U.S. Department
of Transportation

**Federal Highway
Administration**

Publication No. FHWA-RD-95014
January 1997

Human Factors of In-Vehicle Driver Information Systems: An Executive Summary

Research and Development
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, Virginia 22101-2296

FOREWORD

This project developed methods for identifying and selecting a set of functions and features of specific driver information systems that might reduce accidents, improve traffic operations, and satisfy driver needs and wants through the use of focus groups of drivers and expert ratings. These analyses resulted in the selection of five systems for detailed examination: traffic information systems, car phones, navigation, road hazard warning, and vehicle monitoring systems. The effectiveness of alternative designs for each of the selected systems was examined separately in a series of experiments. This work led to empirical data on system use and to a set of design guidelines for driver interfaces.

This report presents key findings of a multiyear research program designed to study selected driver interfaces for future cars. This report will be useful to researchers, Advanced Traveler Information Systems (ATIS) designers, and State and Local transportation agencies concerned with development of ATIS.

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

NOTICE

Technical Report Documentation Page

1. ~~Report No~~ FHWA-RD-95-014	2. Government Accession No	3 Recipient's Catalog No.
4 Title and Subtitle HUMAN FACTORS OF IN-VEHICLE DRIVER INFORMATION SYSTEMS: AN EXECUTIVE SUMMARY		5. Report Date January 1997 6. Performing Organization Code
7. Author(s) Green, P. (Edited by Deborah A. Boehm-Davis)		8. Performing Organization Report No. UMTRI-93-18
9. Performing Organization Name and Address The University of Michigan Transportation Research Institute 2901 Baxter Road Ann Arbor, Michigan 48109-2150		10. Work Unit No. (TRAIS) 3B3B2032 11. Contract or Grant No. DTFH61-89-C-00044
12. Sponsonng Agency Name and Address Office of Safety and Traffic Operations R&D Federa Highway Administration 6300 Georgetown Pike McLean, Virginia 22101-2296		13. Type of Report and Period Covered Final Report September 1991- May 1993 14. Sponsoring Agency Code

15. Supplementary Notes

Contracting Officer's Technical Representative' Ms. Nazemeh Sobhi (HSR-30)

16 Abstract

This report summarizes a multiyear program concerning driver interfaces for future cars. The goals were to develop (1) human Factors guidelines, (2) methods for testing safety and ease of use, and (3) a model that predicts human performance with these systems. After reviewing the human factors literature, focus groups were conducted to assess driver attitudes towards new information systems. Next, the extent to which these systems might reduce traffic accidents, improve traffic operations, and satisfy driver needs and wants was examined. Based on that effort and contract requirements, five functions were selected for further evaluation - route guidance, traffic information, road hazard warning, cellular phone, and vehicle monitoring. For each system, experiments were conducted at a licensing office, involving 20 to 75 drivers, to determine preferred display formats They were followed by a static on-road test of the road hazard warning system, driving simulator experiments for the phone, traffic information, and navigation systems, a response-time experiment examining navigation displays, and a videotape-based experiment concerning navigation and traffic information. Finally, three on-road experiments were conducted using an instrumented car. From this research, tentative standard test protocols and measures were recommended, guidelines were written, and a human performance model was developed.

17 Key Words ITS, human factors engineering, ergonomics, navigation, driver information system, test methods, guidelines.	18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No of Pages	22. Price
Unclassified	Unclassified	44	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 30 centimeters (cm)
1 yard (yd ❑ 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2 = 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2 = 0.09 square meter (m^2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)
1 acre = 0.4 hectares (he) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gr)
1 pound (lb) = .45 kilogram (kg)
1 short ton = 2,000 pounds (Lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp ❑ 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (l)
1 pint (pt) = 0.47 liter (l)
1 quart (qt) = 0.96 liter (l)
1 gallon (gal) = 3.8 liters (l)
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] ^{o}F ❑ y ^{o}C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)
1 centimeter (cm) = 0.4 inch (in)
1 meter (m) = 3.3 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
1 hectare (he) = 10,000 square meters (m^2) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gr) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons

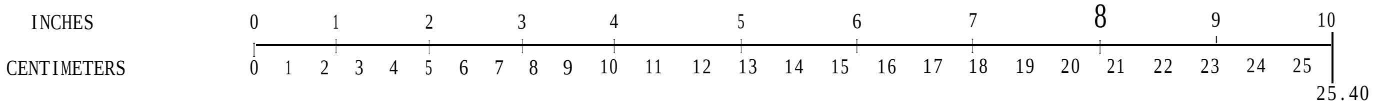
VOLUME (APPROXIMATE)

1 milliliters (ml) ❑ 0.03 fluid ounce (fl oz)
1 liter (1) = 2.1 pints (pt)
1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.26 gallon (gal)
1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

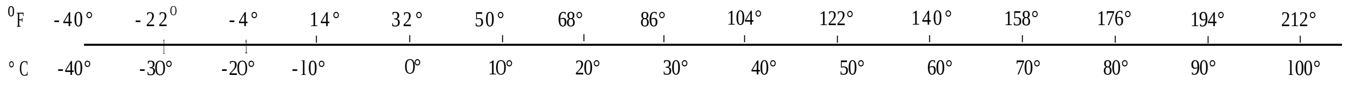
TEMPERATURE (EXACT)

[(9/5) y + 32] ^{o}C ❑ x ^{o}F

QUICK INCH-CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT-CELSIUS TEMPERATURE CONVERSION



For more exact and or other conversion factors, see NBS Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50. SD Catalog No. Cl3 10286.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

PROJECT OVERVIEW

The Federal Highway Administration (FHWA), through its Intelligent Transportation Systems (ITS) program, is aiming to develop solutions to the most pressing problems of highway travel. The goals are to reduce congestion, improve traffic operations, reduce accidents, save energy, and reduce air pollution from vehicles by applying computer and communications technology to highway transportation. If these systems are to succeed in reducing the Nation's transportation problems, they must be safe and easy to use, with features that enhance the driving experience. The contractor carried out a program to help evaluate potential ITS-related driver information systems for cars of the near future.

The work conducted under this program took the following approach:

- Identification of specific driver information systems that might reduce accidents, improve traffic operations and satisfy driver needs and wants.

- Investigation of appropriate design alternatives for the selected in-vehicle information systems. As decisions were made concerning interface alternatives, design guidelines were developed.

- Development of a computational model that predicts in-vehicle driver performance for ITS information usage.

- Formulation of a test protocol for assessing safety and ease of use for individual systems.

Figure 1 provides an overview of the research program. The program began with a general literature review of driving instrumentation and methods used to evaluate them. This literature review was carried out in parallel with focus groups who provided their subjective reactions to advanced instrumentation. Subsequently, the relative extent to which various driver information systems might reduce accidents, improve traffic operations, and satisfy driver needs and wants was analyzed. That analysis resulted in the selection of traffic information systems and car phones for detailed examination. Route guidance, road hazard warning, and vehicle monitoring systems were also selected for further examination, as required by the contract.

Each of the five systems selected was examined separately. In a typical sequence, patrons at a local driver licensing office were shown mockups of interfaces, and they were asked the extent to which they understood and preferred each interface. Interface alternatives were then compared in laboratory experiments measuring preferences, response time and lane variance using part-task simulations and driving simulators.

To check the validity of these results, several on-road experiments collected performance and preference data for the various interface designs. The on-the-road experiments were conducted in a 1991 Honda Accord station wagon equipped with a driver information

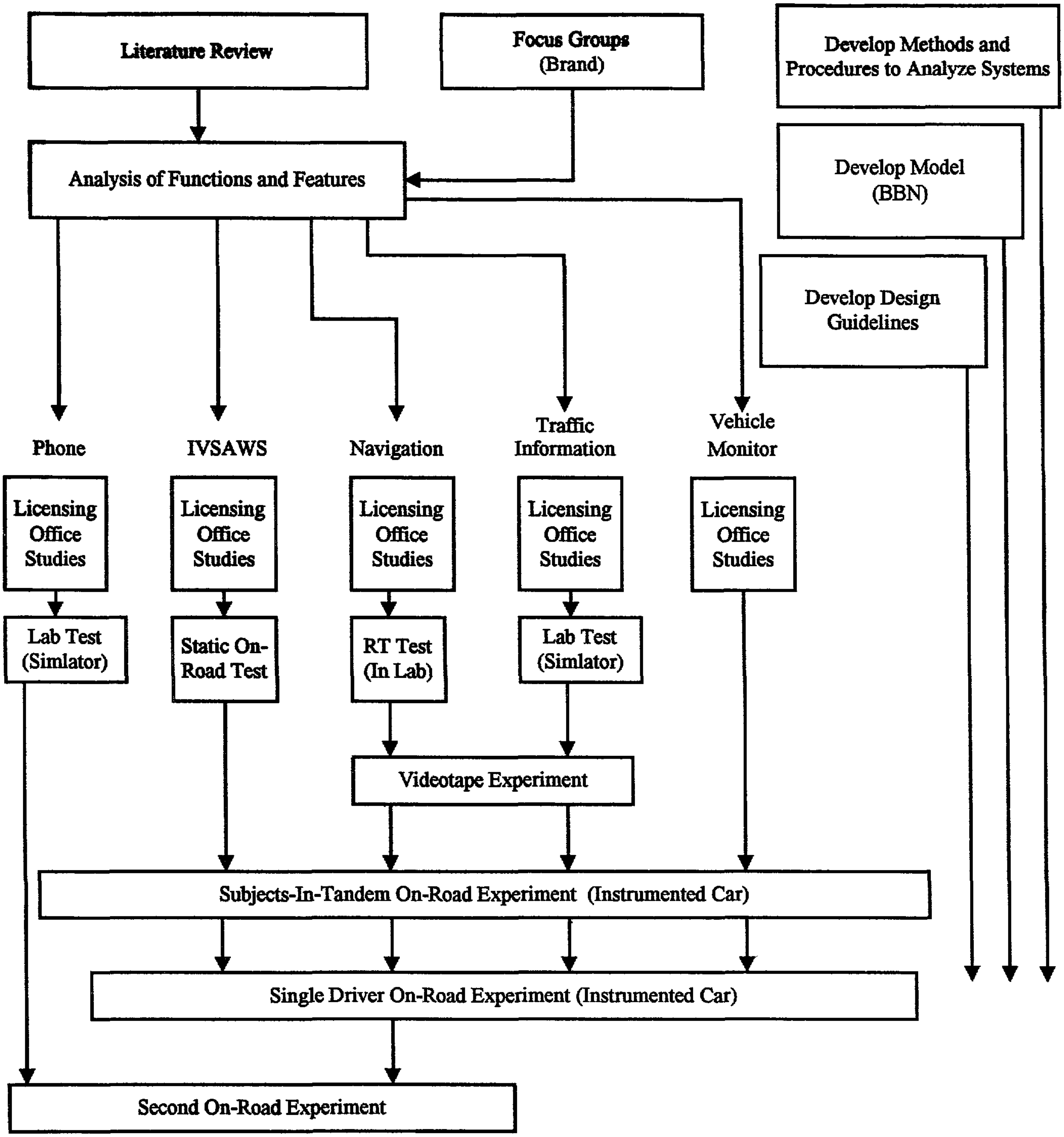


Figure 1. Project overview.

system. (1) The vehicle was instrumented to record measures including lane position to the nearest 0.031 m (0.1 ft), speed to the nearest 0.161 km/h (0.1 mi/h), steering wheel angle, throttle position, and brake status (on/off). Output from the driver information system appeared on one of two 127 mm (5-in) color LCD displays mounted on top of the center console. Route guidance information could appear on the left LCD, on a small head-up display, or by voice through a speaker placed between the driver and passenger.

The data generated from this project were summarized in a set of design guidelines for driver interfaces.(2) Topics covered in this document include general design principles and general design guidelines for manual controls, voice controls, visual displays, and auditory displays. Specific guidelines for the five systems were also examined in detail. Explanations and examples are provided for most of the guidelines in this document.

The general design principles address issues such as consistency, driver expectations, appropriate sequencing of information, driver memory demands, appropriate metaphors, and user control. The specific guidelines for route guidance displays include auditory guidance (e.g., content, timing, use of landmarks, alerts, recall), maps (e.g., detail, orientation, elements of color), and guidance arrows (e.g., design, placement). Traffic information guidelines consider information elements of interest, desired display formats, the use of color coding, the display of lane blockage, and methods for retrieving traffic information. For car telephones, issues covered included dialing modes, labeling of buttons, and display design.

Concurrent with the experimental work, methods for testing and evaluating driver interfaces, design guidelines, and a model to predict driver performance while using in-vehicle information systems were developed.

Technical reports were generated to describe each of the experiments conducted. Appendix A shows the technical reports associated with each experiment shown in figure 1. Appendix B provides a summary of the salient features of each experiment.

LITERATURE REVIEW

The first phase of this project consisted of a set of literature reviews. These reviews were designed to provide a basis for further work and to inform the selection of features and functions for in-vehicle displays. The initial review focussed primarily on U.S. human factors research on route guidance aspects of navigation.(3) A later report reviewed the European and Japanese research on this same topic, as well as methods and measures that might be used to evaluate driver information systems.(5)

Critical research identified by these reviews includes the Cross and McGrath work on maps, FHWA-funded research on the Experimental Route Guidance Systems (ERGS), the Wierwille, et. al. studies on the Etak Navigator, the Gatling studies on memory for navigation instructions, the Davis studies on in-vehicle auditory guidance (Back Seat Driver), and the Streeter and Walker study comparing auditory and visual systems.

A review of methods and measures used in studies of driver performance and behavior was also conducted. This review summarized previous reviews by DRIVE task forces, Zaidel, and Robertson and Southall.(5,6,7) All three reports indicate that a wide variety of measures are available for studying driver performance.

Key points that emerge from these reports are that there is insufficient data to set objective safety performance standards and that on-road testing is the preferred testing method.(6,7) Measures that appear most promising for use in future studies of driver information systems include the standard deviation of lane position, mean speed, standard deviation of speed, and the mean frequency of driver eye fixations to other locations. In some cases, laboratory performance measures (e.g., errors) were shown to be useful measures. Also of interest are time-to-collision (TTC) and time-to-line crossing (TLC), though hardware for readily measuring those factors in real time is not available. Of lesser utility are workload estimates [e.g., the Subjective Workload Assessment Technique (SWAT) or Task Loading Index (TLX)], especially secondary task measures and physiological measures. In cases where usability measures are of interest, measures specific to the application (e.g., the number of wrong turns made in using a navigation system) should be collected.

FOCUS GROUPS

In parallel with the literature review, focus groups were conducted to establish a baseline of driver preferences for information systems, both current and proposed, and to assist in the selection of systems to be studied. Forty-six drivers of late model cars equipped with advanced information systems (trip computers, touch screen interfaces, head-up displays (HUD, etc.), participated in four focus groups, which were conducted in Los Angeles and New York.

When queried about desirable features, the focus group participants expressed greatest interest in systems that would warn them of potential vehicle malfunctions (such as brake system degradation) or road hazards. Drivers were particularly concerned about malfunctions that would cause them to be stranded on the highway.

