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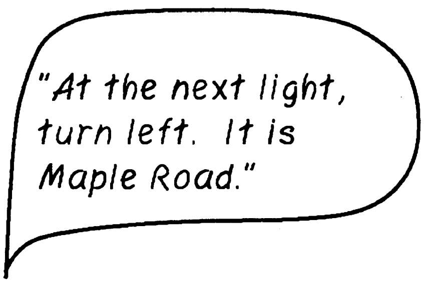
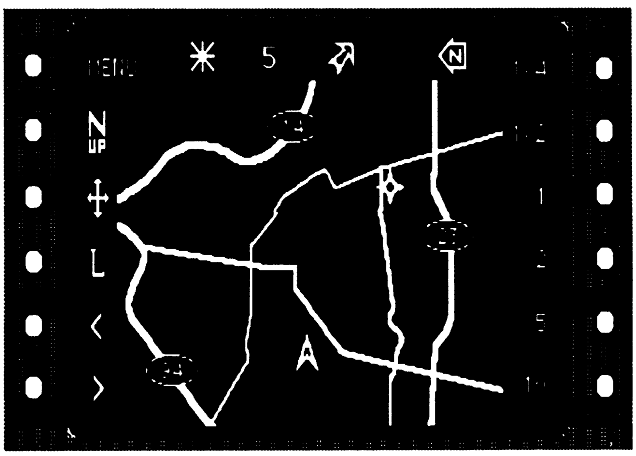
American Human Factors Research on In-Vehicle Navigation Systems

Paul Green





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16. Abstract

This report emphasizes route guidance. European and Japanese research, which is extensive and significant, will be covered elsewhere. Critical research includes the Cross and McGrath work on maps, FHWA-funded research on ERGS, studies by Wierwille and his colleagues of the ETAK Navigator, studies by Gatling and Davis on in-vehicle auditory systems (Back Seat Driver), and comparisons of auditory and visual systems by Streeter and Walker. The following are the main findings:

1. Route guidance maps should be oriented heading up. It may be beneficial to show both the current heading and the four cardinal directions.
2. For ordinary route guidance (well-spaced cross and T intersections, light to medium traffic), instructions should be simple. ("Turn left at the next intersection," not "The next three streets are... When you get to ..."). More complex situations (heavy traffic, rapid turns in succession) have not been examined.
3. Visual and auditory route guidance systems are about equal in usability. Simultaneously providing guidance in both formats may not enhance usability.
4. Of the measures proposed to evaluate visually based navigation systems, eye fixations and navigation errors seem to be the most sensitive to design differences.
5. Missing in the literature are theories that explain why differences occur, studies of untrained users, and studies of elderly drivers.

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FOREWORD

This work was supported in part by a contract from the U.S. Department of Transportation (Assessment of Effect of In-Vehicle Display System on Driver Performance, contract DTFH61-89-C-00044). King Roberts has served as the contract technical monitor. Cathy Wen, Colleen Serafin, Marie Williams, and Gretchen Paelke (all from UMTRI) and Rebecca Fleischman (from General Motors Research Laboratories) provided many suggestions that improved the content of this report. I would also like to thank Paul Olson (from UMTRI) and Mike Sheldrick (from ETAK) for their comments. Finally, Tom Dingus and Melissa Hulse (both from the University of Idaho) provided insights into their research.

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EXECUTIVE SUMMARY

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

This section is a condensation of this report, primarily of the conclusions section, though graphics have been added appear elsewhere in this report. The goal of this report is to provide information that engineers can use to make automotive-navigation systems safe and easy to use. This report reviews the relevant human factors literature with particular emphasis on route guidance. It considers research on automotive maps, the ERGS (Experimental Route Guidance System) interface, second generation systems (ETAK), human performance characteristics, and comparisons of visual and auditory systems. This review only concerns research done in the U.S. and is only part of the picture This constraint was applied because of budget and schedule limitations. However, references to the non-U.S. research appear in other reports for this research program.

Critical research examined here includes the Cross and McGrath work on maps, FHWA-funded research on ERGS, studies of the ETAK Navigator by Wierwille and his colleagues, studies by Davis (Back Seat Driver) and Gatling on in-vehicle auditory systems, and comparisons of auditory and visual systems by Streeter and Walker. For those unfamiliar with the literature, ERGS or the Experimental Route Guidance System, was a concept proposed by the Federal Highway Administration in the late 1960 s. While considerable research was conducted on the idea, an operational system was never field tested. Back Seat Driver was one of the first completely voice-based route-guidance systems. The driver interface utilized a car telephone with a speaker. It was developed by an MIT student for his dissertation but never became a product.

Following are answers to some of the more commonly posed questions concerning navigation systems addressed by this report.

What information should be shown in driver information and navigation systems?

The information desired for navigation depends upon the mode the driver is in (for example, trip planning vs. orientation vs. route guidance). In guidance, simple information about what to do seems adequate, though there are times when other information is desired (for example, the distance to some point ahead as suggested by Cross and McGrath, 1977). The work on ERGS suggests the following: (1) show the immediately occurring turn as well as what to do afterwards, (2) confirm when turns are not required (a "continue" instruction), and (3) provide lane information in addition to turn information. Beyond those recommendations the utility of various information elements (compass, locale identifier, etc.) is unknown.

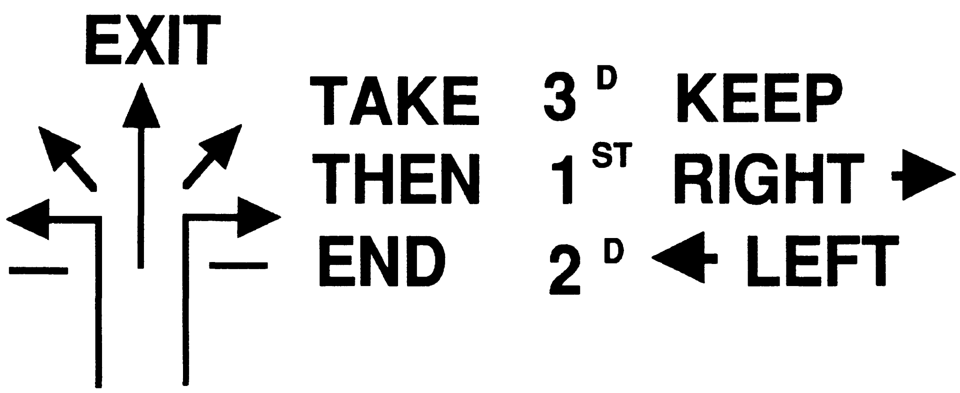
How should electronic maps be designed? What should be shown?

What an electronic map should show depends upon the task. For planning, details are needed. As is suggested elsewhere, planning tasks should be pretrip tasks (Dingus, 1991) using north-up maps. For orientation and route guidance, the map view should be heading up (Adeyemi, 1982). Adeyemi also recommends other cardinal directions should be shown as well.

Detail on route-guidance displays should be minimized. Walker, Alicandri, Sedney, and Roberts (1990, 1991, 1992) show that complex maps are more demanding than simple arrow displays. Stilitz and Yitzhaky (1979) suggest that each additional street shown adds almost 0.4 seconds to search time. Many of the details regarding map design (should streets be single or double line, what should the line width be, etc.) have not been examined but are needed to improve display design.

Drivers use landmarks to navigate, and certainly underpasses, bridges, street lights, and stop signs should be shown on navigation displays. Drivers also use highly visible buildings with signs as landmarks, especially gas stations and fast food restaurants, and it may be desirable to show them as well.

