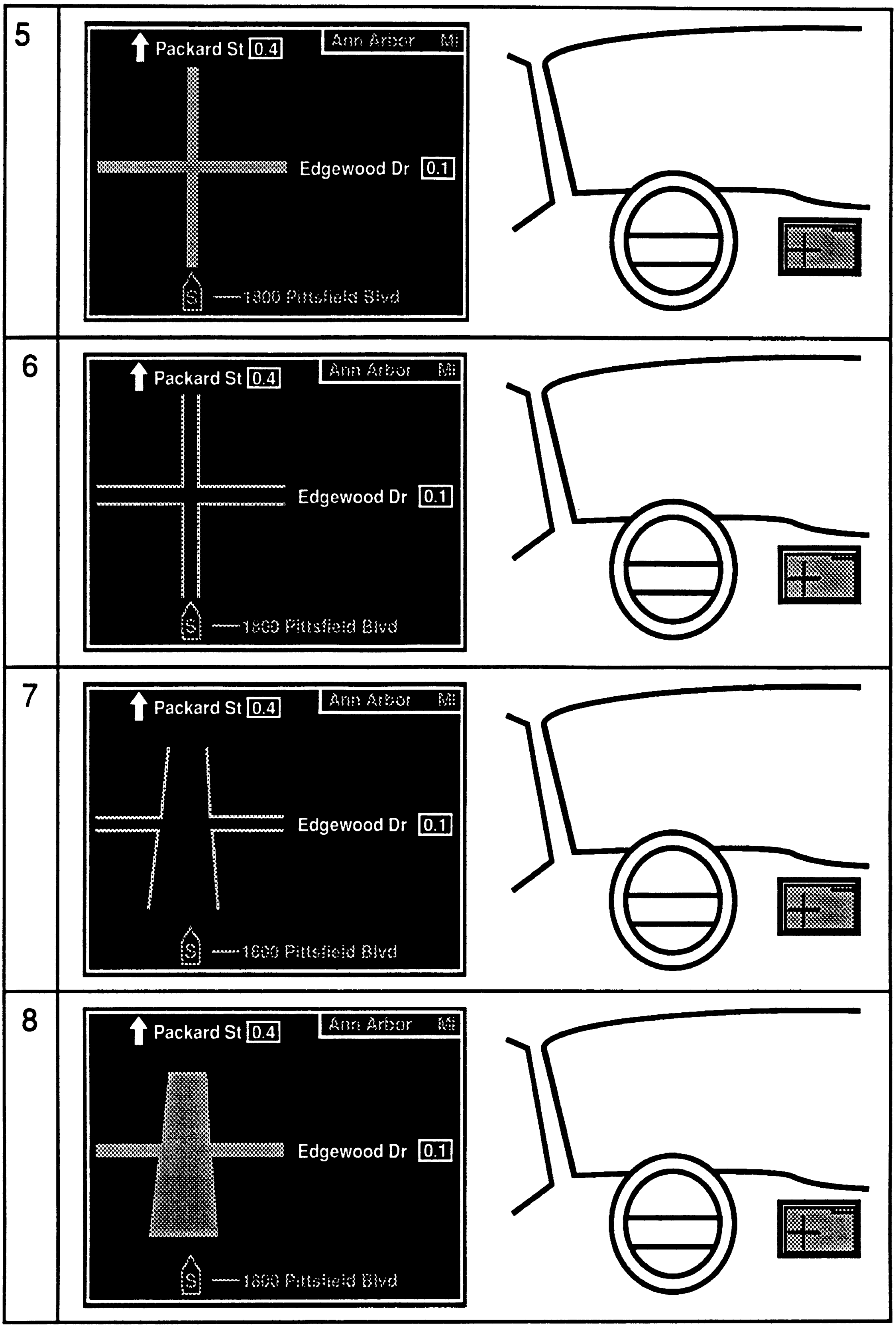


Figure 14. Ranking of designs (continued).