Drivers also complained about diversion of their attention from driving while operating entertainment systems and car telephones. One participant reported being involved in an accident while using these systems. Drivers identified needs such as the integration of car telephones into the dashboard and provision for hands-free dialing.

Finally, interest was expressed in navigation systems. One driver reported being in an accident while driving and reading a map. The Los Angeles focus group expressed a greater interest than the New York groups in all of the advanced features.

However, results from the focus groups must be treated cautiously. Drivers had limited exposure to the advanced systems, so it is difficult to use the data as a basis for determining driver preferences for individual information systems.

SELECTION OF FUNCTIONS AND FEATURES TO INVESTIGATE

The next phase of the project involved identifying functions and features that might appear in future cars and establishing research and implementation priorities for each function or feature. (19,20)

Functions (e.g., navigation or vehicle monitoring) and features (e.g., route guidance, engine monitoring) that could be implemented in future cars were identified from the examining the technical literature and concept cars, and from discussions with industrial liaisons and in-house experts. Options for grouping these features into systems were generated, as well as implications for user interface elements. Nine functions were identified: communication, entertainment, in-car signing, road hazard warning systems, motorist services, navigation, office functions, traffic information, and vehicle monitoring. Forty-four specific features that might be associated with those functions were also identified (see table 1).

Table 1. Ranked list of functions and features.

DIMENSION AND WEIGHTS						
		Accidents	Traffic Operations	Driver		Total Score
				Wants	Needs	
		0.593	0.394	0.005	0.008	1.000
	Functions and Features					
1	**IVSAWS crash site**	**0.80**	**0.83**	**0.0**	**0.63**	**0.81**
2	**IC traffic control**	**1.00**	**0.33**	**0.0**	**0.50**	**0.73**
3	**TI congestion**	**0.54**	**1.00**	**1.0**	**0.84**	**0.73**
4	**IVSAWS compound hazards**	**0.95**	**0.00**	**0.0**	**0.37**	**0.57**
5	**TI construction**	**0.54**	**0.50**	**0.5**	**0.84**	**0.53**
6	**VM path control (tire, brake)**	**0.65**	**0.33**	**0.5**	**1.00**	**0.53**
7	**IVSAWS construction**	**0.54**	**0.50**	**0.0**	**0.50**	**0.52**
8	**IVSAWS railroad crossing**	**0.71**	**0.00**	**0.0**	**0.66**	**0.43**
9	**TI traffic rules**	**0.54**	**0.17**	**0.0**	**0.50**	**0.39**
10	TI freeway management	0.26	0.50	0.5	0.63	0.36
11	IVSAWS school bus	0.26	0.33	0.0	0.50	0.29
12	TI weather	0.46	0.00	0.5	0.79	0.28
13	IVSAWS emergency vehicle	0.26	0.17	0.0	0.50	0.22
14	N/RG trip planning	0.00	0.50	0.5	0.79	0.21
15	IC street signs	0.00	0.50	0.0	0.37	0.20

Table 1. Ranked list of functions and features (continued).

	DIMENSION AND WEIGHTS					
		Accidents	Traffic Operations	Driver		Total Score
				Wants	Needs	
		0.593	0.394	0.005	0.008	1.000
	Functions and Features					
16	IVSAWS traffic supp. control	0.26	0.00	0.0	0.50	0.16
17	ENTR radio	-0.09	0.50	0.0	1.00	0.15
18	VM engine/power	0.00	0.33	0.5	1.00	0.14
19	TI parking	0.00	0.33	0.0	0.84	0.14
20	**VM climate**	**0.00**	**0.00**	**0.5**	**0.50**	**0.01**
21	**VM drivetrain**	**0.00**	**0.00**	**0.5**	**0.50**	**0.01**
22	**VM ingress/egress (door)**	**0.00**	**0.00**	**0.5**	**0.37**	**0.01**
23	**IC destination assistance**	**0.00**	**0.00**	**0.0**	**0.53**	**0.00**
24	**N/RG trip computer**	**0.00**	**0.00**	**0.0**	**0.50**	**0.00**
25	**TI vehicle access**	**0.00**	**0.00**	**0.0**	**0.50**	**0.00**
26	**VM safety systems**	**0.00**	**0.00**	**0.5**	**0.00**	**0.00**
27	**MS transportation**	**-0.26**	**0.33**	**0.0**	**0.63**	**-0.02**
28	**N/RG guidance**	**-0.39**	**0.33**	**0.5**	**0.79**	**-0.09**
29	**COM CB radio**	**-0.39**	**0.33**	**0.0**	**0.50**	**-0.10**
30	**ENTR cassette/CD player**	**-0.26**	**0.00**	**0.0**	**1.00**	**-0.14**
31	MS banking	-0.26	0.00	0.0	0.21	-0.15
32	OFF dictation	-0.26	0.00	0.0	0.13	-0.15
33	MS customs information	-0.26	0.00	0.0	0.00	0.15
34	MS destination assistance	-0.26	-0.17	0.0	0.74	-0.21
35	MS yellow pages	-0.26	-0.33	-0.5	0.21	-0.28
36	OFF electronic calendar	-0.65	0.00	0.0	0.50	-0.38
37	OFF electronic directory	-0.65	0.00	0.0	0.50	-0.38
38	OFF calculator	-0.65	0.00	0.0	0.34	-0.38
39	N/RG orientation	-0.65	-0.17	0.5	1.00	-0.44
40	COM car telephone	-0.65	-0.17	0.5	0.63	-0.44
41	COM radar detector	-0.58	-0.33	0.0	0.63	-0.47
42	ENTR television	-0.51	-0.50	0.0	0.00	-0.50
43	OFF computing	-0.90	-0.33	0.0	0.13	-0.67
44	OFF fax	-0.90	-0.33	0.0	0.13	-0.67

Note: IVSAWS = In-Vehicle Safety Advisory Warning System
IC = In-Car Signing
TI = Traffic Information
VM = Vehicle Monitoring
N/RG = Navigation/Route Guidance
ENTR = Entertainment
MS = Motorist Services
COMM = Communications
OFF = Office

The criticality of these features in relation to improved driving performance was scored on three dimensions: potential for the reduction of accidents, potential for benefits to traffic operations, and potential driver needs and wants. A research team rated each feature on each of the three dimensions (using a five-point scale that went from highly beneficial to highly detrimental). Although this technique relies on a small number of subjects, the overall ratings were found to be relatively insensitive to manipulations in the values of the individual ratings.

The likely impact of each feature on accident reduction was calculated by examining causes of accidents and then rating the extent to which a given feature might help in reducing each of these causes. Specifically, accident causes were divided into three categories based on the Indiana Tri-Level Study: driver error (improper lookout, excessive speed inattention, improper evasive action, and alcohol impairment), environmental conditions (e.g., view obstruction, slick roads), and vehicular problem (e.g., faulty tires, brakes). The accident causes were then weighted based on their relative frequency.

Likely benefits to traffic operations were calculated based on ability to: choose a mode of transportation (e.g., car pool or public transportation vs. private transport), choose a route (e.g., corridors vs. surface streets), or aid traffic flow (e.g., through spreading the rush hour peak or reducing accident clean-up time). The potential benefits for traffic operations score was the average of all the individual aspects.

Ratings of driver needs and wants were based on the focus group work and from hypothetical scenarios of representative driving based on the Nationwide Personal Transportation Study.(4) The driving scenarios were weighted based on the frequency of different trip categories.

Finally, the three dimensions were weighted based on the societal costs of accidents, the dollars saved from improved traffic operations, and likely sales of ITS units to create a total. score. The ratings for each feature on each dimension, along with this total score, are shown in table 1. As can be seen from the table, the features that were most likely to be beneficial included road hazard warnings of accidents, in-car signing for traffic control, road hazard warnings of compound hazards (e.g, icy curves), and traffic information about construction. Features thought to be the least beneficial were office computing and fax functions, and in-car television (for entertainment of the driver). In terms of functions, road hazard warning, traffic information, and navigation systems offered the greatest benefits. This approach provided a reasonable process for the selection of functions and features for further research exploration.

IN-VEHICLE SAFETY ADVISORY AND WARNING SYSTEMS

The In-Vehicle Safety Advisory and Warning System (IVSAWS) will warn drivers of immediate road hazards, road conditions, and situations affecting the road ahead of the driver. The need for warning messages was first identified from the literature.@) A review of hypothetical trips suggested that, if the complete set of warnings identified in the literature was implemented, warnings might be presented quite often to drivers. This fact, coupled with the belief that initial implementations of such a system would have a moderate false alarm rate, led to a concern that an auditory interface would be annoying. For example, public reactions to previous and existing in-car auditory warnings (e.g., "Your door is ajar.") have been poor. Thus, research within this project focussed on the development and evaluation of visual warnings for hazards.

The first experiment evaluated candidate visual warnings for 28 specific road hazards.(9) (See table 2 for a listing of the hazards examined.) In this experiment, 10 of the contractor's employees, licensed drivers who were not involved with the project or with human factors research, selected candidate warnings developed for these road hazards. Next, 75 drivers at a licensing office rank-ordered the candidate warnings for each of the hazards within one of the categories of warnings (in-car signing, atypical vehicles, or emergency vehicles) from best to worst. Figure 2 shows the candidate warnings for one of the 28 hazards, along with the textual description of the hazard presented to the participants. In many cases, one specific candidate warning sign was preferred over the others. In general, text messages were slightly preferred over symbols. Symbolic signs which were ranked highly did not always conform to those in the standard set from the Manual on Uniform Traffic Control Devices (MUTCD).

In another experiment on warning signs, 20 drivers were shown warnings and location symbols while either parked or driving a test route. There were 10 hazard symbol designs (see figure 3) and 4 formats for location graphics: text, arrows, overview, or inside-out (see figure 4). The test materials were drawn on a computer and the output was pasted onto 101.6 by 152.4 mm (4 by 6-in) cards and supported by a mount taped to the instrument panel. Each driver was shown one or more warning symbols and asked to a) state the meaning of the symbol alone while driving; b) state the meaning of the symbol with the location symbol while parked; or c) identify the hazard on the roadway as indicated by the identifier symbol and location symbol while parked on the right shoulder near an intersection.

Table 2. IVSAWS warnings examined.

Warning Category	Warning
In-car signing	Road constructron ahead
	Road construction speed limit
	Accident ahead
	Sharp curve with speed limit
	Train approaching
	Traffic signal out of order
	New traffic signal
	New stop sign
	Right lane merges
	Both lanes shift
	Hazard ahead in opposite lane
	Hazard 1 mile ahead
Atypical vehicle	School bus loading/unloading
	Slow moving vehicle
	Farm vehicle
	Wide load
	Mail truck
	Trash truck
	Snow plow
	Utility vehicle
	Tow truck
Emergency vehicles	Stopped ambulance
	Moving ambulance
	Stopped fire truck
	Moving fire truck
	Stopped police car
	Moving police car
	Police car in chase

The data suggested that although participants understood the warnings presented, they sometimes did not mention whether the hazard was moving or stationary when they described the hazard, an important element. Participants were best able to identify the location of the hazard when the information was presented as text. For warnings of moving hazards (e.g., an ambulance), drivers were often confused about whether the location cue indicated where the hazard was currently located or the direction in which the hazardous vehicle was heading.

These results provided a preliminary indication as to which warnings and location cues drivers understand and prefer. However, these warnings should be tested with a larger sample of drivers.

1. An ambulance is approaching you at high speed with its flashers on.

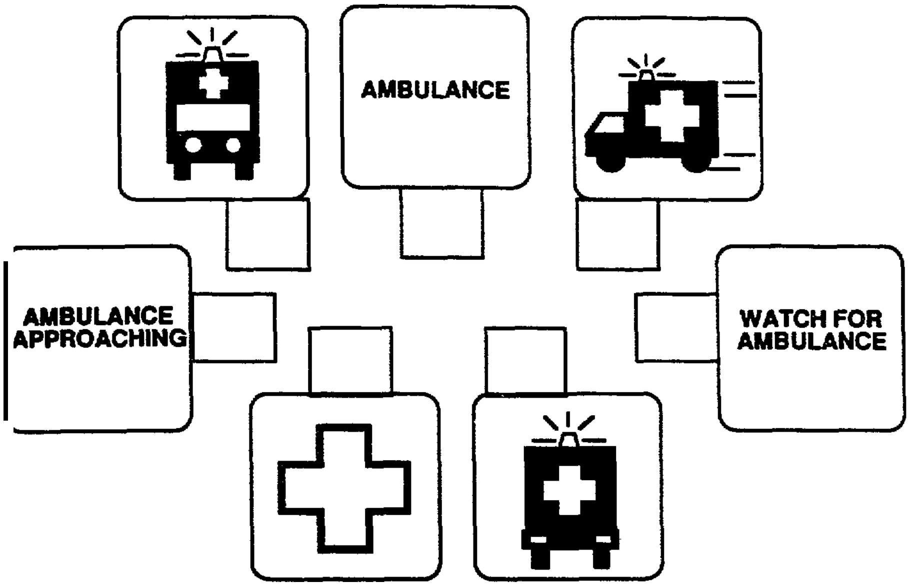


Figure 2. Example ranking form questions.