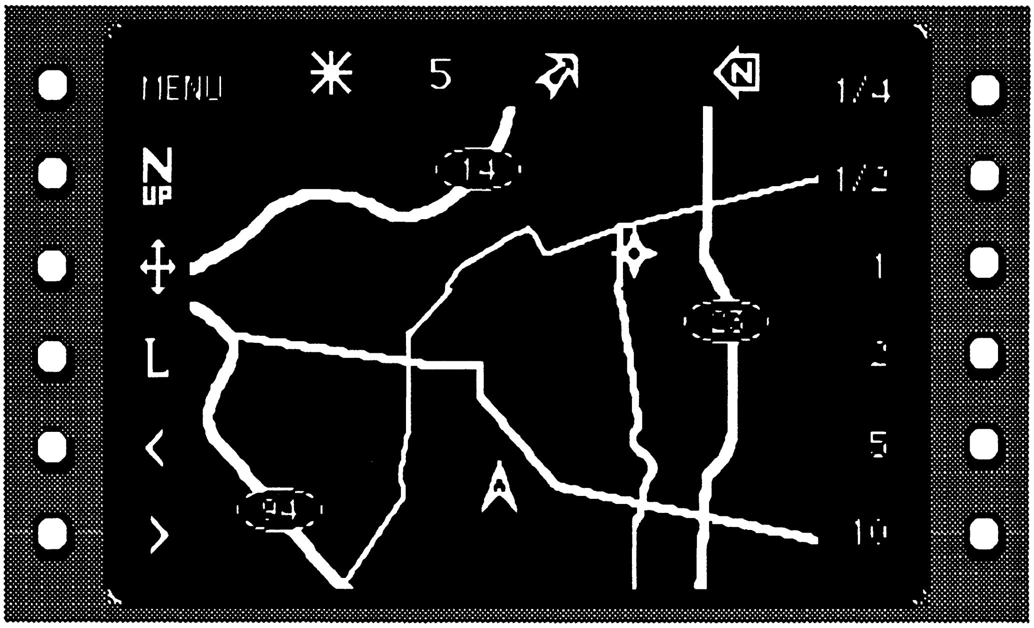
Following are several of the map-like interface designs that have been subjected to empirical testing. The ERGS-II display was the product of FHWA's first route-guidance effort and the ETAK display is a second generation system. (The ETAK Navigator is now the TravelPilot product sold by Blaupunkt.)



ERGS-II Display

How should auditory systems be designed?

Davis's work argues for verbose interfaces, though the supporting on-the-road usability tests were not extensive. Walker's more extensive laboratory test argues for systems that minimize verbiage. The difference may be due to the driving environment. Davis's tests were in congested areas of Boston. Streets come from all directions. Walker considered a grid system with widely spaced turns and highly visible street signs. The only traffic was a lead vehicle (which was not always present). Following are the actions used by Back Seat Driver (Davis) and Streeter, et al.



ETAK Navigation Display

Back Seat Driver Actions

	Action	Explanation
1	Continue	Driver stays on "same" road, taking "obvious" path. (bends under 30°, continuation of painted centerline)
2	Forced Turn	No decision to be made, road bends more than 10° that are "worth mentioning".
3	Turn Around	Heading is opposite of what it should be. (used for dead end streets)
4	Enter	"Drive onto <Name of Expressway>"
5	Exit	"Take exit 23" or "Take the exit for Somerville"
6	Onto-Rotary	"Drive onto the rotary"
7	Exit Rotary	Move off of rotary onto street
8	Fork	None of the branches are obvious. If one branch is stronger than the others it is a continue or a turn. (All must be access ramps or none must be access ramps.)
9	Stop	Designates destination
10	Turn	Anything that doesn't fit above (taking "non-obvious" path, at a decision point)

Instructions Used by Streeter, et al.

Instruction Type	Instruction
Critical direction: Left or right instruction	Drive {x.x} miles to {street_name} and turn {left|right}.
Critical direction: “Continue” instruction	{street_name 1} changes name to {street_name 2}. At {x.x} miles turn {left|right} onto {street_name 3}.
When -to-turn instruction: “If a landmark is available, then”	{landmark} is on the {left (corner)|right (corner)|straight ahead}.
When-to-turn instruction: “If a landmark is not available, then”	{street_before_name} is the street before {street_name}.
Too-far instruction	If you come to {landmark|major str_street}, you've gone too far.
Summary instruction	If you come to {landmark|major str_street}, you've gone too far.
Summary instruction	Remember it's {x.x} miles to your {left|right} turn onto {street_name}.
T-junction	Omit the "too far" instruction.
Junctions of more than two streets	the tricky intersection of street {street_name_1}, street {steet_name_2}, and street {street_name_3}.
Turns separated by 1/10 mile or less, combine the two instructions.	a quick {left|right} onto street {street_name}.

Should route guidance information be visual or auditory (or both)?

The U.S. data do not show a clear advantage for either sensory modality. Walker's study showed that moderately complex systems (both visual and auditory) led to minimal and almost equal (three vs. one) navigational errors. On the other hand, Streeter's research showed that drivers performed best with a simple auditory system (when compared with a map) but did not examine use of a good visual guidance system such as the simple or moderately complex units examined by Walker. When provided with both auditory information and the customized map, drivers did worse than when just given the tape alone.

How have and how should navigation systems be tested?

Navigation systems have been examined both in the laboratory and on-the-road methods, with the protocol depending upon whether the information is visual or auditory. In Rothery's work on ERGS, subjects were shown a slide of a road scene and then a navigation display showing either a lane change or an exiting instruction. They responded by moving the turn signal. Response times and error rates were the dependent measures.

Rothery also had drivers approach an intersection and retrieve navigation information by pressing a button that held a projector shutter open (showing a slide of a navigation display). The dependent measure was the exposure duration, which corresponds to how long the driver looked at the display and not at the road. This method is simple, and, since a working prototype is not required, can be done using sketches of preproduction prototypes and any car, not an instrumented vehicle.

Finally, Rothery suggested using a Senders helmet to limit the viewing time available. (Today, translucent LCD eyeglasses would be used.) Unfortunately, Human Subjects Review Committees are unlikely to approve studies in which people drive down public highways and effectively close their eyes from time to time.

Walker used an instrumented simulator to examine route-guidance displays. Dependent measures included heart rate, speed, lateral placement, response time to instrument panel gauges, and navigation errors. Speed and lateral placement, as well as navigational errors were most sensitive to the design differences, while heart rate was relatively unaffected.

Wierwille has conducted several on-the-road studies using an instrumented car. The vehicle required considerable modification to be used for research purposes. When testing was in progress, two experimenters were required. Both speed and lateral placement, while indicative of design differences, were insensitive. For lateral displacement, scoring was binary (in or out of lane). Eye fixations were quite sensitive to design differences and changed both in frequency and duration in response to external and internal demands. Wierwille had a camera pointed at the drivers and had the data reduced manually, which was tedious and time consuming.

One significant gap in the literature is the lack of comparisons of methods. It is not clear in which situations the laboratory data will predict on-the-road performance-in particular, fixation times, durations, or most likely, total glance times. One would expect reasonable correlations.

Are navigation systems safe? When won't they be?

There is still no definitive evidence on the safety of navigation systems. That evidence will come from on-the-road use and subsequent accident statistics. The best evidence to date is the research of Wierwille, which suggests these systems can be safe, but how safe and if they are safe enough will depend on the implementation. A major concern is that these systems will demand attention and that drivers will stop looking at the road. Wierwille's work indicates drivers respond intelligently to navigation system demands. When traffic is dense or there are demands that require drivers to look at the road, they do. Drivers can get into trouble when an unexpected highway situation arises that they do not attend to quickly. Wierwille's work shows that many of the tasks associated with the ETAK Navigator take much longer to complete than current ("accepted") in-vehicle tasks. Presumably, future navigation systems will be easier to use than the Navigator.

What should be measured when people use navigation systems?

In laboratory experiments, response time and error rates are typically considered. In some cases exposure duration has also been measured. In simulator or on-the-road studies, both navigation performance and driver performance measures are considered. Navigation measures include the number of turns, the number of turn errors, the distance driven, the average speed, and the trip time. The number of errors is the most indicative of between system differences, though time and distance indicate navigation waste and can be converted into costs (lost work time, excess fuel).

Of the driver performance measures, eye fixations seem to be the most sensitive to design differences. Eye fixations require considerable equipment to collect data and are laborious to analyze.

Lane position and speed variations have been recorded by Wierwille, while speed has been considered by Walker. Wierwille examined only if drivers were in or out of a lane. Lane position might have been more sensitive if it was measured more precisely.

What kinds of drivers will have the most problems?