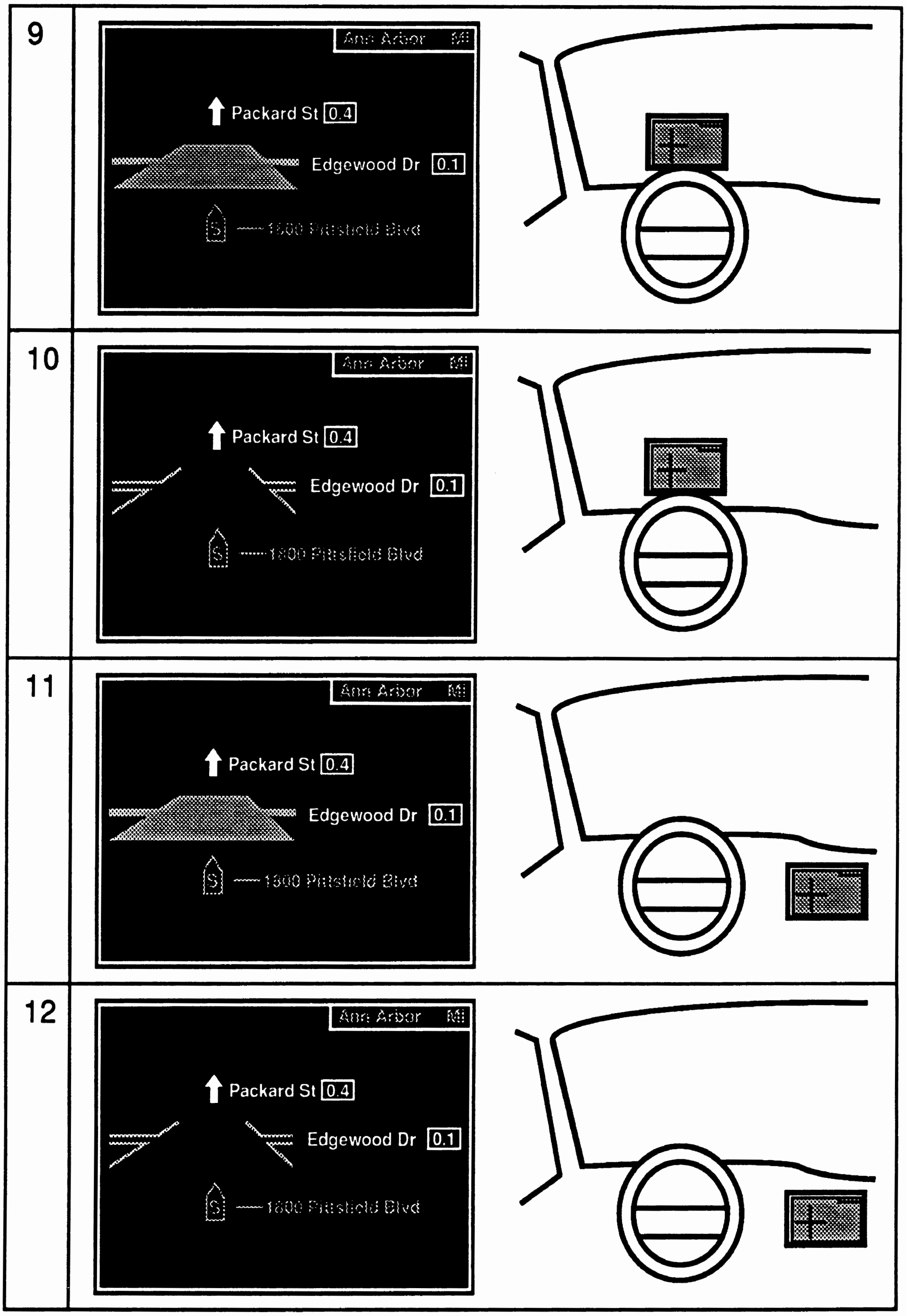


Figure 14. Ranking of designs (continued).

Eye Fixations

Eye fixation data were examined from the first six trials for two participants in all conditions. The data for one female are shown in table 15. The data for one male are shown in table 16. The mean fixation duration to the display was 399 ms (standard deviation = 82 ms) and 613 ms (standard deviation = 213 ms) to the road scene for the young female. For the one male, the mean fixation to the display was 659 ms (standard deviation = 154 ms) and 890 ms (standard deviation = 262 ms) for the road. The number of fixations in a typical trial was 1.2 for the display and 1.9 to the road scene for the younger driver, and 1.1 and 1.4, respectively, for the older driver. The general pattern was as follows: look at the road scene, look at the display, and sometimes look back at the road scene to confirm the response. The second road fixation tended to be brief (which is, in part, why the standard deviations for road scene fixations is large). For the younger driver, the fixation on the HUD display was longer than the IP display. The opposite occurred for the older driver. Because of the small number of fixations analyzed, it is difficult to determine the actual size of this difference. Nonetheless, the mean eye fixation times for these two participants were reasonably well correlated with the mean response times for the sample (r = 0.64).

Table 15. Fixation times for young female.

				Display			Road Scene		
#	Design	Road Format	Loc	Mean Fixation (ms)	Std Dev	Number Fixations per Trial	Mean Fixation (ms)	Std Dev	Number Fixations per Trial
1	Plan	Solid	IP	367	21	1.0	611	204	1.5
2	Aerial	Solid	IP	333	21	1.0	550	263	1.7
3	Persp	Solid	IP	389	54	1.0	518	146	1.8
4	Plan	Outline	IP	383	86	1.0	583	148	1.7
5	Aerial	Outline	IP	411	58	1.0	673	193	1.7
6	Persp	Outline	IP	343	124	1.7	547	133	2.0
7	Plan	Solid	HUD	391	88	1.2	639	177	2.0
8	Aerial	Solid	HUD	310	63	1.2	647	189	2.0
9	Persp	Solid	HUD	358	58	1.3	584	217	2.5
10	Plan	Outline	HUD	328	25	1.0	533	159	1.8
11	Aerial	Outline	HUD	529	179	1.2	789	472	2.0
12	Persp	Outline	HUD	644	203	1.5	675	257	2.0
	IP mean			371	78	1.1	581	184	1.7
	HUD mean			427	175	1.2	645	269	2.1

Table 16. Fixation times for older male.

#	Design	Road Format	Loc	Display: Mean Fixation (ms)	Display: Std Dev	Display: Number Fixations per Trial	Road Scene: Mean Fixation (ms)	Road Scene: Std Dev	Road Scene: Number Fixations per Trial
1	Plan	Solid	IP	644	135	1.0	1038	470	1.8
2	Aerial	Solid	IP	743	177	1.0	834	412	1.8
3	Persp	Solid	IP	613	217	1.2	884	339	1.5
4	Plan	Outline	IP	572	68	1.0	843	340	1.5
5	Aerial	Outline	IP	644	58	1.0	833	180	1.3
6	Persp	Outline	IP	975	416	1.5	1056	254	1.5
7	Plan	Solid	HUD	618	91	1.2	603	120	1.2
8	Aerial	Solid	HUD	677	165	1.0	648	199	1.3
9	Persp	Solid	HUD	721	164	1.2	726	274	1.7
10	Plan	Outline	HUD	567	107	1.0	732	155	1.0
11	Aerial	Outline	HUD	486	146	1.2	816	170	1.2
12	Persp	Outline	HUD	649	102	1.0	701	226	1.3
	IP mean			698	269	1.1	915	354	1.6
	HUD mean			619	147	1.1	704	205	1.3

CONCLUSIONS

Participants made 0.2 percent more errors when responding to head-up displays than to IP displays, indicating that display location has a minute impact on driver errors. With regard to format, participants made the fewest errors in responding to aerial displays, closely followed by plan views, approximately 3 percent and 5 percent, respectively. Performance was far worse with perspective displays, where the error rate was over 9 percent, suggesting perspective displays are not viable. Drivers also made 1 percent more errors in responding to displays where the road was shown as a solid graphic rather than an outline.

The pattern of the response time data was identical to the error data. HUD response times were slightly less than those for the IP locations (1524 versus 1630 ms), though, as indicated by the age by location interaction, HUDs were more effective for older drivers. Aerial views elicited slightly faster responses than plan views (1501 versus 1523 ms) and much slower responses than perspective views (1706 ms), indicating that perspective views are not viable. Finally, solid views elicited slightly faster responses than outlines (1557 versus 1597 ms) and are recommended over outline formats.

The preference data show a similar pattern to the response times. The mean ranks were highly correlated with the mean response times ($r = 0.95$).

Eye fixation times on the displays ranged from 333 to 644 ms for the younger driver and 572 to 975 ms for the older driver. The agreement of the eye fixation data with the other dependent measures was reasonable, given the limited fixation data analyzed (e.g., r = 0.64 with response time).

As a set, these data suggest that aerial or plan view displays should be considered for a navigation display. Also, there are small advantages in using a HUD over an IP display, with the advantages of a HUD being greatest for older drivers. Similarly, there are small advantages for depicting roads as solid graphic objects rather than as outlines.

DISCUSSION

This report describes the development and evaluation of several aspects of a route guidance system. In the initial design studies, route guidance displays were shown to small groups of drivers, sometimes just one driver, who explained his or her perception of the display. Typically, these explanations identified weaknesses in the designs and assisted in the development of design guidelines.