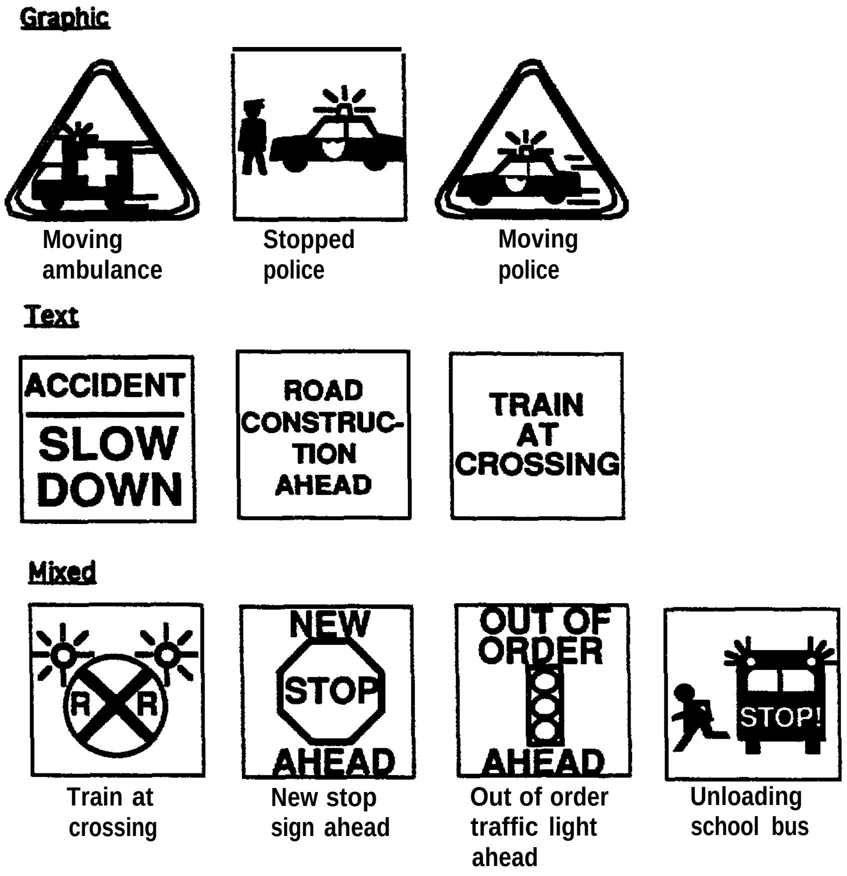
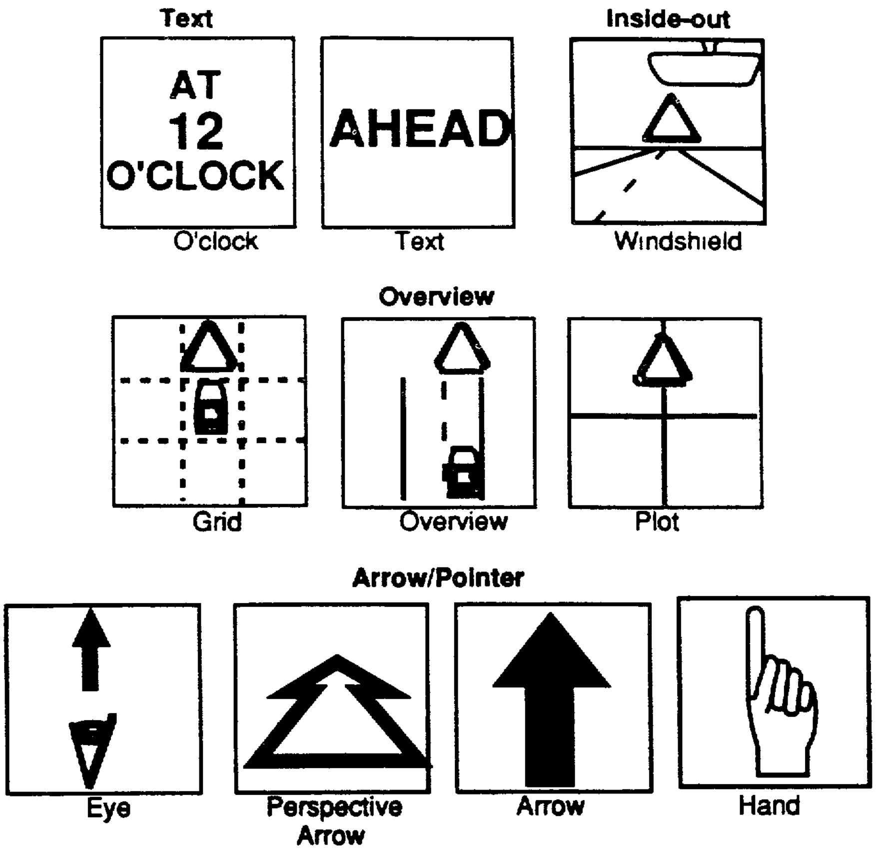


Figure 3. The 10 IVSAWS hazard warning symbols.



Note: All symbols indicate a hazard straight ahead.

Figure 4. The hazard location symbols grouped by format.

ROUTE GUIDANCE

Route guidance refers to the provision of routing information to drivers through an in-vehicle display while driving, typically through turn-by-turn and/or directional information instructions. The literature reviews identified several main findings relevant to route guidance systems.

1. The information desired by drivers depends upon whether the route is being selected or followed. Work on the Experimental Route Guidance System (ERGS) suggests that both the next turn and what to do afterwards should be shown. This work also suggests that there are many circumstances where "continue" instructions (e.g., "do not turn here") are needed.

2. Detail on route-guidance displays should be minimized, and for many situations, simple or enhanced arrow displays may lead to the best driver performance.

However, drivers use landmarks to navigate, and certainly underpasses, bridges, traffic signals, and stop signs should be shown on navigation displays.

3. Verbiage in auditory guidance systems should be minimized. Data from an earlier study (the Back Seat Driver Project) suggested that people preferred less verbose route guidance information.

4. Visual and auditory route guidance systems have been found to have similar levels of usability; further, using a combination of visual and auditory display does not significantly improve performance over the use of either display alone.

5. Navigation systems may pose special difficulties for older drivers, although little data is available on this issue.

6. There is little theoretical literature available; the literature that is available does not provide data on complex intersections and successive maneuvers, on problems encountered by untrained drivers, or on the role of landmarks in route guidance.

Based on this background, a number of alternative formats for route guidance were developed and evaluated.(10,20) In the initial design reviews, selected navigation displays were shown to a small number of the contractor's employees not associated with this research project. They were told the display would appear in cars of the future and were asked to explain what they felt it was showing. The following guidelines emerged from these reviews:

1. Give State initials (e.g., MI) in conjunction with regions to avoid confusing regions with street names.

2. Identify street names with abbreviations (e.g., St., Ave.) to avoid confusing similar street names with each other (e.g., Peachtree Boulevard with Peachtree Road).

3. For upcoming streets or towns, include the word "ahead."

Two experiments were then conducted to examine driver performance and preferences for route guidance display formats. In the first experiment, 60 drivers at a local driver licensing office were shown differing views of nine types of intersections. These views differed in the intersection vantage point: plan, perspective, or aerial. (See figure 5 for examples of two intersections from each of the viewpoints.) Drivers were asked to explain what the displays meant. There were few errors overall, and no differences in the number of errors as a function of viewpoint. However, there were significant differences in driver preferences for viewpoint. The plan view was most preferred, followed by the aerial and perspective viewpoints.

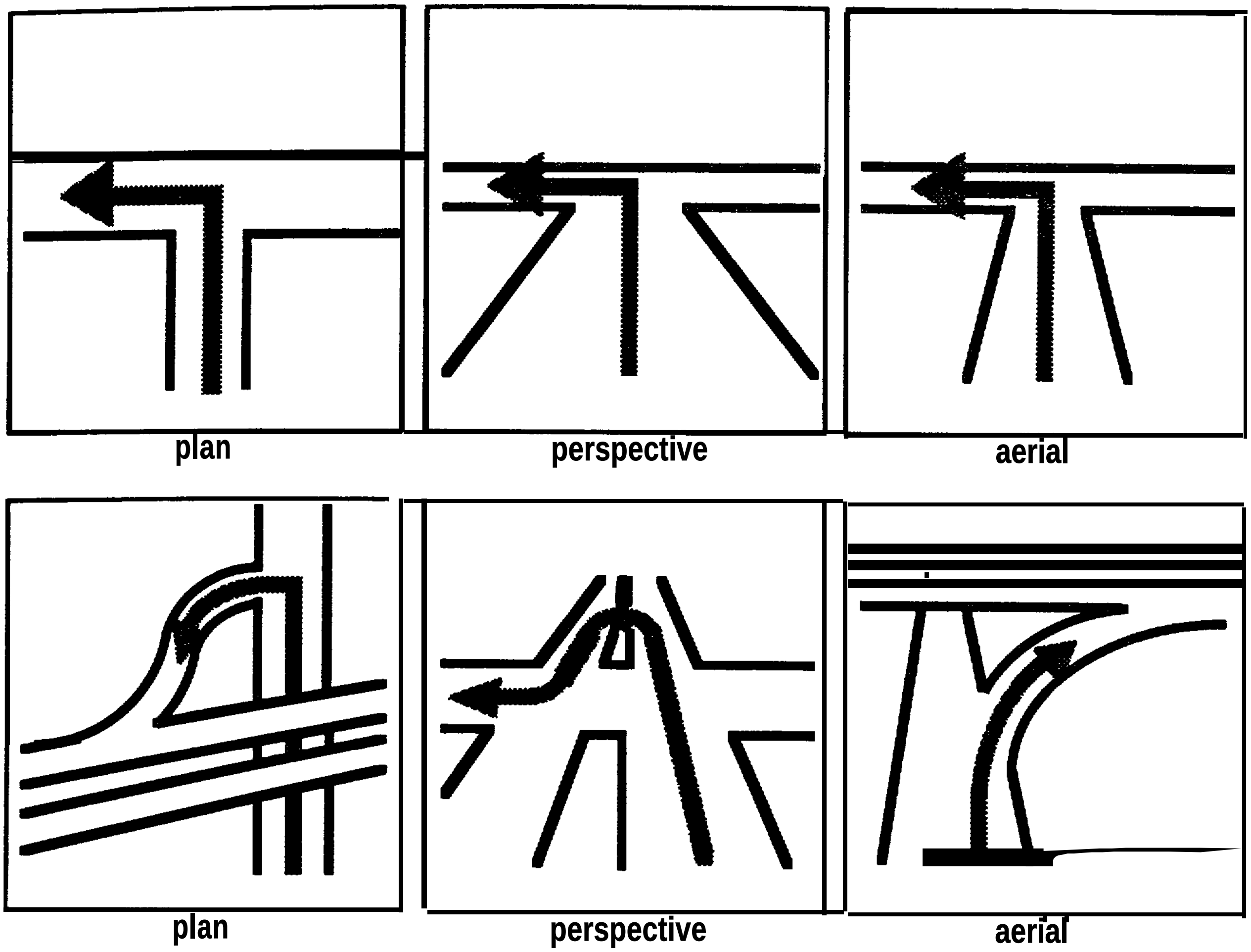


Figure 5. Example graphics from the first navigation experiment.

A subsequent study was conducted to determine the reliability of these results. This study involved a higher fidelity simulation of route guidance decisions. In this laboratory experiment, 12 drivers (6 under the age of 30, 6 over the age of 65) seated in a vehicle mockup were shown slides of daytime scenes of residential intersections photographed from the driver's viewpoint. They were shown on an 2.44-m by 3.66-m (S-ft by 12-ft) screen approximately 6.1 m (20 ft) from the driver. Simultaneously, drivers saw slides of a navigation display (see figures 6, 7, and 8 for same displays). The navigation displays provided either plan, perspective, or aerial views of the intersections, and the intersections were presented either as solid objects or as outlines. Drivers indicated, by pressing "same" or "different" buttons, whether the two images indicated the same type of intersection (cross, Y, T, T-right, T-left). There were three examples of each intersection type. Navigation displays appeared either in the center of the console or in a head-up location. The response times for head-up displays were shorter than those for console-mounted displays, and those for aerial views were slightly shorter than for plan views and much better than for perspective views. Further, responses to the intersections shown as solid objects were shorter than to those shown as outlines. Error, eye fixation, and preference data supported the latency results.

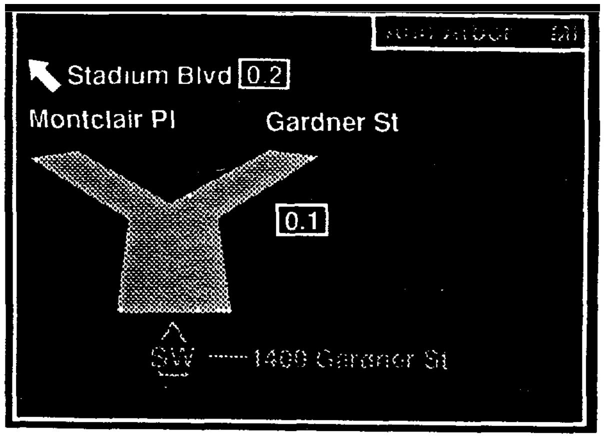


Figure 6. Aerial view of Y intersection.

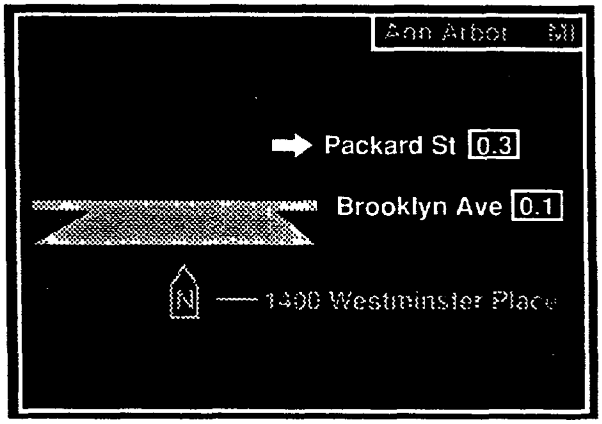


Figure 7. Perspective view of T-intersection.

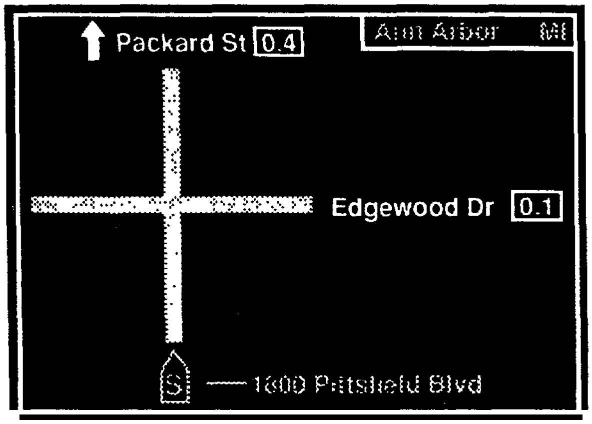


Figure 8. Plan view of cross intersection.

From a methodological perspective, this protocol captured the decision-making task of real drivers. The scenes were quite realistic and the method was sensitive to differences that were expected to be small (e.g., solid vs. outline renderings of the intersections). However, this method was much more expensive and time consuming than the survey approach used in the first experiment. The method is appropriate for examining design alternatives.

An experiment was then conducted to determine whether useful data could be collected from subjects viewing a videotape of a trip while seated in a mockup of a car. Due to technological difficulties in running this experiment, little usable data were collected in this experiment; however, it was important in that it provided us with valuable information on what not to do in future studies.

Three on-the-road experiments were then conducted using an instrumented 1991 Honda Accord station wagon.(1,21,22) These experiments were designed to examine route guidance interfaces. The first experiment was designed to discover flaws in the electronic interface or test protocol that were so serious that the experiment could not continue. In this study, pairs of drivers drove to an initial destination using written directions. At various times along the route, the driver was prompted to operate various controls and read displays in the car. Upon reaching the destination, the driver and passenger worked together to reach another destination, using a simulated electronic route guidance system. Subjects were given no instruction on the use of the systems, but were told that the system would give them information to get to a destination. Subsequently, they were directed to return to their starting point using a highlighted paper map.

The study used interface designs which were based on the laboratory research described previously (see figure 9 for sample screens). These interfaces were presented in one of three formats: head-up display, instrument panel, or auditory. Information relating to the other experimental interfaces (traffic information, IVSAWS, vehicle monitoring) was presented on an instrument panel display. (See figures 10 through 12 for sample screens.) One younger couple and one older couple used each version of the navigation interfaces for a total of six pairs of drivers. Participants were given no instruction on the use of the driver interfaces. They were encouraged to “think aloud” throughout the experiment, and all segments were videotaped.

The main test route was a 19-turn segment that took about 35 min to drive. It consisted of city streets, business districts, and expressways. The route included a variety of intersection types (e.g., crosses, T’s, three intersecting roads, Y’s, jug-handle turn, signed and not signed, signalized). The route was similar to that used in the videotape experiment previously conducted.