Wierwille and Walker both show that drivers 65 and above have more problems using navigation systems than middle aged and younger drivers. Older drivers are more likely to have the income to acquire vehicles fitted with navigation systems. Distinctions among older drivers (65-75 vs. those over 75) needs to be explored.

Where is the literature weak?

In general, the literature on human factors and automotive navigation systems is not different from the general automotive human factors literature in terms of weaknesses.

1. The literature lacks theory. Except for Wierwille's Q value for workload and Adeyemi's work on map search, there have been no attempts to predict performance, information that engineers need to design systems. Even in those cases, reasons have not been offered as to why the equations should be structured as they have been. There is a genuine lack of understanding of the mental processes involved in navigation. In other contexts, data on visual search time, memory scanning, and the like have been used to build useful predictive models of human behavior that identify how long it will take a person to complete a task, sometimes how often they will do it incorrectly, and why problems will occur. (See, for example, Card, Moran, and Newell, 1983; Polson, and Kieras, 1984; Polson and Lewis, 1990.) Ongoing collaborative work in this project emphasizes model development.

2. Additional research is needed on complex intersections and successive maneuvers. Route-guidance studies have emphasized simple intersections and grid networks (e.g., Walker) but route-guidance systems may be most beneficial for

maneuvers in heavy traffic, at complex intersections, and for difficult maneuvers. These are high accident situations.

3. Except for the work on auditory navigation, U.S. research on route-guidance has not examined the role of landmarks. When people give directions, they refer to underpasses, traffic lights, gas stations, and so forth. The extent to which they improve navigation performance, and the time to process them, should be examined. Landmarks may be particularly useful at night when street signs and cross-street curb edges become very difficult to see. Usefulness at night has not been considered in the published literature.

4. To date, research participants have been given careful instructions on the use of the test in-vehicle navigation systems. Real drivers, when they buy a new car, rent a car, or borrow a car from a friend, just put the key in the ignition and go. They generally do not read the manual or attend an introductory class.

Thus, the U.S. literature shows that, in general, simple auditory and visual systems can provide useful route guidance information and, when properly designed, can be superior to paper maps. The usability of these systems by older drivers, novice drivers, and under difficult conditions (especially at night), needs to be explored, as does the usability of third generation systems. If those systems are to be easy to use (and safe), then more thought needs to be given to modeling driver behavior and using that information to engineer improved route-guidance systems. Again, the evidence reported here is only part of the picture. It will be more complete when European and Japanese data are included. In addition, work is ongoing at The University of Michigan, at the University of California-Berkeley (PATH project), and in Orlando (TravTek) on the safety and ease of use of these systems.

WHAT IS AUTOMOTIVE NAVIGATION?

This report reviews the human factors literature concerning automotive-navigation systems with particular emphasis on route-guidance. It is one of the first reports on a large project of methods to design and evaluate driver-information systems for cars of the future. (See Green, Williams, Serafin, and Paelke, 1991 for an overview.) Other reports will describe experiments concerning experiments on navigation-system-interface design and evaluation.

These systems are being designed to improve traffic flow and reduce congestion, reduce accidents by decreasing uncertainty at intersections where most accidents occur, aid drivers unfamiliar with a particular area, reduce wasted time and fuel due to excess travel (and consequently air pollution), and provide other benefits. Discussion of driver travel behavior and the need for navigation aids can be found in Gordon and Wood, 1970; King, 1985; King, 1986a,b; King and Mast, 1987; and King and Rathi, 1987.

The view presented in this report is distinctly American. While the research conducted on this topic in Japan and especially in Europe is extensive (probably more extensive than in the U.S.), neither time nor space allow its inclusion here. Some of that material will be covered in a forthcoming report written by this author. In addition, this paper also touches upon topics that influence the design of electronic navigation systems; in particular, the usability of paper maps and driver navigation information requirements.

The goal of this report is to bring together all of the user engineering data regarding navigation-system interfaces in a single place--details concerning response times, eye fixations, and interface appearance. To avoid endless revision of this report, the time frame was frozen to the beginning stages of this research project. Subsequent research carried out by others (e.g., Coleman, Loring, and Wiklund, 1991; Dingus, Hulse, Krage, Szczublewski and Berry, 1991; Green and Williams, 1992) and as part of this research project (e.g., Green and Williams, 1992), will appear elsewhere.

The Random House Dictionary of the English Language defines navigation as "the art or science of plotting, ascertaining or directing the course of a ship, aircraft, or missile" (Flexner and Hauck, 1987, p. 1282). In traffic engineering parlance, the purpose of a navigation system is to help get drivers from their origin to their destination. There are six basic questions a navigator might ask:

1. Which way am I going?
2. Where am I?
3. Which way is my destination?
4. How do I get there?
5. Is there a better way to get there than my current plan?
6. How could I get to my destination?

Answering each of these questions requires successively more information. The "which way am I going" question refers to heading, something that can be determined from a compass, a device that does not require external support.

"Where am I?" is another orientation question. Depending on the situation, the answer may be general (west side of Ann Arbor) or specific (2300 block of Jackson Road heading west, next major cross street is Stadium Boulevard). In the automotive context, telling a person grid coordinates on a map or longitude and latitude is generally not useful, since drivers have no mental frame of reference (mental map) for that information.

The destination-direction question requires that the system that is providing that information know both one's current location and the location of the destination. While present location can be determined automatically, the destination usually must be entered manually. Sometimes straight line distance to the destination may also be provided.

Question 4 concerns route-guidance, giving the driver instructions on how to get to a destination. To be most useful, such systems need to know network details (the number of lanes, one way streets, etc.) to tell the driver exactly what to do.

Route diversion answers question 5 by giving the driver moment-by-moment alternatives to a destination. Key features of diversion systems include traffic, weather, and incident data.

Finally, trip-planning systems, which deal with question 6, are the most comprehensive of navigation systems. Trip-planning system implementations can be physically quite different from the other classes of systems because trip planning is thought to occur before drivers leave their origin (often indoors) while navigation occurs in a vehicle. As is described in several papers later, drivers often leave for destinations with only a general plan of how to get there and create detailed plans as they go (or when they stop for assistance).

Some have even defined navigation systems more broadly to include information about destination selection (what should my destination be). Those systems generally consider business listings (Norman, Zavoli, and Heideman, 1991). Although such systems are beyond the scope of this paper, the kinds of information drivers might want are described.

ORGANIZATION OF THIS REPORT

The remainder of this paper covers topics in a loose chronological order beginning with a discussion of the research on automotive maps, including literature reviews, surveys of how maps are used, and several experimental evaluations. Subsequent is a description of a first-generation route-guidance system that was visually based (ERGS), followed by studies of the second generation system (ETAK Navigator/Blaupunkt TravelPilot). The next section covers the development of auditory guidance systems, and, finally, experimental comparisons of visual and auditory systems are made.

AUTOMOTIVE MAPS

Currently, paper maps are the primary in-vehicle navigation aid. If visual-display-based electronic aids are to be used as an adjunct to or in place of paper maps, it is important to know what information drivers desire, how the information might be represented, and the performance advantages and disadvantages of various designs and coding schemes.

However, the literature on the design of maps is not particularly strong. Research has been done by both human factors specialists concerned with making usable maps and geographers concerned with theoretical issues. Those interested in the human factors literature should see Hopkin and Taylor (1979) for an overview. Also relevant is Potash (1977), which addresses issues of map symbols and coding (size, color, shape, etc.), as well as research on the utility of various map features providing orientation information. Information on an extensive research program carried out at Hughes Aircraft appears in Carel, Hershberger, Herman, and McGrath (1974a,b). Unfortunately these reports concern airborne navigation where the features are visible and navigation procedures are quite different.

Cross and McGrath (1977)

The most extensive experimental investigation of issues related to automotive maps is the Cross and McGrath (1977) 487-page report. It examines what maps (and other aids) are used for nonlocal, noncommuting travel. This report includes a literature review, interviews with 51 motorists and 59 travel advisors (gas station attendants, tourist bureau personnel, etc.), an enroute motorist survey, a survey of travel aids, and a detailed examination of maps. To verify the accuracy of the maps, several roads in the survey region (West Virginia) were driven. Each sign and landmark was recorded along with odometer readings to establish a "ground truth log."