The driver licensing office experiment revealed few differences among displays, in part because the displays were reasonably well understood and drivers were not under time pressure to respond, contrary to real driving conditions. In terms of preferences, drivers found the perspective view least desirable and preferred the plan view slightly over the aerial view.

The laboratory experiment provided much more comprehensive results. The differences in performance (as measured by response time and errors) between aerial- and plan-view displays were slight, and were clearly superior to the perspective-view display. For perspective displays, the key details were unacceptably small, resulting in poor performance. This weakness is inherent in the design and cannot be corrected. It would be interesting to see if this weakness is also present in full windshield HUDs in which navigation information is superimposed on the outside world.

Response times were shorter and there were slightly fewer errors for solid versus outline formats and HUD versus IP displays. While only a small sample of the eye fixation data were analyzed, the mean fixation times were correlated with the response time data, as was the preferences. Hence, route guidance displays should be aerial view or plan view presented on a HUD or an IP, with the relative benefits of HUDs being larger for older drivers. For those combinations, depicting the roads on the display as outline or solid has a small effect on performance as expected, demonstrating the sensitivity of the response-time protocol. Aerial-view graphics can be more difficult to generate, and, therefore, as a practical matter, a plan view is the preferred implementation. At the present time, driver response times to aerial views of complicated intersections and expressway ramps are unknown. As demonstrated at the 1991 VNIS meeting, use of aerial views is being considered for the ADVANCE traveler information system project, but there are no published data to support the use of aerial displays other than the information in this report. The use of aerial views should be further explored.

With regard to test protocols, the first experiment using surveys carried out at the driver licensing office suggests there are limitations inherent in survey procedures used in identifying design differences. The differences between designs were slight. However, the rankings of the preference data from the driver licensing office experiment were similar to the rankings of the preferences and performance from the final laboratory experiment. The number of errors was low because the task in the survey was excessively easy. It is important that surveys involve active decision making as the driver would do on the road. That does not mean that survey methods cannot be used to examine alternative interface designs. Rather, tasks must encompass more of what drivers actually do. Further, these data argue for the need occasionally to validate survey data with performance experiments. The authors believe that, while quite simple, the Response-Time method used was engaging and involved much of the decision-making that drivers carry out on the road. The method has identified differences among display designs, some that were small (e.g., solid versus outline roads), using a relatively small number of subjects. Further, this method employed high-fidelity road scenes, which would be extremely difficult to simulate at low cost using current computer technology.

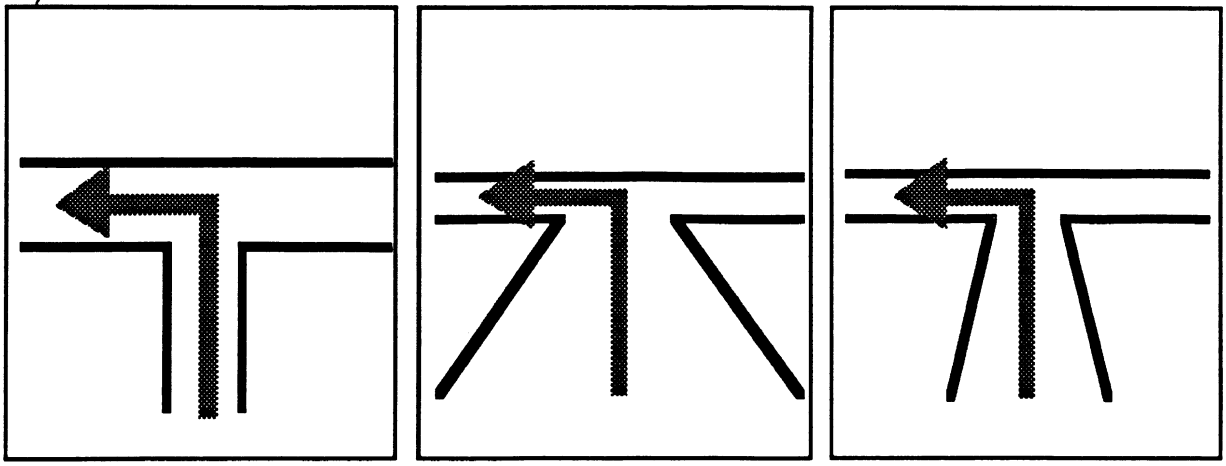
This project examined only residential intersections and did not consider complex intersections or freeway interchanges. Additional data should be collected for them, because it may be more difficult for drivers to use aerial maps for those configurations, hence making them less desirable than suggested by the results from this research. That research should be conducted using a slightly larger range of acceptable response times. Validation of the results of this experiment with real-world data should also be conducted.

As a set, these experiments emphasize the value of utilizing a variety of experimental approaches in developing and evaluating driver interfaces. In the early phases, informal surveys may be adequate to identify design deficiencies. As the interface is refined, more control is needed over the test protocol and in the selection of test subjects that are representative of the driving population. When the design begins to resemble a real application, the task must encompass the actual behavior of drivers, as [the authors believe] the response-time task did. Thus, there is no single ideal experimental approach, but rather a sequence of evaluations that vary widely in how closely they approximate the actual driving task.

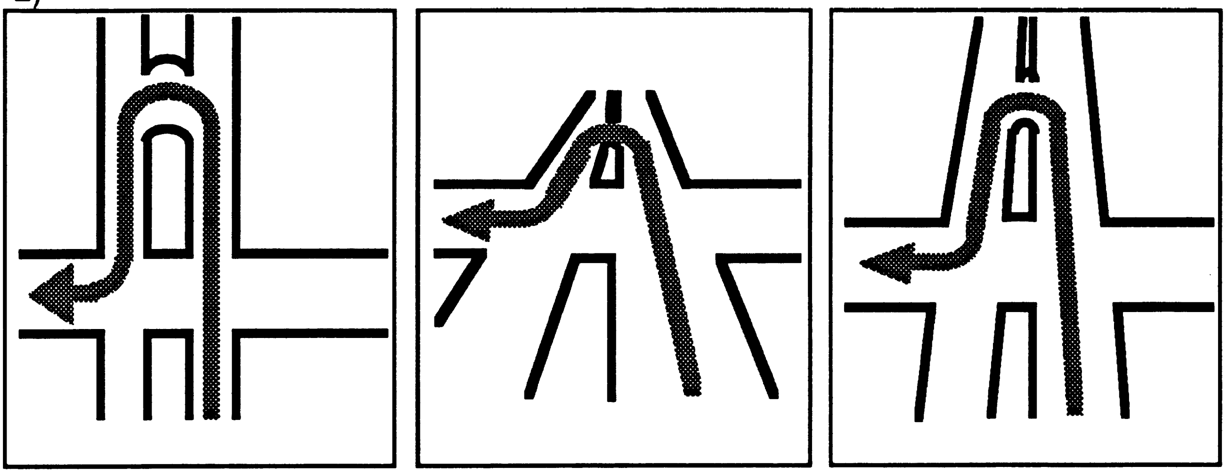
APPENDIX A. NAVIGATION INSTRUCTION PREFERENCES

Please rank from best (=1) to worst (=3).