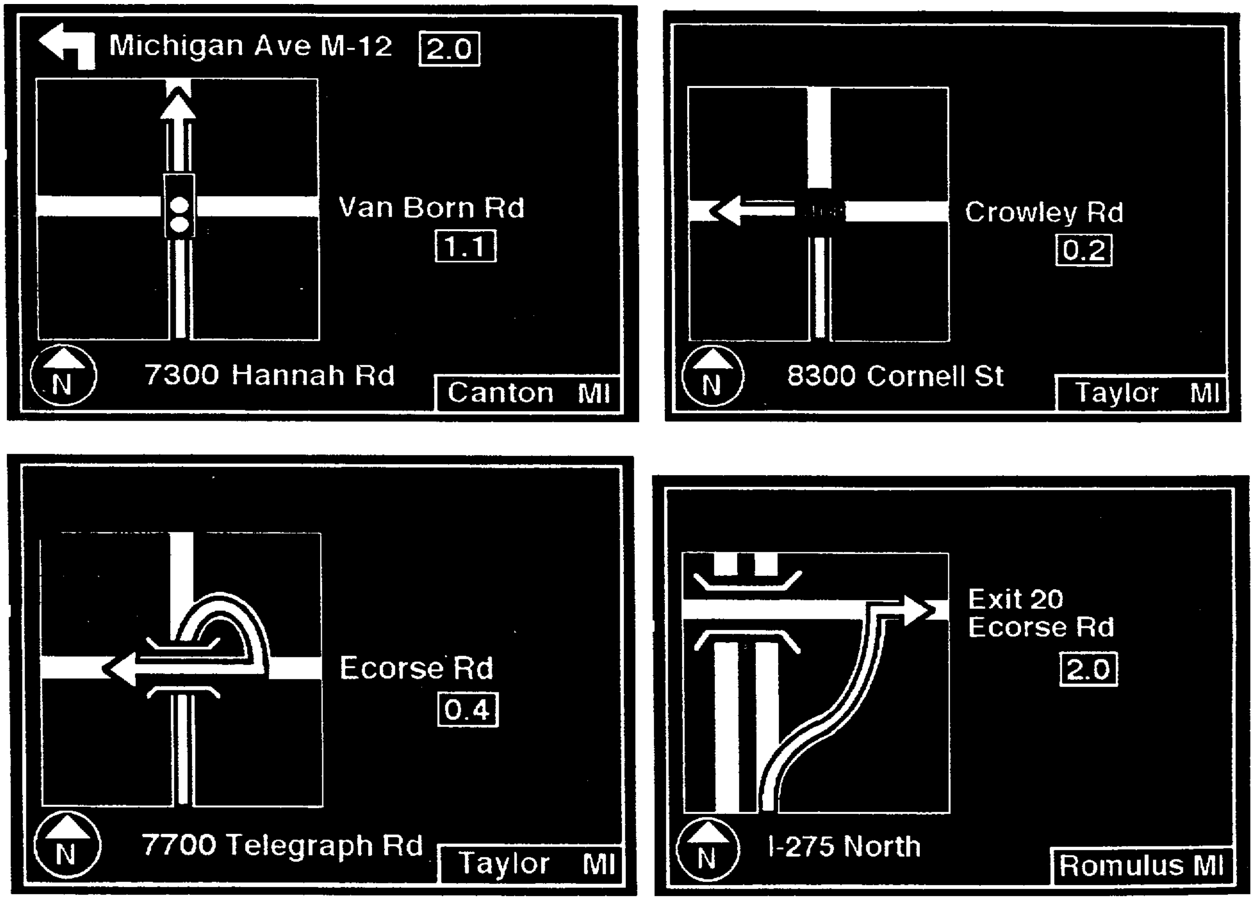
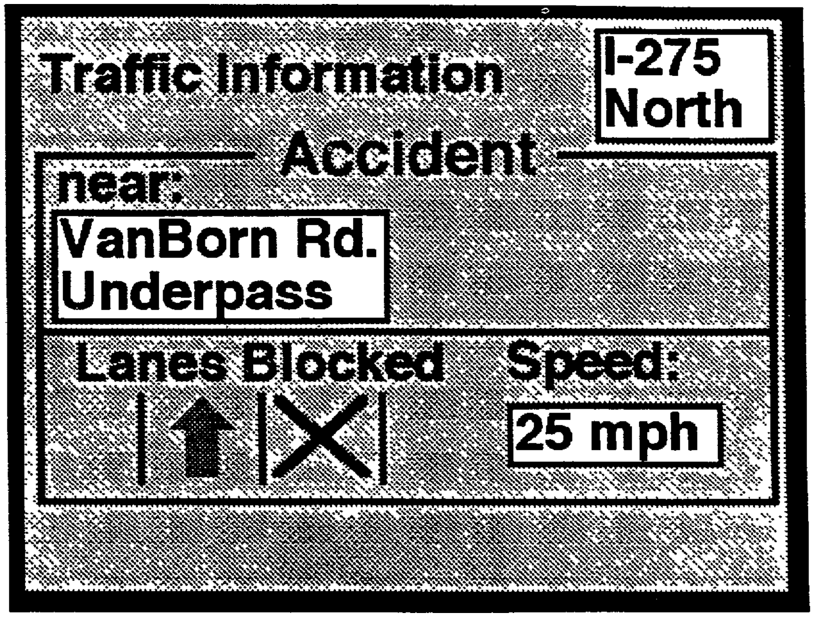


Figure 9. Examples of route guidance screens.


Traffic Information

I-275 North

Accident

near:

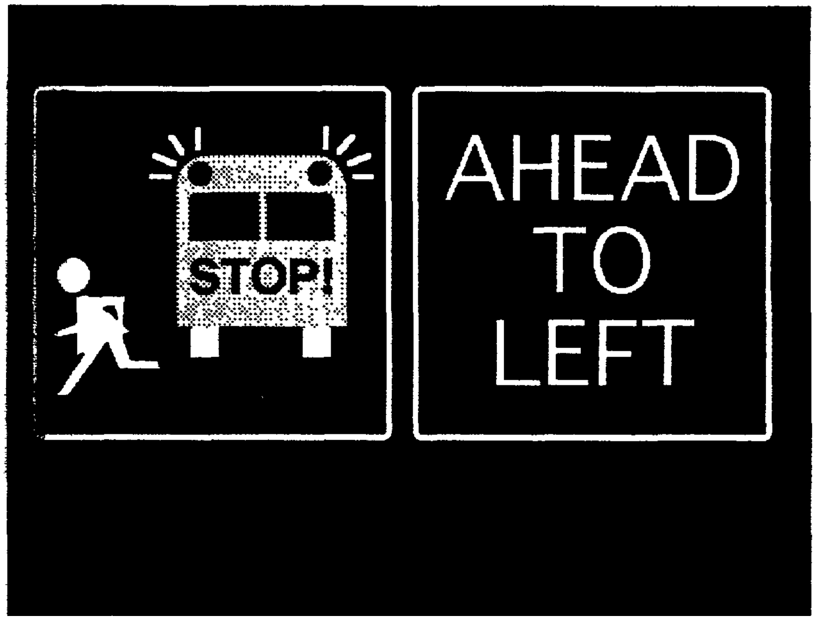
VanBorn Rd. Underpass

Lanes Blocked

Speed:

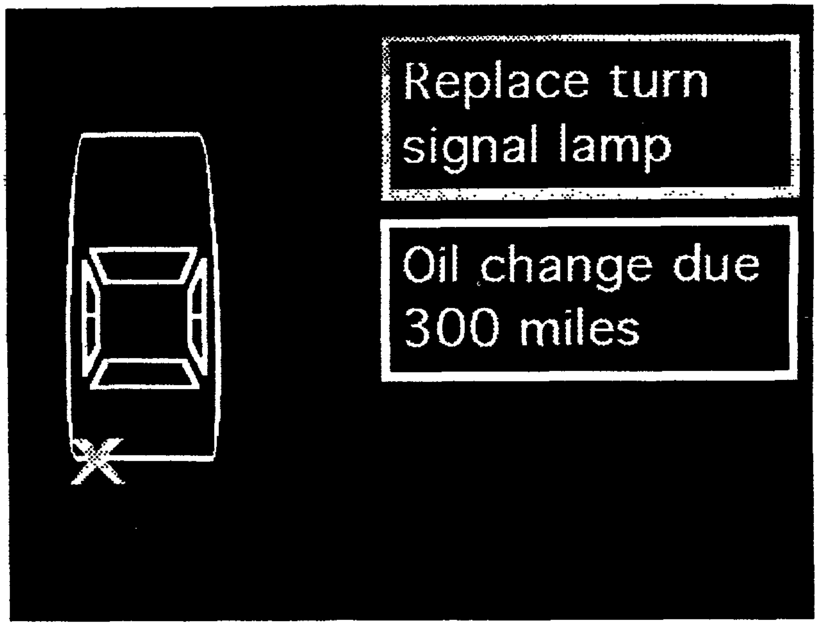
25 mph

Figure 10. Example of a traffic information screen.



AHEAD
TO
LEFT

Figure 11. Example of a two-panelIVSAWS warning.


Replace turn
signal lamp

Oil change due
300 miles

Figure 12. Example of a vehicle monitoring screen.

The experiment identified few problems with the route guidance displays. Drivers were able to follow the guidance given by the navigation system without help from the experimenter. A minor problem was noted with the auditory navigation interfaces. Drivers had a tendency to follow directive commands (e.g., "turn right") without checking traffic conditions (such as disobeying a traffic signal or turning prematurely onto the wrong street). This resulted in the addition of the word "approaching" to the navigation messages. In terms of preferences, drivers rated the three formats for presentation of the navigation information (auditory, panel, or head-up) similarly. However, route guidance tasks were rated as more difficult than more common tasks, such as adjusting an air conditioner fan.

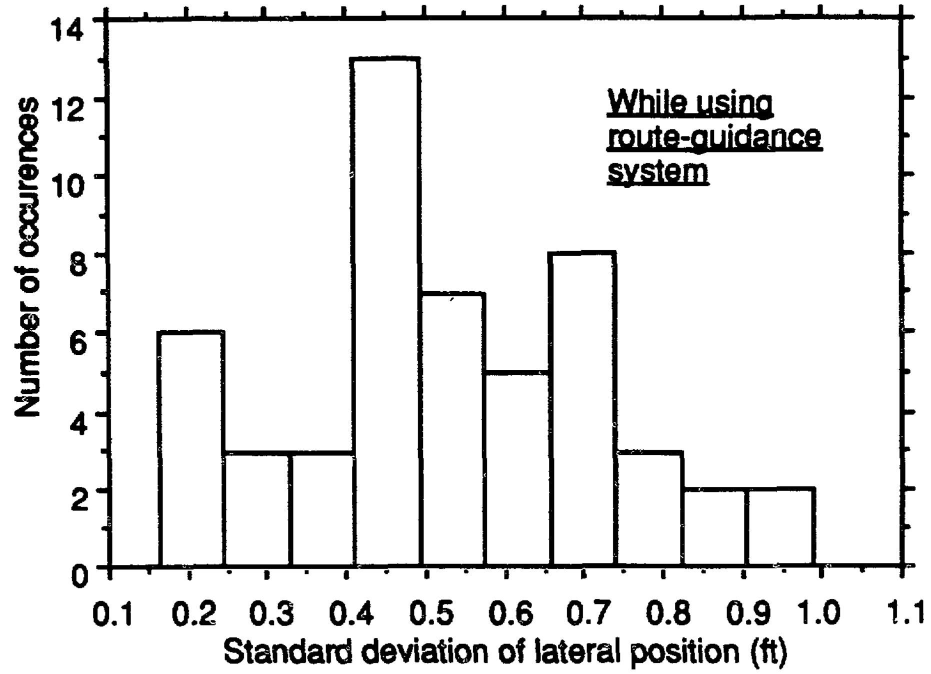
In a second experiment, individual drivers used the route guidance system to drive a preprogrammed route. This study was, designed to expand the fmdings from the previous experiments which examined the effect of alternate driver interfaces for route guidance. A total of 43 drivers were tested, but data from only 30 drivers were analyzable (problems with weather, software, and equipment failure resulted in the loss of data). Each driver used one version of the route guidance system (auditory instrument, panel display, or head-up display) in addition to the traffic information, vehicle monitoring, and IVSAWS displays.

Navigational errors were recorded and analyzed to determine user performance using each type of route guidance display. Turn problems were classified as either “near misses” (where the driver expressed confusion or hesitated) and “execution errors” (where drivers missed a turn or made an incorrect turn). Overall, there were 11 errors for the auditory systems (6 near misses, 5 execution errors), 8 for the panel displays (4 near misses, 4 execution errors), and 6 for the head-up display (5 near misses, 1 execution error). This corresponds to an error rate of 4.4 percent for all types of mistakes and 1.8 percent for execution errors.

Finally, use of the navigation system seemed to change driving behavior very little from the baseline condition (straight roads at steady speeds). Measures included mean and standard deviation of lateral position (see figure 13), mean and standard deviation of speed (figure 14), mean and standard deviation of throttle position (figure 15), and standard deviation of steering wheel angle (figure 16). Of these, the standard deviation of steering wheel angle seemed to be among the most sensitive to attentional demands, showing significant differences between interface types (with auditory best, followed by the head-up and panel displays). Overall, the data suggest that drivers had few difficulties using any of the three implementations of the route guidance system.

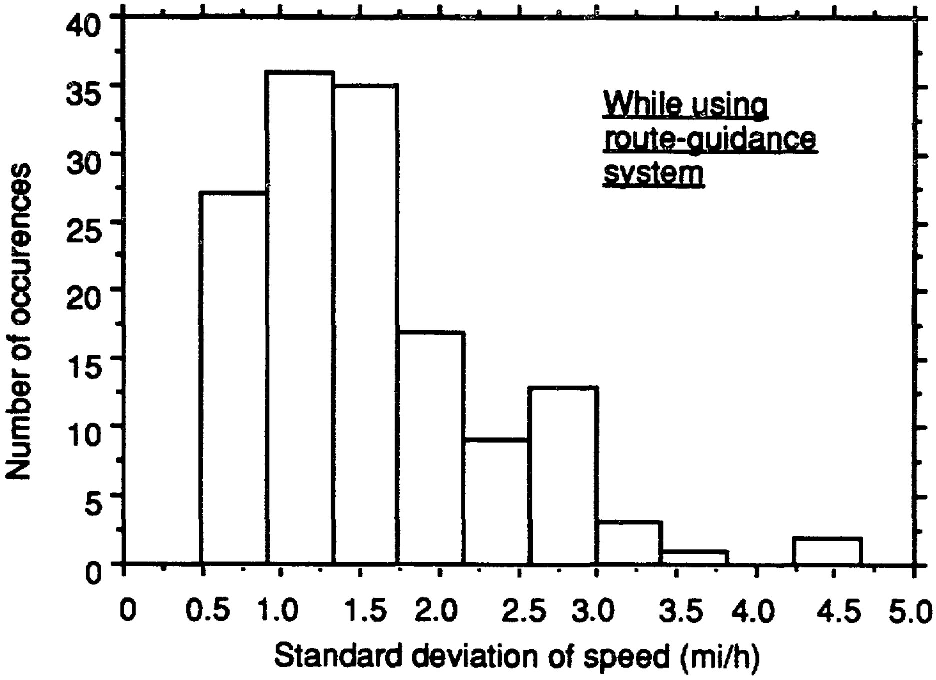
In a third experiment with eight drivers, the navigation displays were modified to delete the countdown bars (to indicate the time to the next decision point) and simplify the interface. The countdown bars were redundant as a mileage counter indicated the distance to the next decision point. Although this study presented displays only on the instrument panel, drivers again encountered few problems in using the in-vehicle systems, and the error rate was 5.3 percent, a figure quite close to the rate from the previous experiment.