The enroute interviews involved 3,117 motorists, of whom 1,137 returned a written survey. Ten percent of the motorists were also asked to show the maps they were using. From the enroute survey, statistics were developed on the purpose and duration of trips, as well as the types of roads traveled. Some of the main findings were:

1. Prior to departure the main source sources of information were highway maps (55%), advice of a friend or relative (25%), road atlas (13%), and auto club advisor (13%). During trips, the sources were guide signs (23%), gas station attendants (15%), and city street maps (11%). In selecting routes, reasons included efficiency (fastest route-54%, shortest route-53%), problem avoidance (safest route-43%, more familiar with route-36%, more miles of multiple lanes-31%, roads in better condition-30%, less chance of getting lost-24%, less traffic-18%, etc.), and pleasure and personal convenience (most scenic route-25%, etc.). The frequency with which reasons were mentioned depended upon whether the trip was for business or recreational purposes. These results have implications for the design of computerized trip planners. If the computer “knew” the purpose of the trip, the information it would need to present to a user would be significantly reduced, and the user interface could be simpler and easier to use.

2. Of those sampled, 25% deviated from their planned routes. Reasons given included "to see an attraction noted on map (8%)," "someone said another route was better (6%)," "escape heavy traffic (6%)," "decided to visit relative/friend (6%)," "see an attraction noted on sign (4%)," "saw interesting looking road (4%)," "roads worse than expected (3%)," "avoid bad weather (2%)," and "sign indicated better route (2%)." Notice that many of these reasons are not associated with traffic or weather that current route diversion systems emphasize.

3. Table 1 shows the availability of trip travel aids, both pretrip and enroute. While most pretrip planning occurred outside the car, in the far future, such planning may take place in the vehicle. Highway maps predominate as trip planning aids.

Table 1. Use of Trip Planning Aids (%)

Aid	Used Before Trip	Used Enroute	Wanted but Couldn't Obtain	Potential Pre-Trip Users
Highway Maps	53	51	9	62
Road Atlas	12	11	1	13
Tour Books/Guides	8	12	2	10
Mileage Guides	8	8	2	10
Hotel or Motel Guides	8	10	3	11
City Street Maps	8	17	8	16
Campground/Trailer Park Guides	6	6	2	8
Restaurant Guides	5	4	3	8
Listings of State Traffic Laws	5	4	3	8
Weather/Temperature Guides	5	3	4	9
Automobile Club Triptiks	4	8	1	5
Travel Articles	2	2	1	3

4. Considerable information was also obtained with regard to existing in-vehicle travel aids. Of the motorists in the enroute survey, 26% had no maps or aids with them that they used or planned to use during that trip, 44% had a state map, 23% had a regional map, 10% had an atlas, 6% had a city street map, 6% had a AAA Triptik, 3% had travel guide books, and 2% had a U.S. map. Of them, 56% had 1 aid, 13% had 2, and 5% had 3 or more. Thus, in general, drivers did not have much information with them and only half the in-vehicle travel aids provided detail at the state level or finer. Thus, detailed local maps provided by an electronic navigation system would add to what drivers have now.

5. Table 2 shows why the drivers surveyed looked at maps enroute. The most common reason, checking the distance between points, seems to be an unexpected first choice. Since the data are for nonlocal trips, these are probably distances to the next town, not the next turn. Motorists look at maps to select the best (shortest, fastest)

route, determine if they are on the correct route, determine where to turn/enter/exit, determine road conditions, and find places for service. These data provide suggestions as to what information electronic navigation systems should display.

Table 2. Why Motorists Looked at Maps

Reason	%
Check the distance between 2 points	68
See if on the correct road	59
See which road to take at junction/intersection	45
Find out which road is shorter	40
Find out where to enter interstate highway	38
Find out where to exit interstate	38
Check the driving time between 2 points	34
Check possible points of interest on route	30
Find the best route through a city/town	28
Check if a road is a freeway	28
Check if road is 2 lanes or more	28
Check for a place to spend night	28
Find the city/town referred to on sign	27
Find a scenic route	26
Find way back to correct route after being lost	22
Check if road is paved	22
Find which route is faster	21
Check if road is divided highway	21
Find a specific point in city/town	18
Check if toll is charged (road)	17
Find place for fuel/service	16
Find a landmark	15
Locate roadside rest area	14
Check for place to eat	13
Check if road is winding	12
Find size of a city/town	12
See if toll is charged (bridge)	7
Find amount of toll	6
Check if road has many steep hills	5
Check layout of freeway interchange	5
Check if unpaved road is passable	1

6. With regard to points of interest, there were striking differences between business and recreational travelers, and by season (winter vs. summer). This again suggests it would be valuable for navigation systems to know the type of trip being made and the time of year. Table 3 shows the points of interest visitedor to be visited by motorists. Readers should realize that visit frequencies will very much depend on the region sampled. For example, military bases are much more likely to be a destination in the Washington, D.C. area where they are quite common, and ski resorts are a very common destination in Colorado in the winter. As before, trips generally have specific purposes and those purposes determine what the driver wants to know, in this case,

points of interest. Trip purpose data could be used to prioritize the display of points of interest data.

Table 3. Points of Interest Visited or to Be Visited by Motorists

Place	%	Place	%
Roadside rest areas	36	Hiking trails	11
Natural attraction	32	Specific streams	11
Park/forest	31	Factories/plants	10
Specific towns for sightseeing	31	Airports	9
Historic site	29	Golf courses	9
Famous man-made attraction	25	Agricultural areas	7
Specific natural attraction	22	Military reservations	7
Public beaches	20	Stadiums, ball parks	7
Camp site	19	Boat Launches	6
Museums	17	Race Tracks	6
Specific lakes	16	Fairgrounds	5
Amusement parks	15	Fish Hatcheries	5
Colleges	14	Libraries	5
Harbors, marinas	13	Railroad stations	4
Wildlife areas	13	Ski areas	4
Cemetery	12		

7. Cross and McGrath (1977) also examined motorist orientation. Some 4.7% of those responding "often felt uncertain of their position or direction of travel" and another 1.5% felt "lost or confused much of the time." These numbers, when totaled, lead to the assertion that at any time, 6% of travelers are uncertain of where they are or are lost. When motorists need directions or information they ask gas station attendants (44%), other motorists or pedestrians (14)%, employees of restaurants, hotels, or motels (13%), official tourist center officials (10%), police officers (7%), and others. As shown in other studies, gas station attendants are the primary source of information.

8. Shown in Table 4 is what the motorists wanted to know. The total exceeds 100% as they sometimes sought multiple items of information. Most common were directions to a specific highway, not complete directions to a destination.

Table 4. What Motorists Wanted to Know

Item	%
Directions to specific highway	48
Directions to specific local destination	42
Where to eat	26
Miles to a point	20
Direction to another city or town	19
Which route is best	17
Motel or hotel	15
Road conditions ahead	14
Driving time to a point	12
Weather ahead	10
Camping	9
Recreational facilities	6
Where to obtain repairs	6
Direction to a specific nonlocal destination	5

9. Table 5 shows the problems reported by drivers for interstate highways and Table 6 shows the data for conventional highways. Readers should note that the reasons given were selected from a list created by the experimenters. They were not free response data, and, as a consequence, the categories overlap somewhat.

Table 5. Problems with Interstate Highways

Problem	%
Made wrong turn at interchange	17
Trouble finding entrance ramp	16
Took entrance for wrong direction	15
Not sure if lost	15
Missed a bypass route planned to take	14
Became confused at interchange	13
Traveled some distance in wrong direction on right road	9
Got off correct route but don't know how	8
Passed exit, couldn't get over in time	7
Had trouble finding food/fuel/lodging referred to on sign	7
Entered and exited ramp by mistake	5
Didn't know beforehand which exit to take	3
Exited because stuck in lane	1

Table 6. Problems with Conventional Highways

Problem	%
Feeling of being lost or on wrong road but not sure	17
Turned in wrong direction at a junction of 2 roads/streets	16
Went straight when should have turned at junction	15
Confused at intersection	15
Missed city bypass planned to take	14
Got off route wanted to be on but don't know how	13
Traveled some distance on wrong road before realizing	10
Traveled some distance in wrong direction on correct road	9
Mistakenly took truck route through city or town	5

10. Finally, with regard to the maps examined, the investigators found inconsistencies in the coding used, both for roads of various classes and other markings. It is not known if inconsistency in the symbols used on electronic displays will create problems for drivers. Clearly, the symbols recommended by AASHTO (American Association of State Highway and Transportation Officials) should be considered.