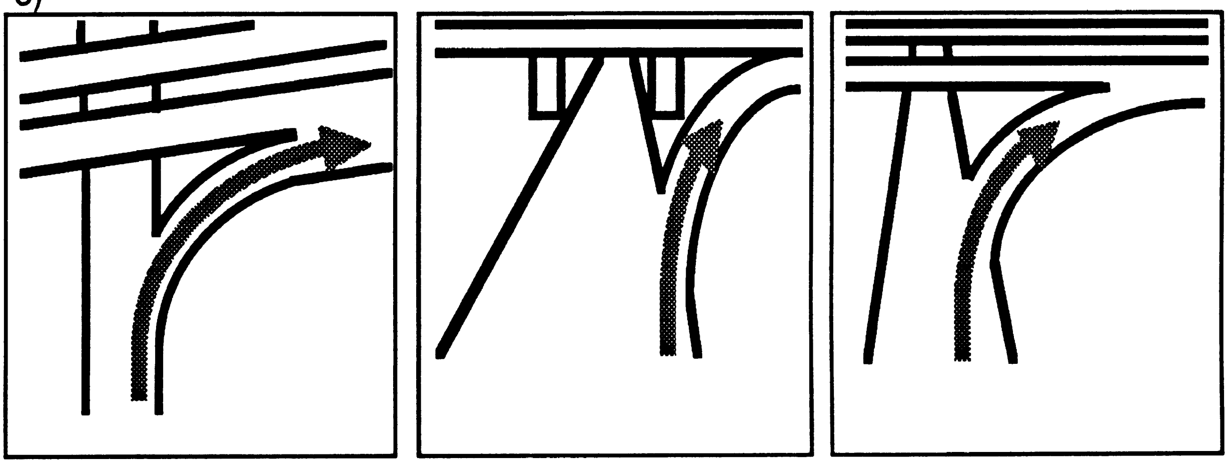
1)



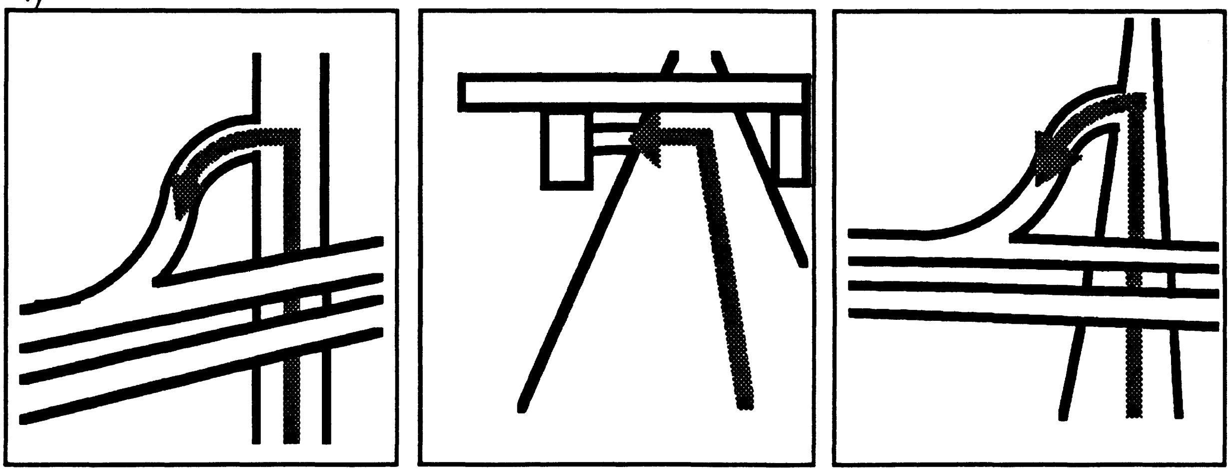
2)



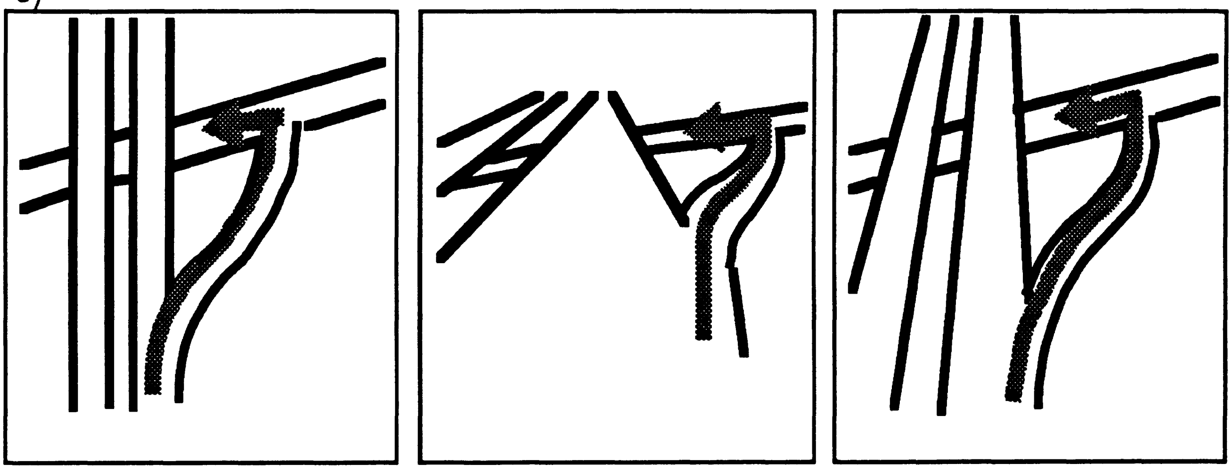
3)