In terms of baseline driving performance (straight roads at steady speeds), lateral standard deviations were typically 0.153 m (0.5 ft) for the baseline condition (driving on a straight road with no added tasks), though the value decreased as speed increased [O. 174 m for 80.5 km/h (0.57 ft for 50 mi/h), 0.168 m for 88.55 km/h (0.55 ft for 55 mi/h), 0.131 m for 104.65 km/h (0.43 ft for 65 mi/h), as shown in figure 17].



1 ft = 0.305 m

Figure 13. Standard deviation of lateral position.



1 mi/h = 1.61 km/h

Figure 14. Standard deviation of speed.

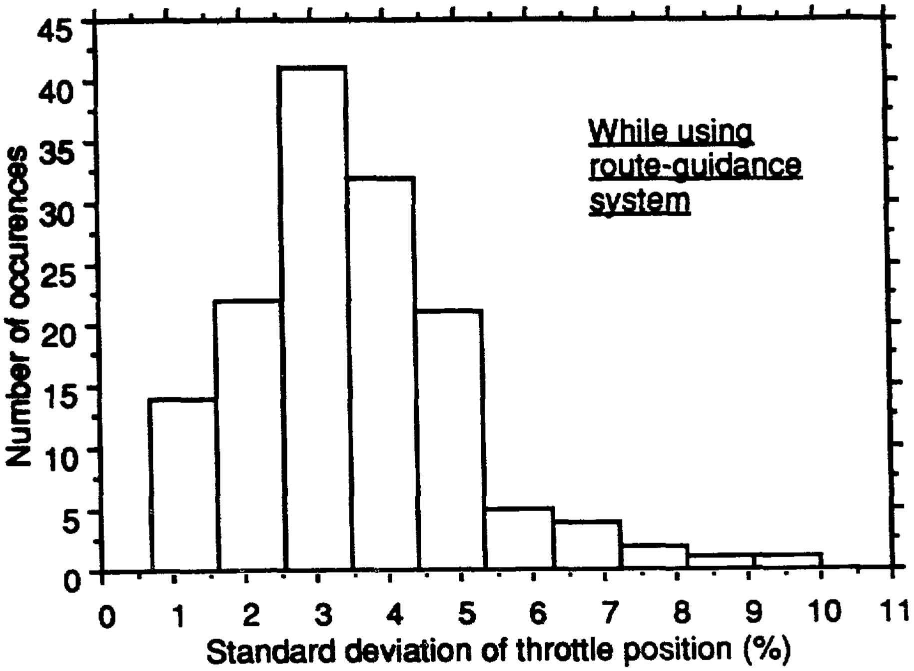


Figure 15. Standard deviation of throttle position.

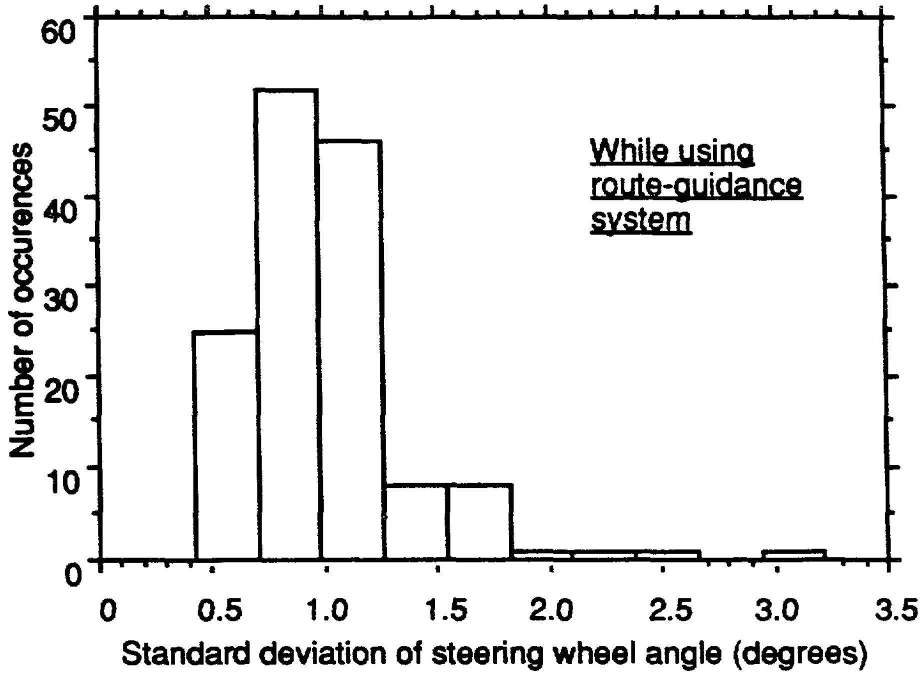
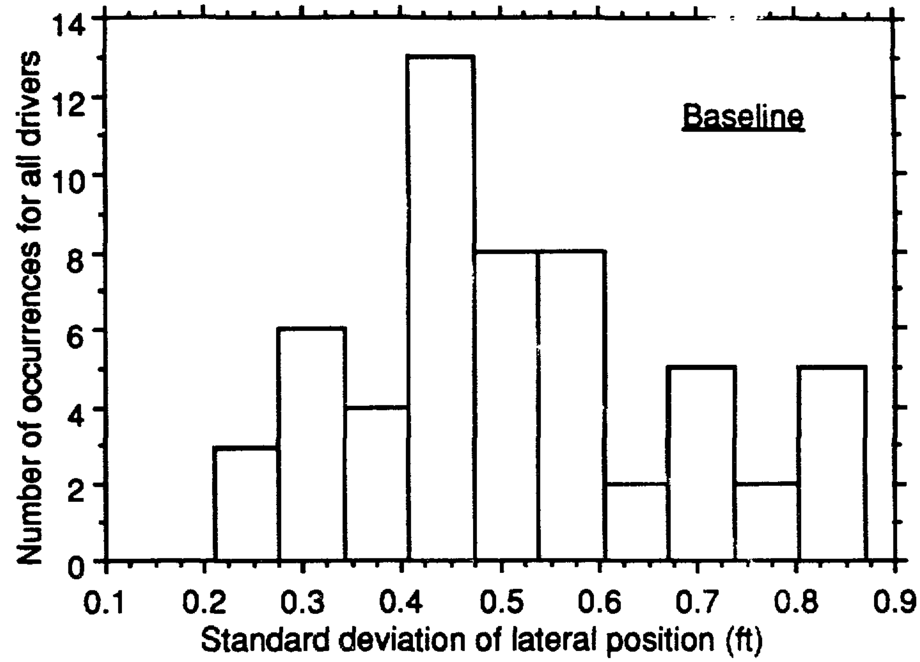


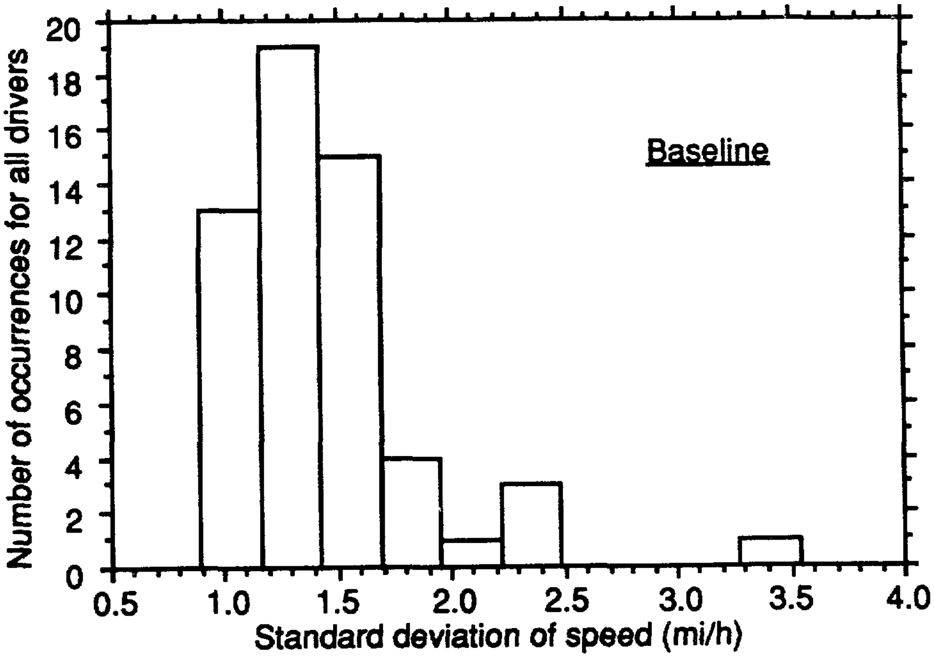
Figure 16. Standard deviation of steering wheel angle.



1 ft = 0.305 m

Figure 17. Distribution of lateral standard deviations for the baseline condition.

Figure 18 shows the standard deviation of speeds for the baseline conditions [typically between 1.61 and 2.42 km/h (1.0 and 1.5 miles/hr)].



1 mi/h = 1.61 km/h

Figure 18. Distribution of the standard deviation of speeds.

Because it is a more direct measure of driver behavior, the standard deviation of steering wheel angle may be a more sensitive measure of attentional demands than lateral standard deviation. As shown in figure 19, that measure was affected by driver age (younger than 30 versus over 60) and the speed of the road on which the data were collected. The standard deviation of steering wheel angle was larger for those segments in which the navigation system was used.

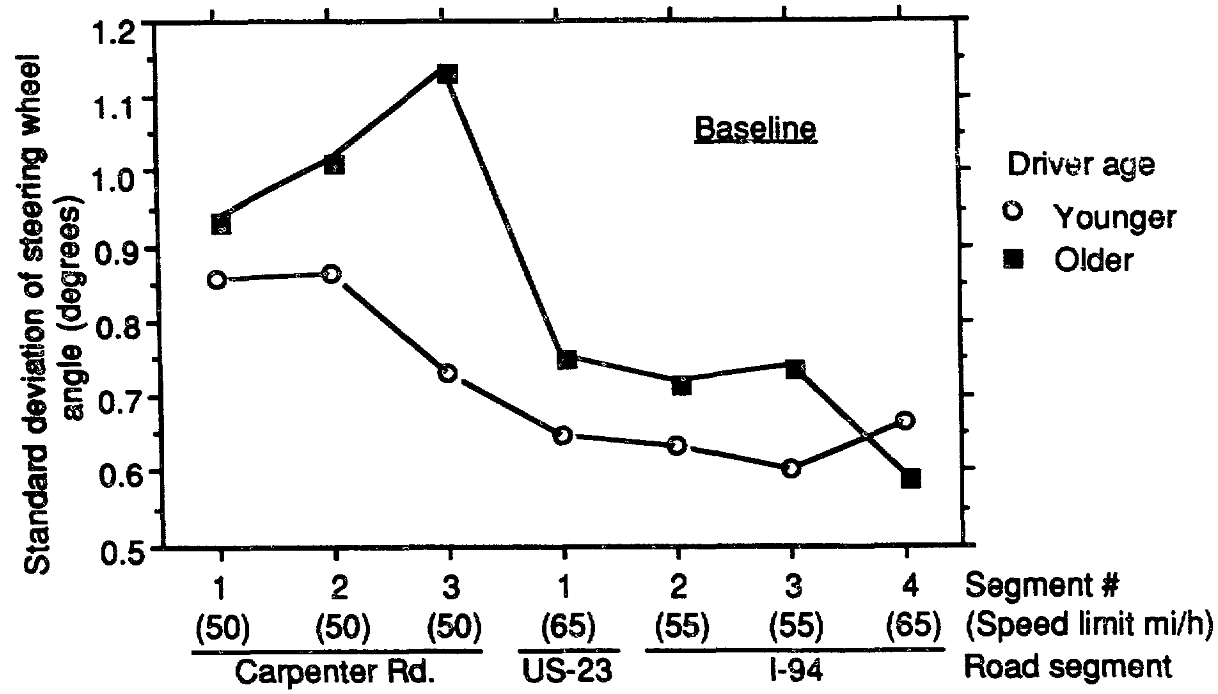


Figure 19.Standard deviation of steering wheel angle for various road segments and driver ages.

As a whole, these data suggest that concurrent use of in-vehicle systems affect driver performance, as measured by speed, lateral variance, and steering wheel angle. Although it is not clear how these performance changes, which were moderated by the type of display being used, relate to the likelihood of being involved in an accident; it is clear that use of these systems changes driving behavior.

TRAFFIC INFORMATION

Traffic information systems present information about the current speed of traffic along specific corridors. The specific questions that were addressed with regard to the design of traffic information systems in this project were: (a) how should drivers retrieve information?; and (b) how should traffic information requested by drivers be presented?

A core set of traffic information features represented in the system were identified based on a literature review, concept cars, industrial liaisons, in-house expertise, and the results from the functions and features analysis. Based on those features, a set of preliminary interface designs were developed. These included interfaces with various retrieval mechanisms along with both textual and graphic displays. Auditory options were not considered in detail, as they have been studied elsewhere (in the literature on highway advisory radio). Preliminary graphic studies revealed that coding traffic density using line width was not feasible because of space constraints. Similarly, there were problems with dynamic coding (e.g., using moving elements).

Aspects of the preliminary designs were examined using psychological models (i.e., the Keystroke Model and the Tullis model) to predict retrieval times and the time to read screens.(12,13) Alternatives identified as being particularly slow to use were eliminated from further consideration. No interfaces appeared to be particularly slow to read; however, the principles behind the analyses were used to redesign several screens.

Several brief usability tests were then conducted on the screens. These tests resulted in improved graphics. They also resulted in rejection of an interface that used gestural input (i.e., hand movements) as no stereotypical hand motions could be defined for some of the needed inputs. Subsequently, 20 patrons of a driver licensing office were asked to evaluate various coding schemes for presenting travel speed (e.g., color vs. text). Presentation of a numeric value for actual travel speed was most preferred by this group. Within the color-coding alternatives, the green-yellow-red combination was best understood.

Finally, a laboratory experiment examining three retrieval methods and two display formats was conducted using a driving simulator.(11) The retrieval methods examined were: a scrolling menu (figure 20), a static graphic menu (figure 21) and a phone-style keypad (figure 22). The display formats examined were text-based (figure 23) and graphic-based (figure 24). Sixteen drivers retrieved specific traffic information on request. Retrieval times for the scrolling menu and static graphic methods were shorter than those for a phone pad method. Although predictions of the actual retrieval times from the psychological model were imperfect (they were off by 10 to 20 percent), it was able to predict the relative speed of the various interfaces perfectly.(14) This supports the utility of using the model as a predictor. Preference and eye fixation data also supported the superiority of the scrolling menu and static menu displays over the phone keypad interface.