For determining the information available and desired by drivers, Cross and McGrath (1977) is still the most valuable source in the published literature and should be required reading for those defining system functionality. It contains a wealth of data indicating type of information desired and presentation problems with paper maps.

Stilitz and Yitzhaky (1979)

Stilitz and Yitzhaky (1979) examined the effect of grid size on street location time for urban maps, a theme quite different from the report described above. In the first experiment, a fixed-size street map of Jerusalem was used (82 x 70 cm, 1:12,500 scale) on which varying number of grid lines were printed. The area covered by the map was not listed. Each subject (125) was given the name of a road (in Hebrew) and its grid coordinate, and was told to point to it. The number of roads/grid square varied. The target location time (T) was equal to 6.55 + 1.2(1/GLS) + 0.36n where GLS, the grid line separation, is .2, .25, .33, .5, and 1 km, and n is the average number of roads/grid square. Notice that the effect of the number of roads/grid square (n) is linear. The authors note that other analyses showed larger values of r^2 when n^2 was included, but they did not present that regression because they could not come up with a reason for the square effect. The results could be due to idiosyncrasies of the geography of Jerusalem (variations in street density, missing street names, etc.).

In a second experiment, 50 people located coordinates on the same set of maps. Using the combined data, the time to locate a street within a grid was equal to 2.1 + .38n, where n is the number of roads in the grid (range of 4 to 25). The data suggest that there will be significant penalties to adding detail to in-vehicle maps, almost 0.4 second for each additional road shown (for 4 or more roads).

Adeyemi (1982)

Adeyemi (1982) examined problems of orientation when a map is north up but the person is facing in another direction. Participating in this experiment were 131 people from Madison, Wisconsin: 51 randomly selected adults (Group 1), 40 students from all disciplines (Group 2), and 40 students in a geography class (Group 3). Before testing took place the experimenter reviewed the four cardinal and intermediate directions on a compass, and gave a brief warm-up test dealing with maps. Participants were also told which way they were facing and given a map of Madison. Where they lived was cut out. Participants then responded to 20 questions concerning 5 topics: (1) inferring the direction of features using an egocentric frame of reference, (2) pointing out the geographic direction of landmarks, (3) orientation during travel (a simulation), (4) orientation between features, and (5) route tracing and sketching. Example questions are not provided.

Group 1 was given a city guide map that showed only north on it. For them, the direction they faced significantly affected how well they answered the questions (96% correct for north vs. 64% for south, 54% for west, and 49% for east). The only differences not significant were between facing east and facing west.

Group 2 was given topographic maps showing the eight compass points while Group 3 saw topographic maps showing north only. Providing the 8 reference points led to significantly better performance on the test (69% vs. 49%). These data argue for aligning maps with the direction a person is facing for orientation and route following tasks (use heading up, not north up) and providing multiple direction markers, not just north. Providing heading only was not examined.

Petchenik and Clawson (1984)

Petchenik and Clawson (1984) provides a review of the geography literature (360 references) from the perspective of a cartographer, a perspective not captured elsewhere in the literature. The literature review covered 5 topics: spatial orientation and ability, map use, where people get navigation information, driver information needs, behavior and performance, and dangers in driving.

The report also describes phone interviews of 200 people conducted in Chicago and Washington, D.C. concerning map usage. Of them, roughly 1/3 had not driven to an unfamiliar local place in the past 6 months. Places driven to and how people found their way are shown in Tables 7 and 8. Frequency data is also provided in the original report. Whether the destination was local or not had a significant impact on where people were going and how they found their way. Because these trips included personal travel, these distributions are different from that reported by Cross and McGrath (1977). The pattern for nonlocal trips is not different from that reported in the literature. Motorists go to the vicinity of the destination somewhat unsure of its location and expect to either search for it themselves or find someone in the area who can direct them to the destination.

Table 7. Unfamiliar Destinations

Place	Local %	Nonlocal %
Business or store	49	23
Friend's house	12	27
Restaurant	12	3
Place of entertainment	10	11
Business client	9	5
Other	9	16
Don't know	2	1
Hotel or motel	0	14

Table 8. How People Found Their Way to Unfamiliar Locations

Method	Local %	Nonlocal %
Called destination for directions	33	28
Looked at map or atlas	32	63
Asked someone for directions	20	20
Drove around	6	2
Other (e.g., Yellow Pages)	5	6
Got in vicinity, stopped for directions	2	10
Don't know	1	0

Finally, this report briefly discusses the relative advantages of written directions and maps for way-finding. They conclude that people prefer directions as text, especially for the local area.

Streeter and Vitello (1986)

This article describes related work on how well drivers read maps and what information drivers want from navigation systems. The first experiment examined individual differences. Some 33 women, ranging in age from 18 to 66, participated. They completed 5 tests from a standard battery concerned with cognition: a calendar test ("What is the seventh working day after the third Monday ...?"), a test of which maps they had seen previously, a maze tracing test, a test of where buildings were on a map, and a route planning test. In the last test, participants determined the shortest route between two points as quickly as possible. Participants were also asked about their navigational ability, their experience with maps, and their navigational habits and preferences (relative importance of cost, distance, time, lack of turns, etc.).

Table 9 shows the results for navigational preferences. On all types of trips drivers wanted to avoid construction and bad roads.

Table 9. What Is Important to Drivers on Trips

Trip	Activity	Importance Rating (1-9, 9=most)
Short	Road construction/bad roads	6.7
	Traffic	6.1
Long	Road construction/bad roads	8.5
	Use of major roads	7.7
	Good scenery	6.5
	Few stop lights	6.5
	Travel time	6.4

When giving directions, the most important factors were giving the directions in words (7.3) and describing landmarks along the way (7.2). For receiving directions, key factors were landmarks along the route (7.9), knowing the name of the street one block before the turn (7.0), and giving the directions in words (6.9). People who said they had poor navigational skills were more likely to want landmarks (county boundary markers, doctors' offices, law offices, factories, and houses) than those with good skills, who preferred street names. Table 10 shows some other interesting differences.

Table 10. What People Preferred vs. Navigational Ability

		Self-rated Navigation Ability	
Task	Preference	Low	High
Route Selection	Minimize # of stop lights	x	
Short trips	Choose a simple route	x	
	Avoid construction And traffic		x
Long trips	Cost	x	
	Minimize # of turns	x	
	Select quiet route		x
Giving and Receiving Directions	Look at a map when receiving route		x
	Draw a map when giving directions		x
	Have a road map in car		x
	Follow someone to a destination	x	
Map-Reading Habits	Think rivers & streets are valuable on maps	x	
	More likely to use street index	x	

Experiment 2 concerned how routes selected depend on familiarity with the area and how routes selected compare with standard "graph search" procedures. There were 3 groups of subjects: 20 "experts" who drove to work (Bell Labs-Holmdel, NJ), 10 "experienced" people who lived in the area, and 12 "novices", students from nonlocal colleges. The experts gave verbal directions on how they drove home. From them, 12 routes were selected. People in the experienced and novice groups were given maps on which the origin (Bell Labs) and the homes of 12 of the experts were marked. They traced out the routes they would choose.

Table 11 shows the errors made. Novices made an average of 1.06 errors per map, experienced an average of 0.65. Most of the errors involved getting on and off expressways, though there were some absurd errors involving treating nonroads (e.g., county boundaries) as roads.