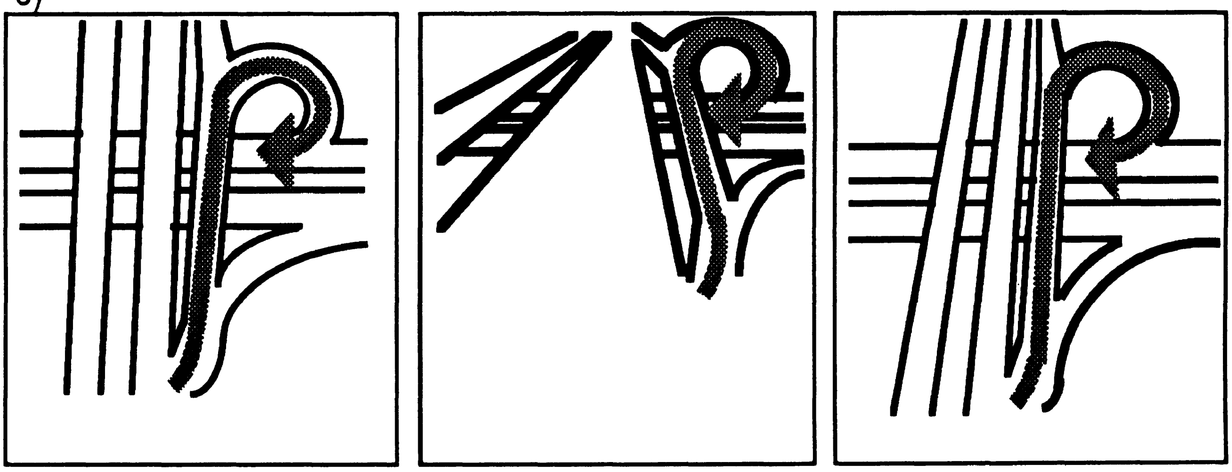
4)



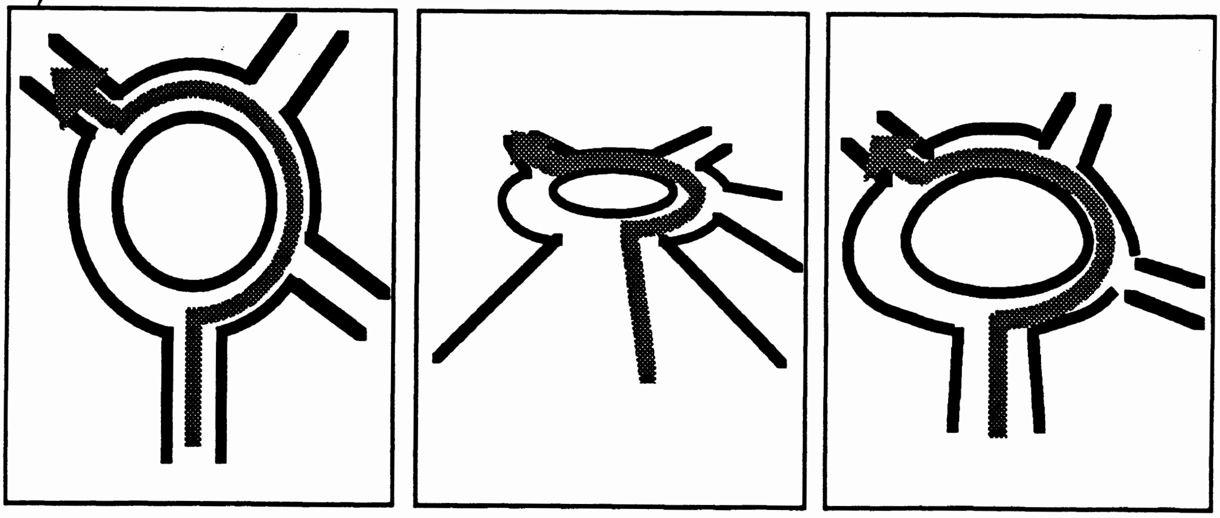
5)



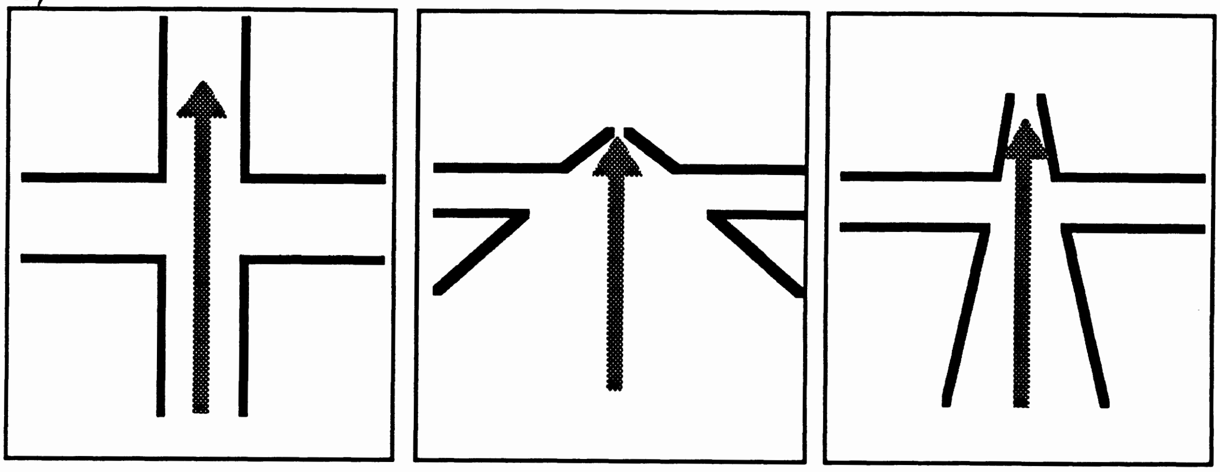
6)



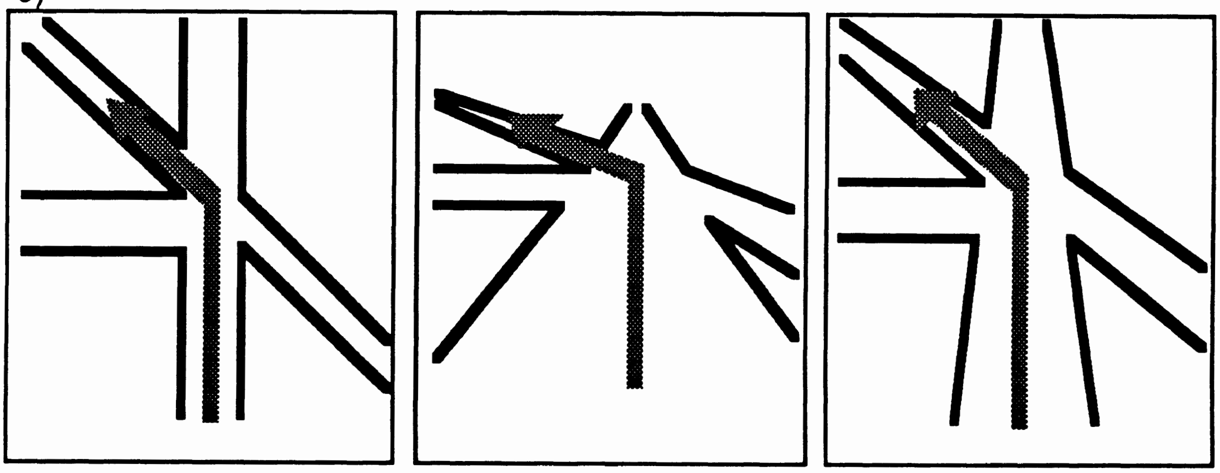
7)