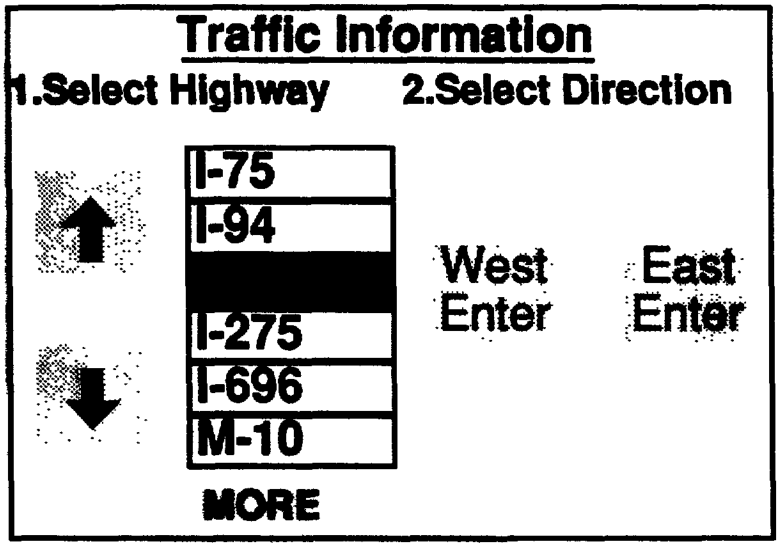


Figure 20. Bi-directional scrolling menu (arrow-menu) interface.

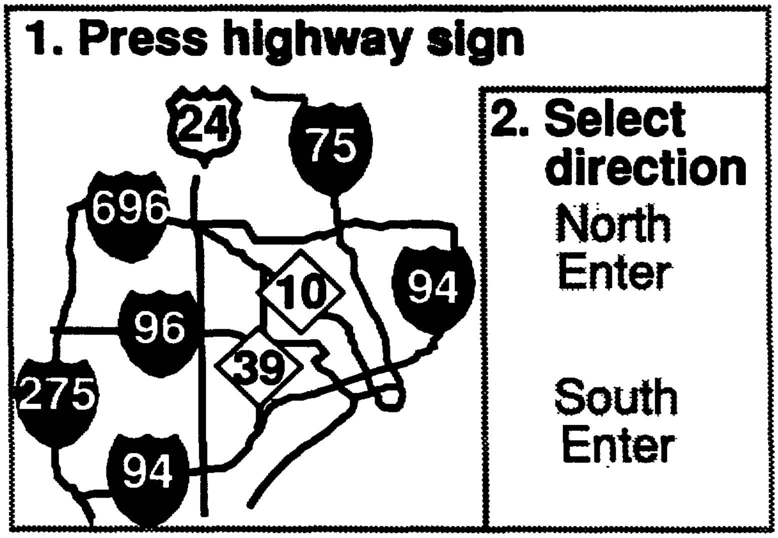


Figure 21. Static graphic of Detroit highways used for selection (graphic-menu).

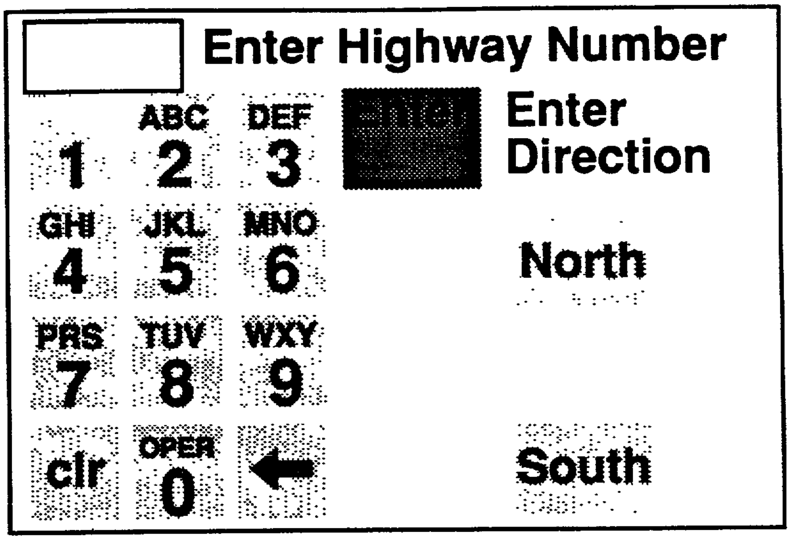
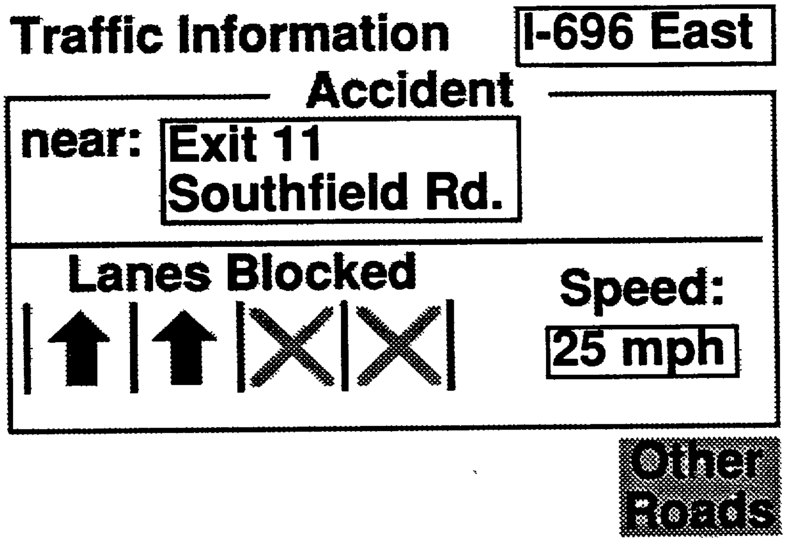


Figure 22. Phone-style keypad used for highway number entry.


Traffic Information I-696 East

Accident

near: Exit 11 Southfield Rd.

Lanes Blocked

Speed: 25 mph

Figure 23. Text-based traffic information screen.

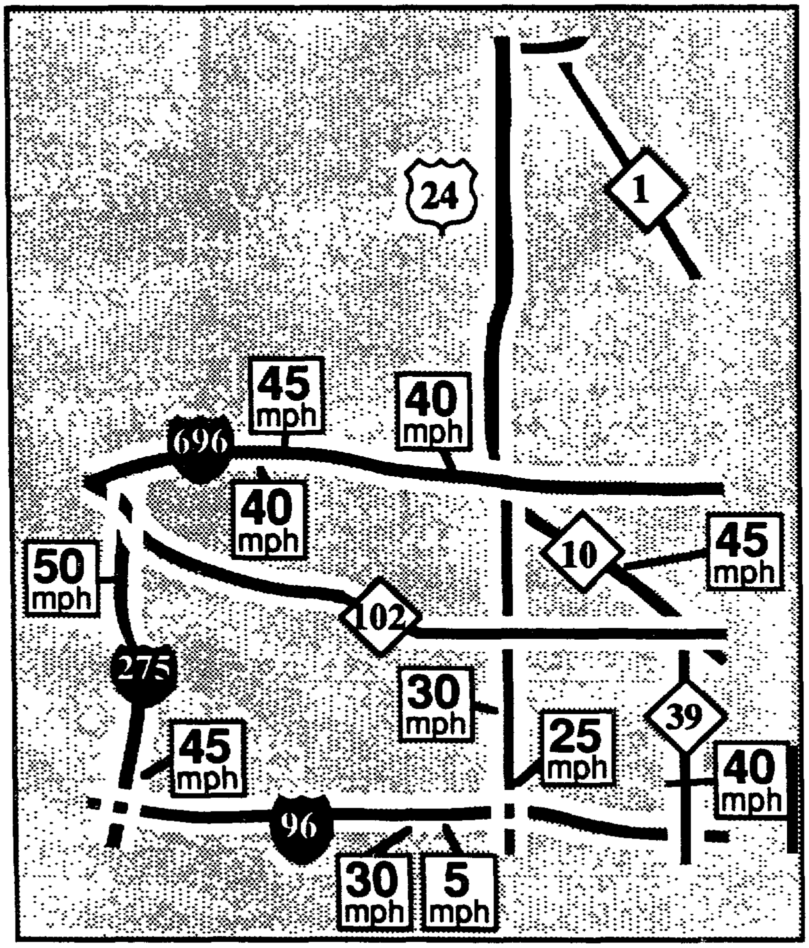


Figure 24. Graphic-based system with travel speeds.

VEHICLE MONITORING

Vehicle monitoring is concerned with presenting information to drivers related to the operation and maintenance of the car (e.g., oil, brakes). The issues of concern here were how much drivers understand about the functioning of their cars, and how warnings of impending operational/maintenance needs should be structured and displayed to produce the highest levels of comprehension.

In an initial study, 27 drivers were interviewed at a local driver licensing office to determine how familiar drivers were with the operation of their cars.(23) They were asked a series of 25 questions such as "What is an alternator for?" or "What happens if the brake fluid is low?" Their responses were recorded and scored for accuracy using a four-point scale going from completely correct to no correct information. Table 3 shows the mean level of understanding for each of the items. As can be seen in the table, accuracy of the answers ranged from 22 to 100 percent.

Table 3. Items understood by participants.

Item	% correct	Understanding
Low radiator fluid	100	sufficient
Worn tire	100	sufficient
Poor wheel alignment	96	sufficient
Blown fuse	89	sufficient
Low power steering fluid	89	sufficient
Low tire pressure	89	sufficient
Low engine oil level	85	sufficient
Shock absorber function	85	sufficient
Strut function	81	marginal
Clutch function	81	marginal
Antilock brake function	78	marginal
Battery function	78	marginal
Low brake fluid	78	marginal
Reasons for engine oil change	78	marginal
Transmission fluid function	67	insufficient
Antilock brake failure	63	insufficient
Low oil pressure	63	insufficient
Catalytic converter function	63	insufficient
Alternator failure	59	insufficient
Fuse function	56	insufficient
Master cylinder function	52	insufficient
Alternator function	50	insufficient
Oxygen sensor function	26	insufficient
Accessory drive belt	22	insufficient

In a second study, 60 drivers were asked to construct warning messages for nine operational/maintenance functions (replace drive belt, add fluid, door ajar, fuse, light out, add oil, suspension, washer fluid, wheel alignment) to determine preferences for warning messages. Participants were presented with the label of the function name, and additional words that could either precede or follow the function name. (See figure 25.) The numbers to the left of the additional words in the figure indicate how many of the subjects preferred to have each phrase in the warning message. For example, 19 of the 60 drivers said “low” should appear before “brake fluid” and 38 said there should be no trailing phrase.

19	Low	**brake fluid**	38	(none)
16	Add		12	needed
12	Refill		7	reservoir
5	(None)		1	tank
4	Replenish		1	levels
2	Running out of		0	bottle
1	Add more		1	[skipped]
1	Check			
0	Add some			

Preferences: Low brake fluid
Add brake fluid

This message structure also applies to:
Power steering fluid
Transmission fluid
Clutch fluid

Figure 25. Preferences for brake fluid warning message structure.

In a third experiment, 20 drivers at a local licensing office were shown a mockup of a warning display using the preferred wordings generated in the previous study and a mimic of a car indicating the location of the problem. Drivers were asked to state what each warning meant, what actions they would take, and when they would take them. Responses were summarized for each warning in terms of what the warning meant to the drivers and in terms of how quickly they would respond to the warning.

Overall, a few drivers had problems distinguishing the front from the back of the car mimic. Drivers did not realize that color coding was being used to indicate the seriousness of problems. Even when the seriousness was understood, drivers were reluctant to stop on the side of the highway.

IN-VEHICLE TELEPHONES

Four experiments were conducted to study car-phone interfaces.(15,24) These experiments were intended to examine alternative interfaces and to provide laboratory task performance data for calibrating a computational model to predict driver performance with in-vehicle information systems.

In the first experiment, 19 people at two local driver licensing offices were shown a HyperCard'? simulation of a car phone on a 228.6 mm (9-in) display. Seven phone functions were demonstrated and participants were asked how they would label buttons that activated these features. No strong agreement was expressed in what specific functions were called, except for the answer function. However, several choices for function names and abbreviations were identified through this study.

A second experiment examined label abbreviations. Drawings of labeled car telephones were developed based on the candidate labels generated in the previous experiment. Abbreviations of the labels were generated using different formats including vowel deletion, truncation, or a mixture of the two. Twelve participants, most of whom had never used a car telephone, were shown these drawings and asked to state what functions were present on the telephone handset. Surprisingly, use of mixed format abbreviations, the least consistent method, resulted in the fewest errors of interpretation. Based on this experiment, the following labels (and abbreviations) are recommended for use on car telephones: power (Pwr), Call, End, delete (Del), memory (Mem) and recall (Rcl).

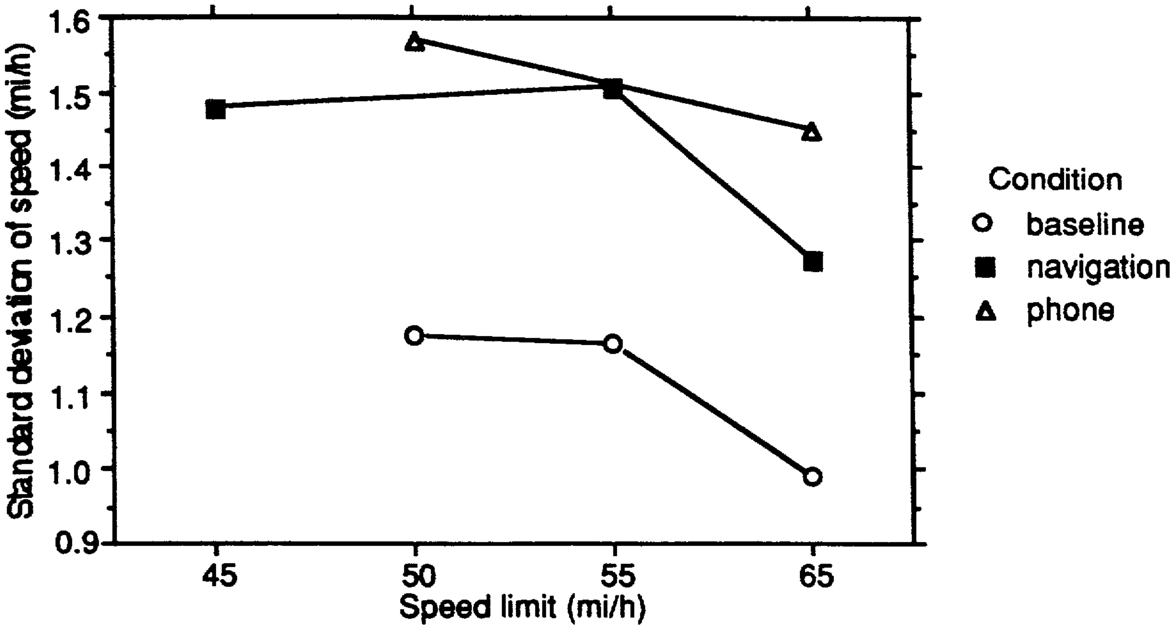
In the third experiment, 12 drivers (6 under 35, 6 over 60) operated a simple driving simulator and used a car telephone. The telephone was either manually dialed or voice operated. Display of the phone number dialed was either mounted on the instrument panel or on a simulated head-up display. Telephone numbers dialed were either local (7 digits) or long distance (11 digits), and could be familiar or unfamiliar. In addition, there were four conversational tasks, two of which were fairly ordinary (e.g., talking to the experimenter) and two of which required some mental processing (e.g., listing items from a semantic category). Participants made eight telephone calls while performing these secondary tasks.