Table 11. Route Tracing Errors for 12 Trips

	Errors (%)	
Error Type	Experienced	Novice
Illegal entry to limited-access road	54	62
Illegal exit from limited-access road	23	33
Boundary markers (e.g., county line) used as road	12	5
Route did not end at destination	7	0
Railroads and rivers used as roads	2	<1
Route did not begin at origin	1	0

Table 12 shows the kinds of routes people selected. Experts used their local knowledge and made greater use of local roads. Expert routes were about 5% shorter using all the data, but about 7% shorter for the routes that could actually be driven. They also involved slightly fewer turns, but not significantly fewer. Finally, Streeter and Vitello describe in great detail the strategies used by drivers to develop routes. Readers should see the original paper for those details.

Table 12. Road Types Selected (%)

Road Type	Experts	Experienced	Novices
Limited-access only	17	40	62
Limited-access & secondary	0	1	7
Secondary only	8	18	10
Secondary & local	33	19	8
Local only	42	21	12

As other studies show, drivers placed a high priority on knowledge of construction and traffic, information usually not provided by maps. In terms of using maps, novices made just over one error per trip, others .65 errors per trip. Most of the errors were associated with getting on and off of limited-access roads. If electronic navigation systems mimic paper maps directly, these errors are likely to continue to occur.

Summary

In summary, two reports provide comprehensive reviews of the literature pertaining to automotive navigation and the use of maps, Cross and McGrath (1977) and Petchenik and Clawson (1984). Although they were completed quite a few years ago, little research was done in the 1980 s on maps for cars, so these reports are still quite current. Maps are the predominant source of pretrip planning information, followed by road atlases. The typical driver does much of the detailed planning enroute, often heading in the right direction and then acquiring additional instructions on the way. At any given time, about 6% of drivers are uncertain where they are. Thus, clearly there are motorists who could use automotive orientation and route-guidance systems.

A key source of information is often maps, but drivers sometimes lack maps that are more detailed than state maps. Maps that show individual streets and details of expressway exit and entrance geometry should be of great use to drivers, especially in light of Streeter's research. Drivers also want information on construction and traffic, information not currently given on maps. According to Adeyemi, those maps should be oriented heading up, and, to help drivers orient themselves, it is desirable to show all four cardinal directions or possibly all eight compass directions. Research on maps shows that it takes about 2.1 seconds to scan one grid section of a map (which could correspond to a single in-vehicle screen) with just under 0.4 seconds being added for each street to be viewed).

On longer trips, about 25% of all drivers divert from their planned routes. No single reason seems to predominate. It is clear, however, that the type of information that might cause them to divert (traffic, tourist attraction, etc.) is trip specific. To reduce driver search time, it may be desirable to organize business listings (electronic yellow pages) based on the purpose of a trip. For these trips, rest areas were the number one point of interest, information not given by many navigation systems.

A final theme that appears in several studies is the importance of landmarks for route-guidance. As shown by Streeter, landmarks are particularly important to people unfamiliar with an area. Those familiar with an area make greater use of street names.

DEVELOPMENT AND TESTING OF FIRST GENERATION VISUALLY BASED SYSTEMS (ERGS)

The development of the Experimental Route Guidance System, ERGS, was supported by the U.S. Federal Highway Administration (Prewitt and Trabold, 1968; Stephens, Rosen, Mammano, and Gibbs, 1969; Trabold and Prewitt, 1969). Federal Highway awarded contracts relating to the driver interface with both Serendipity Associates (a consulting firm) and General Motors designing actual interfaces. There was also a contract to support development of a Head Up Display (HUD) (Benzinger and Bell, 1969).

Serendipity's Efforts

Serendipity's work began with a detailed task analysis of what drivers do at intersections and how far in advance information was needed (the information lead distance). (See Eberhard, 1968; Eberhard, Jones, Kolsrud, and Schoppert (undated).) It was assumed the driver was unfamiliar with the area of interest. Based on their analysis, they report that 2459 feet would be required for a worst-case lane-change and 483 feet for a speed-change maneuver. The lane-change example assumed a truck merging left, an aged driver, poor visibility, and a wet road surface.

Presumably during the early design stages of ERGS, it was decided drivers would enter a five-letter code word for a destination, using small thumbwheels on the instrument panel. At each intersection the driver received instructions concerning what they should do. If the driver did not follow the recommendation, the instructions were automatically updated at the next intersection.

Based on these ideas, the display shown in Figure 1 was developed. Critical information provided by the display included 1) an indication (a tone) of an approaching choice point, 2) the proper lane for the choice point (keep left, keep right), and 3) information if ERGS is interrupted (int) or malfunctioning (mal) and the routing instructions should be ignored. The word "exit" is used to identify when drivers should exit an expressway. The "then ERGS 0-9" is used for complex intersections, especially traffic circles, in conjunction with special external signs in which each street is given an ERGS number. The display was also color coded. (See Eberhard, Jones, Kolsrud, and Schoppert (undated) for details.)

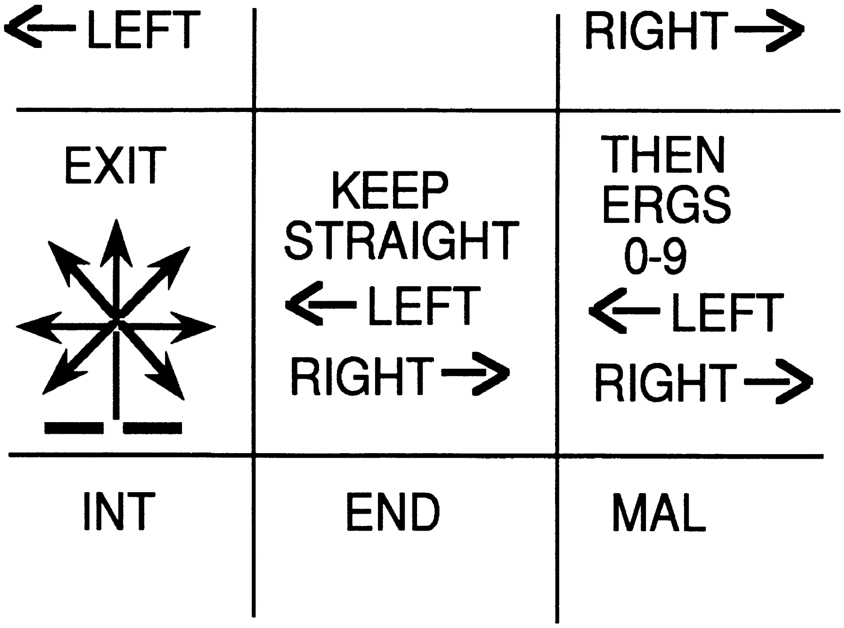


Figure 1. Early version of the ERGS Display.

To obtain reactions to this system 561 people watching a film explaining ERGS at the Smithsonian Museum ("Guiding Tomorrow's Motorist") were surveyed. There is no indication that participants operated a prototype of the system. Of them, 43% said they would buy such a system (mean price=$149). Those who would buy it were people who are lost more often. Their strongest preference was for showing highways connecting the suburbs and downtown (37%), but there was also considerable interest in showing interstates between cities (23%) and downtown shopping and business (24%). Lane change information was also desired (87%) with the strongest preference being a display supplemented by a warning tone (34%), where the display should show both words and arrows (81%). Most respondents (75%) wanted both appropriate and inappropriate paths shown. Finally, a head-up display was strongly preferred over dash-mounting (78 vs. 22%).

GM

General Motors used an intersection micromap as a starting point for their design (Rothery, Thompson, and von Buscek, 1968). GM did not use Serendipity's numbered exit scheme because it did not work well in poor visibility and required many new road signs. (See Figure 2 for an example.)

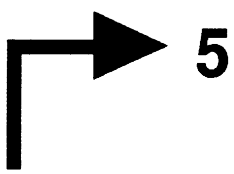


Figure 2. Routing Arrow with Branch Number

The initial micromap and first modification of it are shown in

Figure 3. The modifications were made because drivers viewed complex maneuvers of successive turns as a single unified response.