8)



9)



APPENDIX B. NAVIGATION STRUCTURED INTERVIEW

Hi, I'm __________ and I'm with the University of Michigan Transportation Research Institute. We're designing systems to be used in cars of the future, and we're currently working on a navigation system. This would be an electronic display in your car, maybe something like this (Marie's picture) that would give you directions as you drive. You could tell it where you wanted to go, and it would tell you where to turn, making your drive easier.

We're beginning to design the navigation system now, and would like to get your input. I have some sample directions that the navigation system may give you (show one), and I'd like you to tell me what you think of them. Would you be willing to give your input?

(if yes) - Great. I'm going to show you pictures that may be given to you by a navigation system while driving. I'd like you to tell me what you think the pictures mean. Keep in mind there are no wrong answers, I'm just interested in your opinions.

OK, pretend that you're driving down a road and you see this on your navigation display. (Show figure 1.)

1) What do you think the navigation system is telling you?
TL other ____

Where? __________________ ( ) got the idea

What do you think the intersection is like?
T road ending other ____________________

2) Now, suppose the navigation system showed this (figure 2).
What do you think the navigation system is telling you? ( ) got the idea
TL/TR other ____________________

What is the intersection like?

____

3) Now, suppose the navigation system showed this (figure 3).
What do you think the navigation system is telling you? ( ) got the idea
TR other ____________________

What is the intersection like?

hwyramp other ____________________

4) Now, suppose the navigation system showed this (figure 4).
What do you think the navigation system is telling you? ( ) got the idea
TL other ____________________

What is the intersection like?

hwyonramp other ___________________

5) Now, suppose the navigation system showed this (figure 5).
What do you think the navigation system is telling you? ( ) got the idea
TL other ___________________

What is the intersection like?

hwyofframp other ___________________

6) Now, suppose the navigation system showed this (figure 6).
What do you think the navigation system is telling you? ( ) got the idea
hwytohwy other ___________________

What is the intersection like?

hwyjnct other ___________________

7) Now, suppose the navigation system showed this (figure 7).
What do you think the navigation system is telling you? ( ) got the idea
TC other ___________________

What is the intersection like?

TC other ___________________

8) Now, suppose the navigation system showed this (figure 8).
What do you think the navigation system is telling you? ( ) got the idea
Strt other ___________________

What is the intersection like?

2road other ___________________

9) Now, suppose the navigation system showed this (figure 9).
What do you think the navigation system is telling you? ( ) got the idea
TL other ___________________

What is the intersection like?

complex other ___________________

Thanks for your help. Now I'd like to know which way you prefer to have traffic instructions displayed. For each type of intersection, I'll show you three options. Please rank them from best (1) to worst (3).

Key to Appendix B abbreviations--

TL - turn left
TR - turn right
T - T intersection
hwyramp - highway ramp
hwyonramp - highway on ramp
hwyofframp - highway off ramp
hwytohwy - highway interchange
hwyjnct - highway junction
TC - traffic circle
Strt - start
2road - two roads crossing
complex - complex intesection

APPENDIX C. ADDITIONAL TEST SEQUENCE SPECIFICATIONS

Slide carousel contents.

+ = cross, Y=Y, T=T, R = T right, L=T left
a, b, c are different intersections within the type

Slide Position	Road Scene		Nav Display		Correct Response
1	Y	c	Y	c	same
2	Y	a	R	c	different
3	R	b	R	b	same
4	L	a	Y	b	different
5	T	c	T	c	same
6	R	c	+	c	different
7	T	a	T	a	same
8	+	b	+	b	same
9	+	a	T	a	different
10	R	a	R	a	same
11	Y	c	T	c	different
12	+	c	L	a	different
13	+	c	+	c	same
14	+	a	+	a	same
15	T	a	R	b	different
16	Y	b	L	c	different
17	+	b	R	a	different
18	L	b	+	b	different
19	T	b	T	b	same
20	L	c	L	c	same
21	R	b	L	b	different
22	L	c	T	b	different
23	T	b	Y	a	different
24	Y	a	Y	a	same
25	T	c	+	a	different
26	Y	b	Y	b	same
27	L	b	L	b	same
28	R	a	Y	c	different
29	R	c	R	c	same
30	L	a	L	a	same

Sequence of test blocks.

Block	subject # 1	2	3	4	5	6
1	4 IP practice	4 IP practice	4 IP practice	4 IP practice	4 IP practice	4 IP practice
2	IP plan solid	IP aerial solid	IP prspct solid	IP plan outline	IP aerial outline	IP prspct outline
3	IP aerial solid	IP prspct solid	IP plan outline	IP aerial outline	IP prspct outline	IP plan solid
4	IP prspct solid	IP plan outline	IP aerial outline	IP prspct outline	IP plan solid	IP aerial solid
5	IP plan outline	IP aerial outline	IP prspct outline	IP plan solid	IP aerial solid	IP prspct solid
6	IP aerial outline	IP prspct outline	IP plan solid	IP aerial solid	IP prspct solid	IP plan outline
7	IP prspct outline	IP plan solid	IP aerial solid	IP prspct solid	IP plan outline	IP aerial outline
8	1 HUD practice	1 HUD practice	1 HUD practice	1 HUD practice	1 HUD practice	1 HUD practice
9	HUD plan solid	HUD aerial solid	HUD prspct solid	HUD plan outline	HUD aerial outline	HUD prspct outline
10	HUD aerial solid	HUD prspct solid	HUD plan outline	HUD aerial outline	HUD prspct outline	HUD plan solid
11	HUD prspct solid	HUD plan outline	HUD aerial outline	HUD prspct outline	HUD plan solid	HUD aerial solid
12	HUD plan outline	HUD aerial outline	HUD prspct outline	HUD plan solid	HUD aerial solid	HUD prspct solid
13	HUD aerial outline	HUD prspct outline	HUD plan solid	HUD aerial solid	HUD prspct solid	HUD plan outline
14	HUD prspct outline	HUD plan solid	HUD aerial solid	HUD prspct solid	HUD plan outline	HUD aerial outline