Overall, driving performance was better (as measured by lane variance) and dialing times were shorter with the voice-operated telephone than with the manual telephone, regardless of where the display was located. Drivers also made fewer dialing errors in the voice-operated conditions. Thus, voice appears to be an effective way of improving the safety and performance of car telephone use while location appears to be a less significant factor.

Driving performance was also affected by which task was being executed and by driver age. Dialing a telephone call had a negative impact on driving performance (i.e., greater lane variance); however, talking on the phone did not appear to affect driving performance. With respect to age, older drivers displayed greater lane variance and longer dialing times than the younger drivers. Age also interacted with display format. Although voice improved performance for both older and younger drivers, the benefits of voice operation were particularly noticeable for the older drivers. Finally, subjective preferences for the alternative interfaces were examined. Eight of the twelve drivers preferred the voice condition in the head-up location over all of the other alternatives, suggesting that this might be the most preferred implementation.

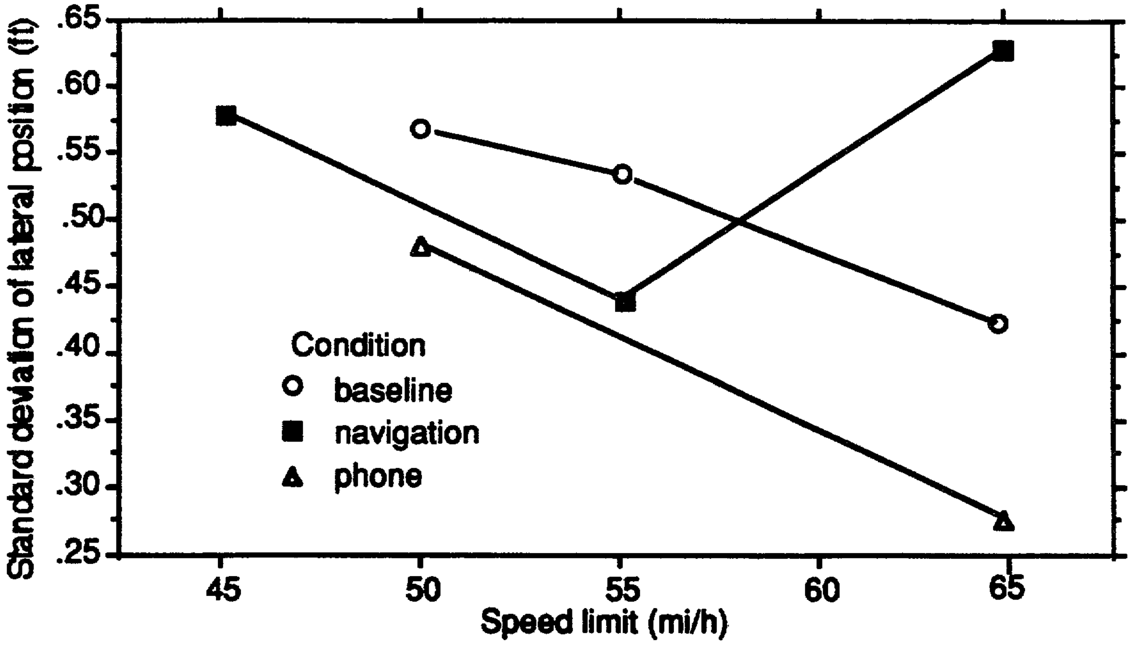
The fourth experiment investigated the effect of using a car phone on actual driving performance. This experiment was conducted in the instrumented car, with software added to simulate a manually-dialed car telephone. The telephone tasks were similar to those used in the laboratory simulation. Participants made 12 telephone calls, including 3 practice calls while parked, 3 practice calls while driving, and 6 actual calls while driving. Except for dialing, the call duration was fixed for each task (35 to 60 s). Each of the three telephone conversation tasks was executed while driving on a 80.5 km/h (50 mi/h) road, and on a 104.65 km/h (65 mi/h) expressway. Calls were placed by all drivers at the same locations along the test route.

The standard deviation of steering wheel angle was 0.8 degrees, except for the dialing task, where values of 1.1 were obtained. These data suggest that use of the telephone had only a minor impact on driving performance. However, use of the phone had a more significant impact on how steadily participants maintained their speed. As shown in figure 26, the standard deviation of their speed was greater when using the telephone [mean of 1.932 km/h (1.2 mi/h) for the listening task and 2.335 km/h (1.45 mi/h) for other telephone tasks]. In contrast, participants showed better lateral placement while using the telephone than while off the telephone (figure 27). Finally, use of the telephone had only marginal impact on the standard deviation of steering wheel angle (figure 28) and on the standard deviation of throttle (figure 29).



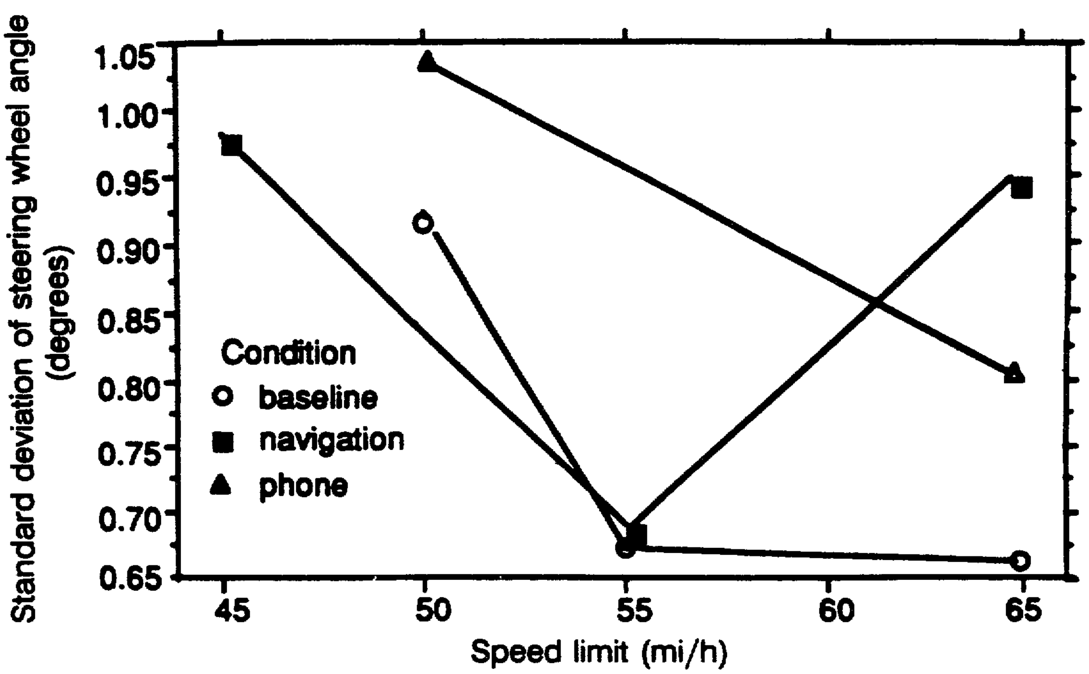
1 mi/h = 1.61 km/h

Figure 26. Effect of concurrent task on standard deviation of speed.



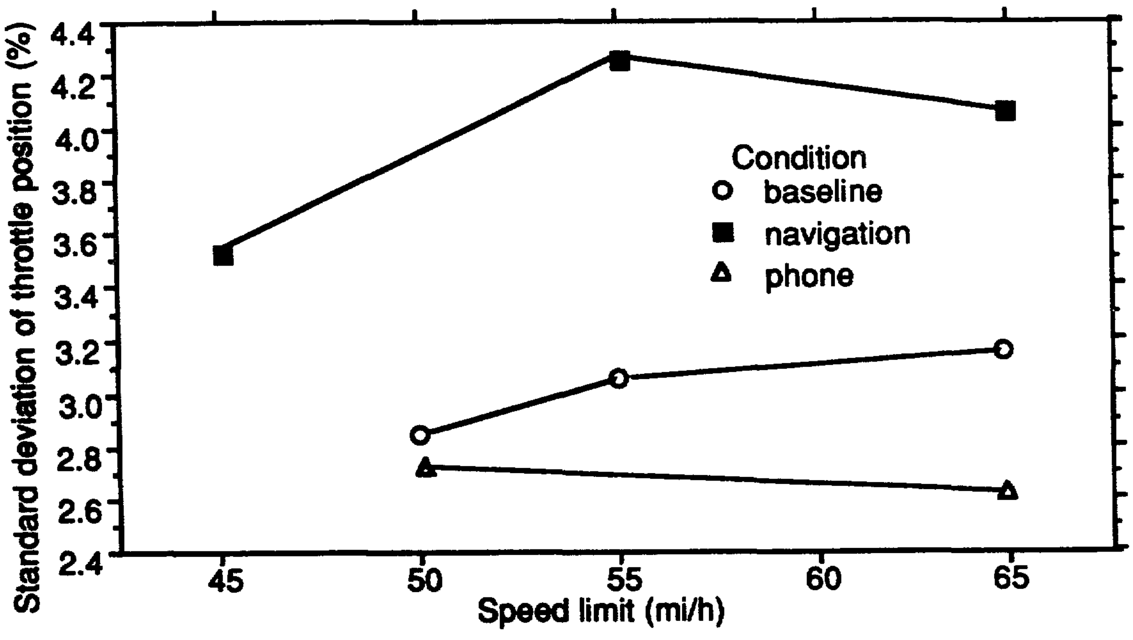
1 mi/h = 1.61 km/h

Figure 27. Standard deviation of lateral position for various conditions and speeds.



1 mi/h = 1.61 km/h

Figure 28. Standard deviation of steering wheel angle for various conditions and speeds.



1 mi/h = 1.61 km/h

Figure 29. Standard deviation of throttle position for various conditions and speeds.

GUIDELINES

A major product of this contract was a guidelines document that was written to provide suggestions for the design of safe and effective ITS systems.(16) This document describes: design principles, general guidelines for manual control, spoken input and dialog, visual and auditory displays; specific guidelines for navigation input and displays; specific guidelines for displaying traffic information, vehicle monitoring information, road hazard warnings and in-vehicle telephone information; and guidelines for integrating information from a number of sources. For most of the guidelines presented, a commentary and examples of how they should be applied are provided.

The general design principles address issues including consistency, driver expectations, sequence of use, driver memory demands, metaphors, and user control. Although these guidelines are not quantitative, they proved to be quite useful in making design decisions throughout this project. The general design guidelines include such topics as requirements for reach, selection of control types, command confirmation for speech input, minimizing what the driver needs to read, legibility requirements, use of international symbols, rules for generating abbreviations, justification of display fields, required levels of auditory tones, and tone discrimination.

The specific guidelines for route guidance displays included information about auditory guidance (content, timing, use of landmarks, alerts, recall), maps (detail, orientation, element, use of color), and guidance arrows (design, placement). Traffic information guidelines describe information elements of interest, desired display formats, the use of color coding, the display of lane blockage, and methods for retrieving traffic information. For in-vehicle telephones, the issues covered were dialing mode (voice versus manual), labeling of buttons, the attentional demands of conversation, and display design. For vehicle monitoring, the issues were the identification of information elements, presentation modality, graphics, and abbreviations. For IVSAWS, the guidelines were focussed on the selection of graphics and the identification of hazard location.

These guidelines were created as the interfaces were developed, based upon the laboratory, simulator, and on-the-road tests using both young and older drivers. As a result, all the guidelines described were useful in the design of displays used in the research done under this contract. The guidelines provided represent the first attempt to develop comprehensive, detailed guidelines for advanced driver information systems. Although significant gaps still remain, the set of guidelines provides a sold basis for starting the design of future products.

ASSESSMENT PROTOCOL

Another major aspect of this project was the development of a methodological approach to assessing the safety and ease of use of driver information systems. Two protocols were developed during this project: an on-the-road test to certify the basic interface, and a survey methodology to be used at driver licensing offices when only small changes are made to the basic interface. The document describing this work provides all of the details to run these protocols, including the equipment, materials, software, test sequence, number and types of subjects needed, and the data analysis approach.(17)

The on-the-road test requires an instrumented car which can be driven on a specific route from Belleville to Canton, Michigan. This route is reasonably close to the engineering centers of the three primary U.S. automobile manufacturers and the research offices of domestic suppliers and foreign manufacturers. It is also identical to the route used for the on-the-road experiments in this project. This route is useful as we now have baseline data for measures such as lane and speed variance. However, for each dependent measure available, there is little in the literature to describe normative data, so it is difficult to calibrate the results from experiments using these measures. Further, methods for computing how driver behavior (and these measures) change as a function of variables such as road geometry, traffic, and weather remain to be described. Thus, the protocols are offered as suggestions only, recognizing that they need considerable review. Further, the on-the-road test is likely to be costly, and could take considerable time to complete, so it will have to be used sparingly.

HUMAN PERFORMANCE MODEL

In conjunction with the experimental work, a simulation model was developed to predict driver behavior and system performance when the driver executes concurrent steering and auxiliary in-vehicle tasks.(14,18) This model, which is based on optimal control theory, consists of two component computer models — a "procedural model" and a "driver/ vehicle model." The procedural model represents drivers in terms of their perceptual, neuromotor, and cognitive responses. Further, the model provides input to the driver/vehicle model about when certain tasks will be executed and the impact of that execution in terms of resources needed by the driver to perform these activities. Thus, this component deals primarily with time to complete in-vehicle tasks and with the task-selection and attention-allocation procedure. The driver/vehicle component is designed to predict control of the path of the car. Thus, this component models closed-loop continuous control (steering behavior). This component takes as input a description of the driving environment, driver characteristics, and simulation parameters. The two components work in tandem to form the Integrated Driver Model (IDM), which predicts a variety of performance measures (e.g., deviations from centerline, or deviations in speed).

As part of the project, data from the laboratory and on-road experiments were used to set the initial parameters of the driver/vehicle model. Once the model was calibrated using these data, the full model (IDM) was run to determine the predicted outcome of various manipulations in the driving environment (e.g., using a car phone).

The model was able to predict the following experimental trends correctly:

- Compared to single-task driving, steering performance degrades when an auxiliary task is imposed.