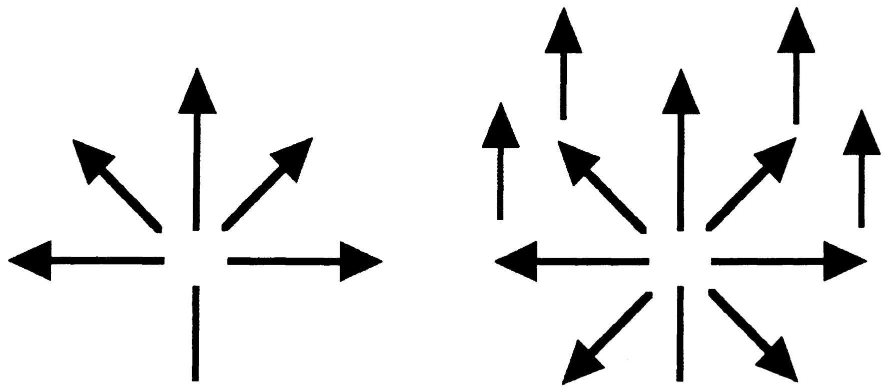


Figure 3. Initial and First Modification of the Micromap

Drivers had problems with this design at traffic circles in undescribed informal tests. Figure 4 shows the original and modified designs chosen to reduce this tendency.

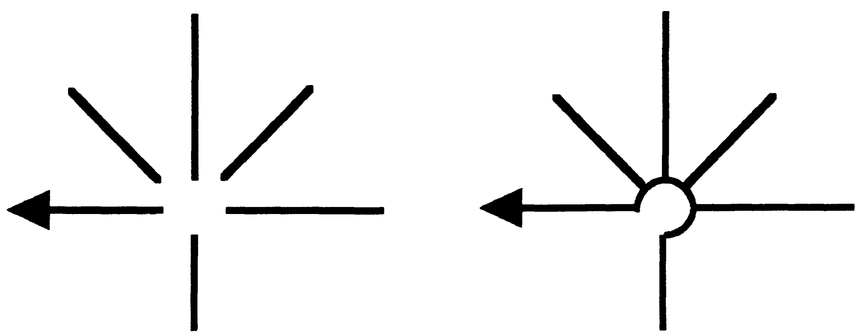


Figure 4. Further Modification of Micromap

Further, it was observed that at traffic circles, drivers counted the arms to locate the exit branch, in part because the view shown on the map was incompatible with the view through the windshield. To examine the merits of using text instead of the micromap, 8 drivers were shown images similar to the right hand side of Figure 4 or the equivalent text ("Take 4th right"). Drivers approached a traffic circle with 6 exit branches 5 times. Slides of the guidance instructions (micromap and text) were projected on to a screen mounted on the instrument panel. The driver controlled the exposure duration via a shutter cable. The exposure duration was shorter for text than for the micromap for every trial except the first one. The mean times were 1.18 seconds for the text and 2.02 seconds for the micromap. Text displays were also rated as more satisfactory (1.9 vs. 4.4, where 1=highly satisfactory and 7=highly unsatisfactory). These results led to the proposal shown in Figure 5.

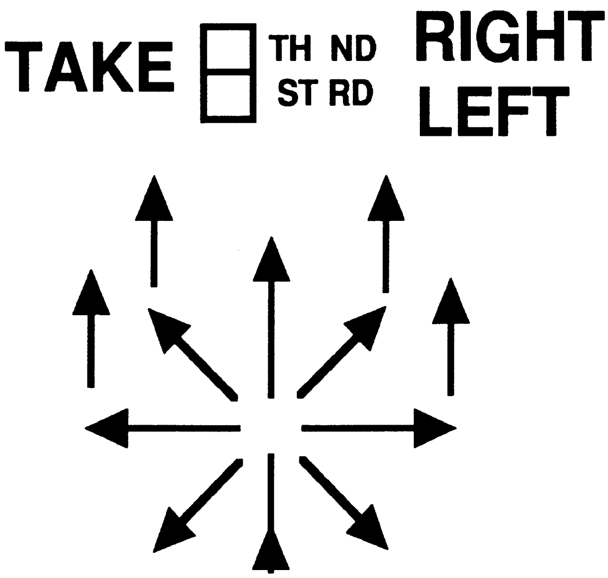


Figure 5. First Micromap Design to Incorporate Text
(Note: Exit branches were numbered 1-9)

Those changes did not eliminate problems that drivers had with instructions to change lanes. To examine alternatives, drivers were shown road scenes shot from inside a car (either the right or left lane of a dual-lane highway). Subsequently, a slide of one of the eight images was shown on a screen simulating the ERGS display. (See Figure 6.) If a lane-change instruction was shown and the driver was in the proper lane, a verbal acknowledgment was required. For lane changes and turns, drivers moved a turn signal in the appropriate direction. The mean time to respond to text lane-change messages was slightly less than the graphics (950 vs. 1019 ms). For exit messages, text took significantly longer (1050 vs. 789 ms). For this reason, text-based lane-change messages were added to the ERGS display, resulting in the ERGS-I proposal of December, 1967. (See Figure 7.)

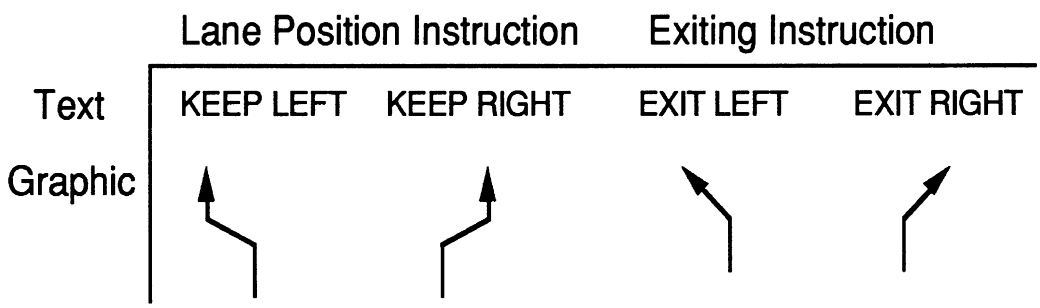


Figure 6. Text vs. Graphic Comparison

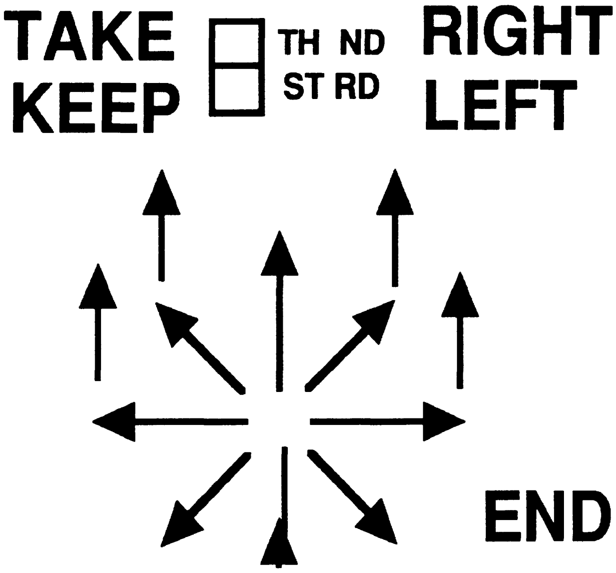


Figure 7. ERGS-I Display

The keep-right/keep-left messages were fine-tuned in a subsequent experiment in which either all letters or only the first letter of each word was capitalized. In addition, supplemental arrows could be included (pointing left or right). Fourteen people responded to slides of the message by pressing a corresponding left or right button. There was no difference due to case (both 450 ms), with arrows decreasing the response time slightly (461 vs. 439 ms) but not significantly. As a consequence, upper case text with arrows was added to the revised display.

Further analysis showed drivers had difficulties when two exits from an arterial were closely spaced. Other refinements included the addition of the word "then" for closely spaced maneuvers and the elimination the discontinuity between "tree" arms to more clearly represent turns. These changes led to the ERGS-II display shown in Figure 8. Figure 9 shows a sample of messages that can be generated.