Block	7	8	9	10	11	12
1	4 HUD practice	4 HUD practice	4 HUD practice	4 HUD practice	4 HUD practice	4 HUD practice
2	HUD plan solid	HUD aerial solid	HUD prspct solid	HUD plan outline	HUD aerial outline	HUD prspct outline
3	HUD aerial solid	HUD prspct solid	HUD plan outline	HUD aerial outline	HUD prspct outline	HUD plan solid
4	HUD prspct solid	HUD plan outline	HUD aerial outline	HUD prspct outline	HUD plan solid	HUD aerial solid
5	HUD plan outline	HUD aerial outline	HUD prspct outline	HUD plan solid	HUD aerial solid	HUD prspct solid
6	HUD aerial outline	HUD prspct outline	HUD plan solid	HUD aerial solid	HUD prspct solid	HUD plan outline
7	HUD prspct outline	HUD plan solid	HUD aerial solid	HUD prspct solid	HUD plan outline	HUD aerial outline
8	1 IP practice	1 IP practice	1 IP practice	1 IP practice	1 IP practice	1 IP practice
9	IP plan solid	IP aerial solid	IP prspct solid	IP plan outline	IP aerial outline	IP prspct outline
10	IP aerial solid	IP prspct solid	IP plan outline	IP aerial outline	IP prspct outline	IP plan solid
11	IP prspct solid	IP plan outline	IP aerial outline	IP prspct outline	IP plan solid	IP aerial solid
12	IP plan outline	IP aerial outline	IP prspct outline	IP plan solid	IP aerial solid	IP prspct solid
13	IP aerial outline	IP prspct outline	IP plan solid	IP aerial solid	IP prspct solid	IP plan outline
14	IP prspct outline	IP plan solid	IP aerial solid	IP prspct solid	IP plan outline	IP aerial outline

APPENDIX D. EXPERIMENTER'S TASKS

Prior to arrival of participant:
Make sure there are blank consent forms, biographical forms, support voucher, the system ranking form, and money for payment.

Check Lab Ex 1 Block listing and note the proper order of slide carousels.

- Plug in light behind wall.
- Put red reflector stand in front of wall in line of HUD.
- Put black paper over keyboard labels.
- Switch on two power strips by PC, including all individual plug switches.
- Turn on computer.
- Switch on third power strip.
- Check that the variacs are on (two behind buck only).
- Turn on florescent light by PC.
- Put shape practice carousel on IP projector and road scene carousel on wall projector.
- Set shutter and Kodak controller switches to IP.
- Run FOCUS2.
- Switch on black power supply.
- Open both shutters and advance to slide 1. Check alignment and focus of IP and wall projections. Send projectors to zero. Quit focus2.
- Put shape carousel on HUD projector.
- Set shutter and Kodak controller switches to HUD.
- Run FOCUS2. Open shutter 1 and advance to slide 1. Check alignment and focus of HUD. (This may be easier to fix with black box lifted off.) Send projectors to zero. Quit focus2.
- Verify that HUD projector is zeroed.
- Check which display subject does first. Turn shutter and controller switches accordingly.
- Put shape practice carousels on wall projector and correct display projector.
- Put display carousels in order. Two stacks of three. If subject begins on IP, put display carousels on rear table. If subject begins on HUD, put display carousels on front wooden table.
- Go to NAV directory. Run RT2P. Load N1P1.INP. Make output file NAV1S#.OUT
- Check that keys 3 and 4 are exposed on keyboard.
- Turn on power supply behind driver's seat.

Complete as much of the biographical form as possible.

When participant arrives:

Are you ____? Hello, my name is ______ and I am one of the experimenters working on the street information study. Before we get going I would like to note this experiment takes approximately 1 and a half hours and you will be paid 15 dollars for your time. If you would like to visit the rest room, now would be a good time to do so. Also smoking is prohibited in this building, so please refrain from doing so.

Go into lab. Flip "Experiment in Progress" sign over on door.

The purpose of this experiment is to determine the best way to present drivers with information regarding road intersections. The results of this study will be used for designing systems for use in future vehicles. Since you may be driving one of those vehicles, your opinion is important.

Before we start, there is some paperwork to complete. First, you need to sign this official consent form the university requires us to give you, which basically repeats in writing what I just said.

Ask participant to sign consent form.

And, we need to know a little more about you.

Fill out Bio form with subject.

Test subjects vision. Make sure both eye switches are on.

Have participant sit in buck.

We want to know how a computer should tell drivers where they are and where the display should be in the car.

You will sit here in the driver's seat and, projected on the wall in front of you, will be road scenes. At the same time on one of the small screens will be shown our street information system. Your task is to decide if the scene shown on the car screen matches the scene shown on the wall, and to respond by pressing a button.

Position yourself as if you were driving. Can you see the red reflector in front of the wall? Can you see it without stretching?

Adjust seat if necessary, using electric controls.

Lay your hand on the black keyboard on your right with these two fingers on the two keys. Are you comfortable? Would you like the seat moved at all?

Adjust seat again if necessary.

Move red reflector out of way behind wall.

Practice on IP/HUD

Before we get into the actual study, you need practice at responding to slides. In these two practice runs, the slides show shapes: squares, circles, triangles, etc. On the gray wall, there will appear a large shape and at the same time a shape will be shown on the small screen (in the middle of the car)/(in front of) the car. If the shapes are the same, press the left button. If they are different, press the right button. Touch respective fingers. **Half of the slides will match, and half will not match. The shapes on the small screen inside the car can be solid or outline, but only the type of shape has to match. For example, if both are triangles, they match. If you get one wrong you will hear a tone informing you.**

Do you have any questions?

Answer questions.

There will be 56 slides in each of these two practice blocks. Remember, same (wiggle index finger right hand) **and different** (wiggle middle finger right hand).

I am going to turn off the lights now.
Turn out lights.
Are you ready?
Do 2 practice blocks.

IP/HUD test
Move shape carousel to other display projector (IP to HUD, or HUD to IP), put road scenes in wall projector, and put first display carousel on proper projector.
Now it is time to respond to the real system. On the wall will appear slides of intersections. On the small screen (inside)/(up on the hood of) the car, will be a simulated image from a computer. If they match, press the left (or "same") button as you did in practice. If they are different, press the right button. Try to respond as rapidly and accurately as possible.
Point to the buttons.
Don't worry about the street names matching. When the intersections match, the street names will also. We are only interested in evaluating the display of the intersection. Again half of the slides will match, and half will not match.
Do you have any questions?
Answer questions.
This set is 60 slides. There will be six sets and then a break.