- Increasing the difficulty of the driving task in a complex environment results in more attention to the driving task and worse steering performance.

- Contrary to expectations, when attention-sharing between driving and an auxiliary task is relatively frequent, steering performance is slightly better during intervals when more attention is paid to the auxiliary task than to the driving task.

On the other hand, the model predicted that increasing the relative importance of the auxiliary task (through instructions) would result in less attention to the driving task and a consequent degradation in performance. However, the corresponding experiment showed no trends in either attention or performance.

The model was also used to predict the effects of a concurrent in-car telephoning task on lane-keeping performance and visual scanning behavior. The model predicted that a voice-dialing task would require less visual attention overall than the manual-dialing task, and that dialing a familiar number would require less visual attention and fewer scans inside the car than dialing an unfamiliar number.

Although the model performed well in the instances cited, as with any mathematical model of the human operator, one has to be cautious in extending the model beyond known results because of the complexity of human behavior. However, this model is quite promising, and it represents an important step in modeling driver performance.

METHODOLOGICAL ISSUES RAISED

In the course of completing this contract, a number of methodological issues were raised. The first of these arose from the use of focus groups to identify desired new features. In the course of conducting the focus groups, we discovered that users have a very difficult time identifying desired new features for products when they have not experienced those features. Further, casual review of prototypes or early versions of the systems (through, for example, watching a videotape of the system) is insufficient to provide users with a basis for evaluating a new system. Interaction with the system is critical to obtaining reliable, relevant data from focus groups.

A second methodological concern arose from the specification (in the contract) of a top-down approach to analyzing driver information interfaces. This approach didn't work in this contract. First, top-down analysis often assumes that there is only one structure that describes the problem; however, systems do not always fall into traditional hierarchical schemes. In this contract, for example, information about congestion could be part of a navigation systems or a traffic information system, making top-down decomposition difficult. Second, the approach assumes that elements are independent. In the case of a car equipped with a telephone, its number pad and access to the outside world provide additional interface and contact options for a traffic information system. Third, top-down analysis assumes that design is sequential. In real design, however, completing one step often reveals new options and insights into previous steps. Finally, top-down analysis assumes complete knowledge of one's options. However, this is clearly not the case for ITS interfaces.

SUMMARY

This project had three objectives. The first objective was to develop methods for identifying and selecting a set of functions and features of specific driver information systems that might reduce accidents, improve traffic operations and satisfy driver needs and wants. This goal was achieved through the use of focus groups of drivers and expert ratings. These analyses resulted in the selection of five systems for detailed examination: traffic information systems, car phones, navigation, road hazard warning, and vehicle monitoring systems.

The effectiveness of alternative designs for each of the selected systems was examined separately in a series of experiments. This work led to empirical data on the use of these systems in simulated situations. The data also led to a set of design guidelines for driver interfaces and a general and well-constrained assessment protocol.(17)

The third objective was to develop a model predicting driver performance. That model was developed and calibrated using laboratory and on-the-road driving data. The model was felt to be of use in that in one of the validation tests, the model was able to predict apparently anomalous results that have appeared in the literature.

Thus, the primary goals were achieved. Although there are many functions and features that were not investigated in this work, some cases where baseline data remain scanty, and where further model validation is required, the project represents a major first step in understanding how future driver information systems should be designed and evaluated to produce safe and easy-to-use systems.

REFERENCES

1. Sweet, R.E., and Green, P. (1993). UMTRI's Instrumented Car, ***UMTRI Research Review,*** January-February, pp. l-l 1.

2. Green, P., Williams, M., Serafin, C., and Paelke, G. (1991). Human Factors Research on Future Automotive Instrumentation: A Progress Report, ***Proceedings of the 35th Annual Meeting of the Human Factors Society,*** Santa Monica, CA: Human Factors and Ergonomics Society, pp. 1120-1124.

3. Green, P. (1992). ***American Human Factors Research on In-Vehicle Navigation Systems,*** (Technical Report UMTRI-92-47), Ann Arbor, MI: The University of Michigan Transportation Research Institute.

4. Klinger, D., and Kuzmyack, J.R. (1986, August). ***Personal Travel in the United States, Volume I: Nationwide Personal Transportation Study 1983-1984,*** Wheaton, MD: COMSIS Corp.

5. Green, P. (1993). ***Measures and Methods Used to Assess the Safety and Usability of Driver Information Systems,*** (Technical Report UMTRI-93-12), Ann Arbor, MI: The University of Michigan Transportation Research Institute.

6. Robertson, J. and Southall, D. (1992). ***Summary Report on the Feasibility of Developing a Code of Practice for Driver Information Systems,*** Loughborough, Leicestershire, United Kingdom: ICE Ergonomics Ltd.

7. Zaidel, D.M. (1991). ***Specification of a Methodology for Investigating the Human Factors of Advanced Driver Infoomzation Systems*** (Technical Report TP 11199 (E)), Ottawa, Canada: Road Safety and Motor Vehicle Regulation, Transport Canada.

8. Streff, F., Ervin, R., and Blower D. (1991). ***In-Vehicle Safety Advisory an Warning System (IVSAWS)--Task B--Final Report,*** (Technical Report UMTRI-9 l-33), Ann Arbor, MI: The University of Michigan Transportation Research Institute.

9. Hoekstra, E., Williams, M., and Green, P. (1993). ***Development and Driver Understanding of Hazard Warning and Location Symbols for IVSAWS,*** (Technical Report UMTRI-93-l@, Ann Arbor, MI: The University of Michigan Transportation Research Institute.

10. Williams, M., and Green, P. (1992), ***Development and Testing of Driver Interfaces for Navigation Displays,*** (Technical Report UMTRI-92-21), Ann Arbor, MI: The University of Michigan Transport&ion Research Institute,

11. Paelke, ***G.,*** and Green, P. (1993). ***Development and Testing of a Traffic Information Systems Driver Interface,*** (Technical Report UMTRI-93-20), Ann Arbor, MI: The University of Michigan Transportation Research Institute.

12. Card, S.K., Moran, T.P., and Newell, A. (1983). ***The Psychology of Human-Computer Interaction,*** Hillside, NJ: Lawrence Eribaum Associates.

13. Tullis, T.S. (1983). The Formatting of Alphanumeric Displays: A Review and Analysis, ***Human Factors, 25(6),*** pp.657-682.

14. Levison and Cramer. (1993). ***Description of the Integrated Driver Model,*** (BBN Report 7840), Cambridge, MA: Bolt, Beranek and Newman.

15. Serafin, C., Wen, C., Paelke, G., and Green, P. (1993). Car Phone Usability: A Human Factors Test, ***Proceedings of the Human Factors Society 37th Annual Meeting,*** Santa Monica, CA: Human Factors and Ergonomics Society, pp. 220-224.

16. Green, P., Levison, W., Paelke, ***G.,*** and Serafin, ***C.*** (1993). ***Preliminary Human Factors Guidelines,*** (Technical Report UMTRI-93-21), Ann Arbor, MI: The University of Michigan Transportation Research Institute.

17. Green, P. (1993). ***Suggested Procedures and Acceptance Limits for Assessing the -Safety and Ease of Use of Driver Information Systems,*** (Technical Report UMTRI-93-13), Ann Arbor, MI: The University of Michigan Transportation Research Institute.

18. Levison, W.H. (1993). ***A Simulation Model for the Driver's Use of In-Vehicle Information Systems,*** (TRB Paper 930935), paper presented at the Transportation Research Board Annual Meeting, Washington, DC., January 10-14, 1993.

19. Serafin, C., Williams, M., Paelke, G., and Green, P. (1991). ***Functions and Features of Future Driver Information Systems,*** (Technical Report UMTRI-9 1- 16)) Ann Arbor, MI: The University of Michigan Transportation Research Institute.

20. Green, P., Serafin, C., Williams, M., and Paelke, G. (1991). What Functions and Features Should Be in Driver Information Systems of the Year 2000? (SAE paper 912792), ***Vehicle Navigation and Information Systems Conference,*** (VNIS' 91), Warrendale, PA: Society of Automotive Engineers, pp. 483-498.

21. Green, P., Williams, M., Hoekstra, E., Wen, C. and George, K. (1993). ***Initial On-the-Road Tests of Driver Information System Interfaces: Examination of Route Guidance, TrafficInformation, IVSAWS, and Vehicle Monitoring,*** (Technical Report UMTRI-93-32), Ann Arbor, MI: The University of Michigan Transportation Research Institute (in preparation).

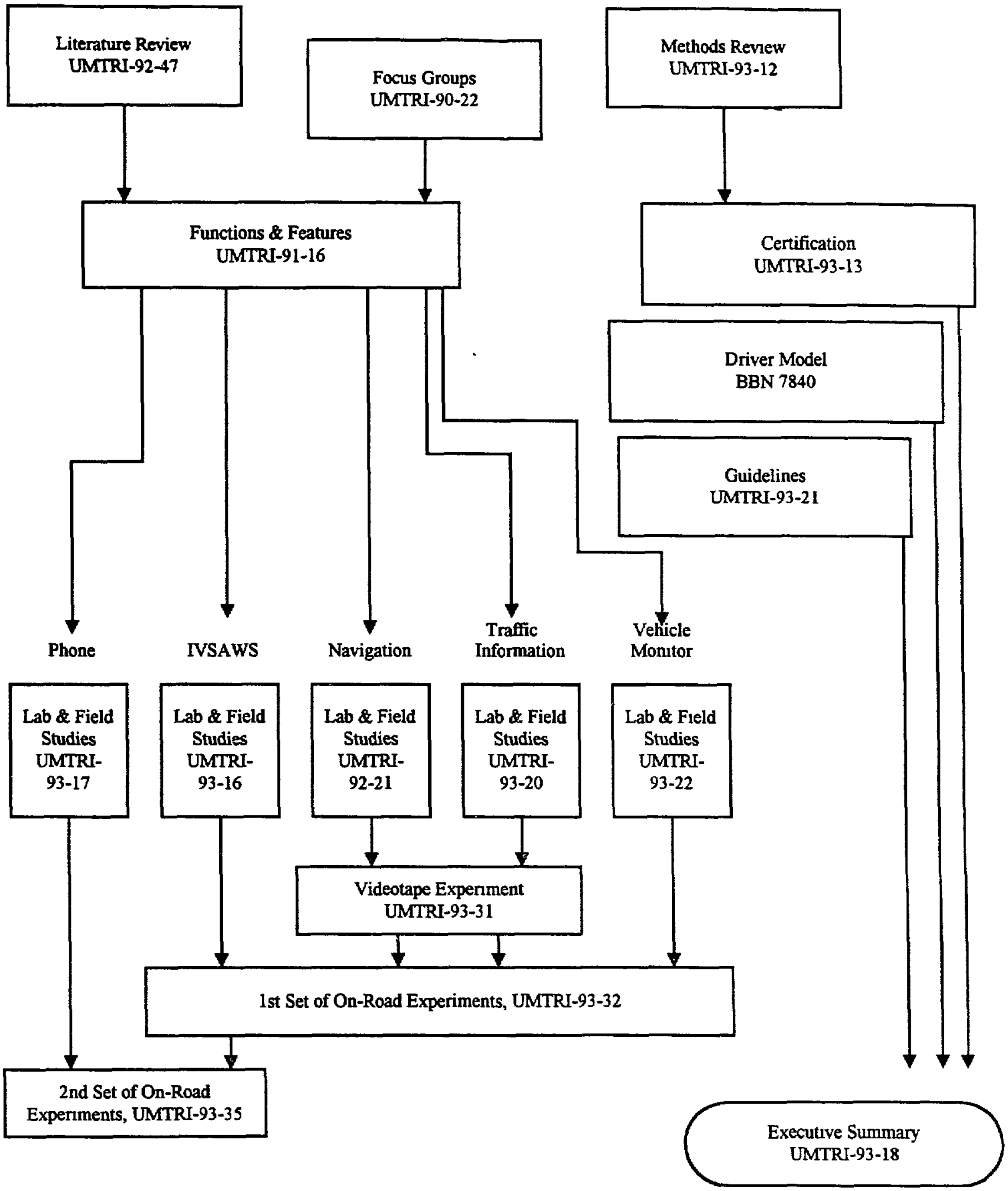
22. Green, P., Hoekstra, E., and Williams, M. (1993). ***Further On-the-Road Tests of Driver Interfaces: Examination of a Route Guidance System and a Car Phone,***

(Technical Report UMTRI-93-35), Ann Arbor, MI: The University of Michigan Transportation Research Institute (in preparation).

23. Williams, M., Hoekstra, ***E.,*** and Green, P. (1993). ***Development and Evaluation of a Vehicle Monitor Driver Interface,*** (Technical Report UMTRI93-221, Ann Arbor, MI: The University of Michigan Transportation Research Institute.

24. Serafin, C., Wen, C., Paelke,***G.,*** and Green, P. (1993). ***Development and Human Factors Tests of Car telephones,*** (Technical Report 93-17), Ann Arbor, MI: The University of Michigan Transportation Research Institute.

APPENDIX A: LIST OF PROJECT REPORTS



APPENDIX B: LIST OF EXPERIMENTS CONDUCTED

#	UMTRI Report	System	# Subjects	Method	Topic
1	90-22	All systems	46	Focus group	Public desire for new information systems and specific features
2	93-16	IVSAWS	10	Survey	Warnings for hazards
3	93-16	IVSAWS	75	Survey	Best warning text and graphics
4	93-16	IVSAWS	20	In-car interview	Best location cues for warnings
5	93-17	Car telephone	19	Interview	Suggestions for labels for simulated telephone
6	93-17	Car telephone	12	Interview	Preferred abbreviation method
7	93-17	Car telephone	12	Driving Simulator	Dialing times and driving performance for HUD and IP location, voice and manual dialing
8	93-22	Vehicle monitor	27	Interview	General knowledge of vehicles and malfunctions
9	93-22	Vehicle monitor	60	Survey	Wording of vehicle monitor warnings
10	93-22	Vehicle monitor	20	Survey	Understanding of various warnings
11	93-20	Traffic information	<20	Interview	Understanding of graphics, gesture stereotypes
12	93-20	Traffic information	20	Survey	Color coding, retrieval strategies
13	93-20	Traffic information	16	Driving simulator	Retrieval times, eye fixations for various screen designs, general understandability
14	92-21	Route guidance	<20	Interview	Display format
15	92-21	Route guidance	60	Survey	Plan versus aerial versus perspective format
16	92-21	Route guidance	12	Response time	Display format, location, graphics for road
17	93-31	Route guidance, traffic info.	48	Respond to videotape	Role of landmarks and presentation modality (auditory, visual) on interface usability
18	93-32	All systems except telephone	12	On road, subjects-in-tandem	Looked for severe problems with interface design

19	93-32	All systems except telephone	43	On road (singly)	Lane, speed, throttle, steering wheel variance, glance freq. safety & usability ratings
20	93-35	Route guidance and phone	8	On road (singly)	Lane, speed, throttle, steering wheel variance, glance freq. safety & usability ratings

*U.S. GOVERNMENT PRINTING OFFICE: 1997 427~721/60124