RUN TRIALS IN THE ORDER SPECIFIED IN SUBJECT LISTING
As carousels are used place them on the car seat in order starting on the edge closest to the front of the room.
Give feedback at the end of each block ("You are doing fine", etc...)

When finished, put shape carousel on wall projector.

Quit RT. Switch shutter and Kodak controller to other display. Re-run RT2P with N1P3.INP.

TAKE A BREAK

Now we are going to move to the other small screen (up on the hood directly in front of you)/(inside of the car). To get used to it, there will be one practice run again with the shape slides.
Do 1 practice trial.

RUN REMAINING TRIALS IN THE ORDER SPECIFIED IN SUBJECT LISTING
Take carousels from car seat in order from one closest to front of room. Stack used ones on table closest to display projector.

Quit RT.

Turn on lights. Show subject pictures of each system in each location with signs on table reading "best" and "worst".

I want you to rank these systems from best to worst, by placing them in a row on the table with the one you like the best closest to the sign that says "best", and the one you like the worst closest to the sign "worst".
Have subject rank. Write down ranks and mix design ranking sheets.

Have subject fill out support voucher and pay subject.

After subject leaves:
Take disk to NCR in MW's office and copy file to 3 1/2 floppy and copy to Mac hard drive **Nav1 output** folder.

APPENDIX E. CONSENT FORM

Driver Responses to a Street Information System

Participant Consent Form

We are working on a system to show drivers information about local streets to help them when they are lost. A well designed system can be used at a glance, so people can concentrate on driving. Responses from typical drivers such as you, will help identify the best way to show this information.

While sitting in a driving simulator, you will respond to slides of displays by pressing buttons. A computer will record how long it takes to respond and the errors made. We may videotape this session, but only if you allow us. We will not release any identifying information, so your responses will remain confidential.

The experiment takes about 1-1/2 hours for which you will be paid $15. There will be 1 scheduled break midway through. If you have any problems completing this experiment, you can withdraw at any time. You will be paid regardless.

I have read and understand the information above.

______________________________ Print your name	________________ Date
______________________________ Sign your name	________________ Witness (experimenter)

It is okay to videotape me: yes no (circle one)

APPENDIX F. BIOGRAPHICAL FORM

University of Michigan Transportation Research Institute
Human Factors Division

Biographical Form Date:

Name: ________________________________

Male Female (circle one) Age: ____________

What is your native language? (circle one)

English Chinese Japanese Korean Spanish
Other: ____________________

Occupation: ________________________________
(If retired or student, note it and your former occupation or major)

Education (circle highest level completed): some high school / high school degree; some trade/tech school / trade/tech school degree; some college / college degree; some graduate school / graduate school degree

What kind of car do you drive the most?

year: ________ make: ____________ model: ____________

Annual mileage: ____________

Have you ever driven a car with a navigation system? yes no

Does your car have a Head-Up Display (HUD)?
(If you don't know what it is you probably don't have one.)

yes no -----> Have you ever **driven** a car with a HUD? yes no

How comfortable are you using maps?

very comfortable / moderately comfortable / neutral / moderately uncomfortable / very uncomfortable

Do you have any experience in drafting? yes no kind: ____________

Do you have any drawing or artistic painting skills? yes no kind: ____________

Can you touch-type? yes no

TITMUS VISION: (Landolt Rings)

1	2	3	4	5	6	7	8	9	10	11	12	13	14
T	R	R	L	T	B	L	R	L	B	R	B	T	R
20/200	20/100	20/70	20/50	20/40	20/35	20/30	20/25	20/22	20/20	20/18	20/17	20/15	20/13

APPENDIX G. ADDITIONAL DATA ON REPETITIONS

			Repeats					
			Short		Long		No	%
System	Correct	Incorrect	Cor	Incorr	Cor	Incorr	Respns	Repeated
1	720	35	---	2	7	2	---	6.0
2	720	22	---	---	17	1	---	5.3
3	720	63	---	---	8	5	---	9.5
4	720	33	---	1	16	3	---	6.9
5	720	20	---	1	19	1	---	5.4
6	720	94	3	1	89	25	---	22.7
7	720	39	---	1	1	1	2	5.8
8	720	36	---	---	6	1	---	5.6
9	720	43	---	---	4	1	---	6.2
10	720	34	---	---	---	---	---	4.5
11	720	20	---	---	3	---	---	3.1
12	720	86	1	2	15	5	---	13.1

Note-- Cor = Correct , Incorr = Incorrect, Respns = Responses

APPENDIX H. ANOVA TABLE

ANOVA of response times within the deadlines.

		SS	DF	MS	F	p
MEAN	mean	2.1476E+10	1	2.148E+10	22579.077	<.001
PEOPLE	Sex = X	8.3049E+07	1	83049300	87.315	<.001
	Age = A	2.5178E+08	1	251780000	264.712	<.001
	Subject(A, X)	9.2004E+08	8	115005000	120.912	<.001
PROTOCOL	Blocks	1.8067E+08	11	16424545	17.268	<.001
	Key (same/diff)	1.3667E+07	1	13667000	14.369	<.001
	Repetition	2.5866E+07	1	25866000	27.195	<.001
DISPLAY	Location	2.4192E+07	1	24192000	25.435	<.001
	View	7.2580E+07	2	36290000	38.154	<.001
	Road Format	3.3022E+06	1	3302200	3.472	0.04
	Type	3.7071E+07	4	9267750	9.744	<.001
	Intersection	4.3920E+07	10	4392000	4.618	<.001
INTERACTIONS	LV	7.7600E+04	5	15520	0.016	ns
	LW	1.8825E+06	1	1882500	1.979	0.122
	LT	1.8209E+06	4	455225	0.479	ns
	LI	1.7093E+06	10	170930	0.180	ns
	VW	2.1593E+06	2	1079650	1.135	0.261
	VT	1.4960E+06	8	187000	0.197	ns
	VI(T)	5.5619E+06	20	278095	0.292	ns
	WT	2.4513E+05	4	61282.5	0.064	ns
	WI(T)	2.5167E+06	10	251670	0.265	ns
	LVW	5.4548E+05	2	272740	0.287	ns
	KR	3.7250E+05	1	372500	0.392	ns
	XA	7.5868E+05	1	758680	0.798	ns
	XL	8.4608E+07	1	84608000	88.954	<.001
	AL	4.0929E+06	1	4092900	4.303	0.023
FACTOR SUBTOTAL		5.0912E+08	101	---	---	
POOLED ERROR	Pooled Error	8.1209E+09	8538	951146.04	---	
TOTAL	Total	3.0106E+10	8640			

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