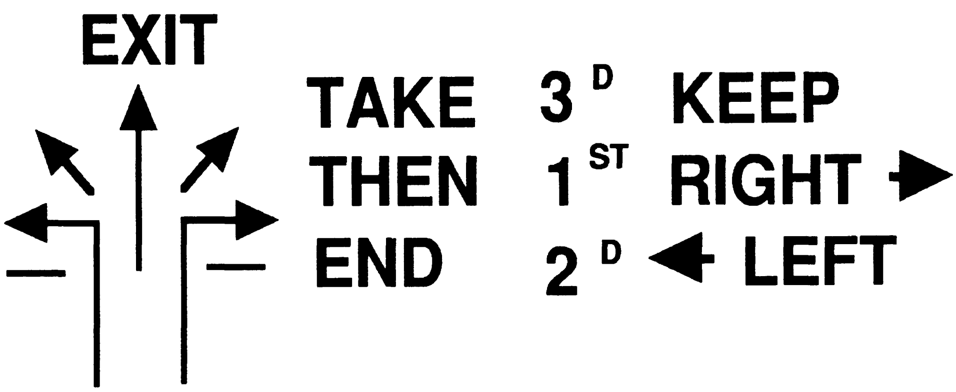


Figure 8. ERGS-II Display

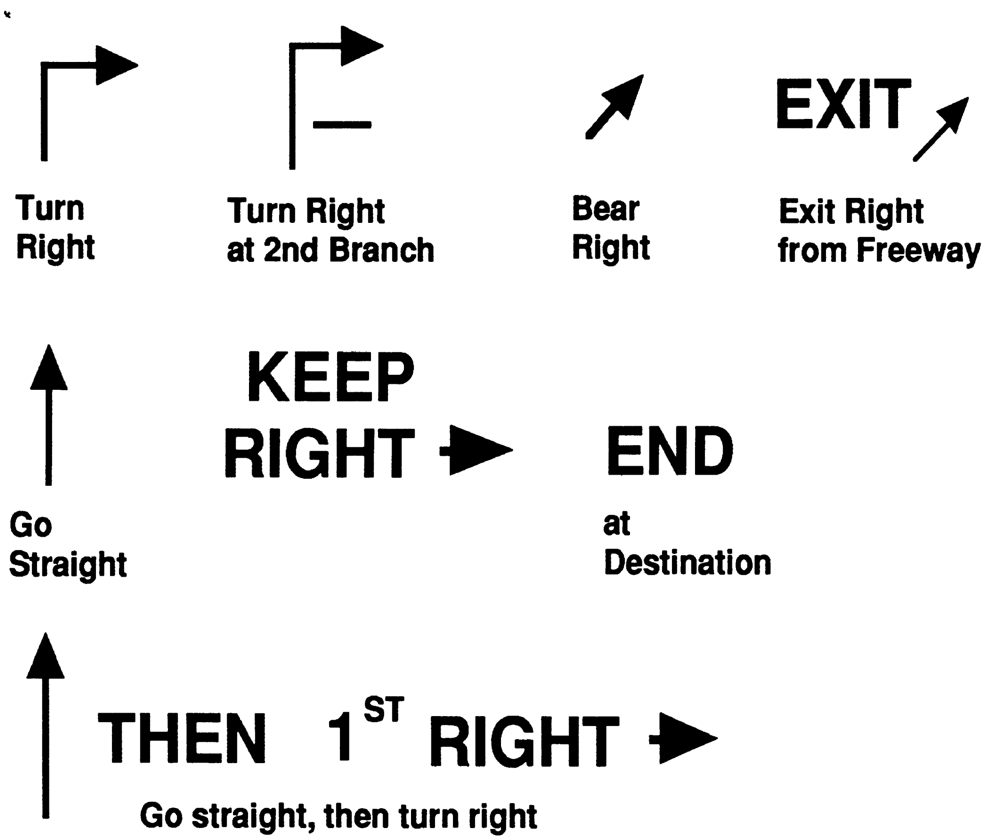


Figure 9. Some Typical Messages to Drivers

In addition to providing details on the evolution of the ERGS display, the Rothery paper describes some of the measures that might be used to examine driver performance with a route-guidance system. They conclude that eye-fixation data are "of rather limited value" in routing tasks (Rothery, Thompson, and von Buscek, 1968, p. 42). This conclusion may be based on concerns for the difficulty of collecting fixation data at the time (less true now). They have a favorable view of Senders helmet-based measures (in which a translucent visor periodically blocked the driver's view), as well as response-time data collected in the laboratory. In such studies, the time that the road could be seen is the measure of performance. In addition, Rothery, et al. commented on several other measures (spare mental capacity, steering wheel output--especially steering wheel reversal rate, brake pedal actuation records reflecting driver uncertainty at decision points, and others).

Rothery, et al. proposed several studies relating to navigation. To examine routing-aid content, drivers would be shown a map and then create a set of directions to a destination (a sketch, a list of directions, etc.). Preferences would be obtained as a function of route complexity. The results might suggest the most appropriate format for route-guidance for a particular journey.

In a related experiment, drivers would be familiarized with a route to either a distant or fabricated destination using a map. They would then be shown intersection slides and the ERGS display (or conventional routing aids). At each decision point their task would be to indicate which direction they should go (straight, right, left, diagonal) by pressing a button. The response-time data would indicate the relative effectiveness of alternative aids and interactions with decision-point characteristics. Using the same basic task, Rothery, et al. also proposed experiments concerning the number of signs at choice points and the role of illumination levels.

On-the-road studies in which the use of ERGS is simulated via preprogrammed instructions were also proposed by Rothery, et al. Details of the navigational and interface issues are not described. Rothery suggests that studies of spare mental capacity (workload as measured by a secondary task), steering behavior, and stress (as indicated by GSR) should be conducted, but details are not provided. Also noted as being necessary are studies in which drivers enter a destination into an encoder and then try to follow the ERGS output. Dependent measures would include trip time, speed, routing errors, and so forth.

Unfortunately, none of these studies were conducted. A review of the ERGS program indicated that although a very favorable cost-benefit ratio existed at the time, the cost to implement the program was enormous. Consequently, because of other priority national programs, additional funding for research, development, and implementation was not authorized. However, a great deal of thought went into the design of ERGS by some very talented people, so there is much to be learned from its history. That effort was supported by several small-scale laboratory studies and a careful task analysis. Except where design was limited by the display technology available at the time, interfaces should follow the following implementation recommendations of Rothery, Thompson, and von Buseck, 1968:

1. Show the immediately occurring turn as well as what to do afterwards.
2. Confirm when turns are not required (a continue instruction).
3. Provide lane information in addition to turn information.
4. The desired form of instructions varies with the task. Text messages are slightly better for lane-positioning (keep left) while symbolic messages are better for exit messages.

It is not recommended, however, that the ERGS display graphic be used for current systems in its original form. Trying to accommodate traffic circles had a significant impact on the design, an intersection which is relatively less common today. On the other hand, ERGS did not consider freeway interchanges, which other studies have shown are important to drivers.

Not only is the design noteworthy, but also are the methods for collecting data in the laboratory studies--(1) response times to slides of guidance displays presented in unison with slides of road scenes and (2) response times to slides of guidance display where drivers control the exposure of the guidance display. There should be good agreement between the results of those studies and much more expensive on-the-road eye-fixation experiments, but that linkage has not been examined experimentally.

STUDIES OF SECOND-GENERATION VISUALLY BASED SYSTEMS (ETAK NAVIGATOR)

Staal (1987)

Staal's letter describes an obscure study of driver reactions to the ETAK Navigator. It does not contain any performance data.

Because it is referred to in several sections of the paper, and is so central to ideas about the design of automotive navigation systems, a detailed description of the ETAK Navigator/Blaupunkt TravelPilot is given. Figure 10 shows some typical navigator screens. The small monochrome display has twelve adjacent push buttons, six on each side. The Navigator shows detailed street maps, which have an adjustable map scale. The system does not provide route-guidance though it does show one's current location, and allows for entry and display of a destination.

To enter a destination, drivers use both numeric and alpha modes. Drivers first enter the street address through the numeric mode by pressing keys corresponding to each number. Next, using the alpha mode, they select a region of the alphabet (e.g., A-F) and then a character for each letter of the street name. Finally, after a few letters are entered in, a typical shortcut is to go to a scrolling list of street names and to select the name based on a partial match.

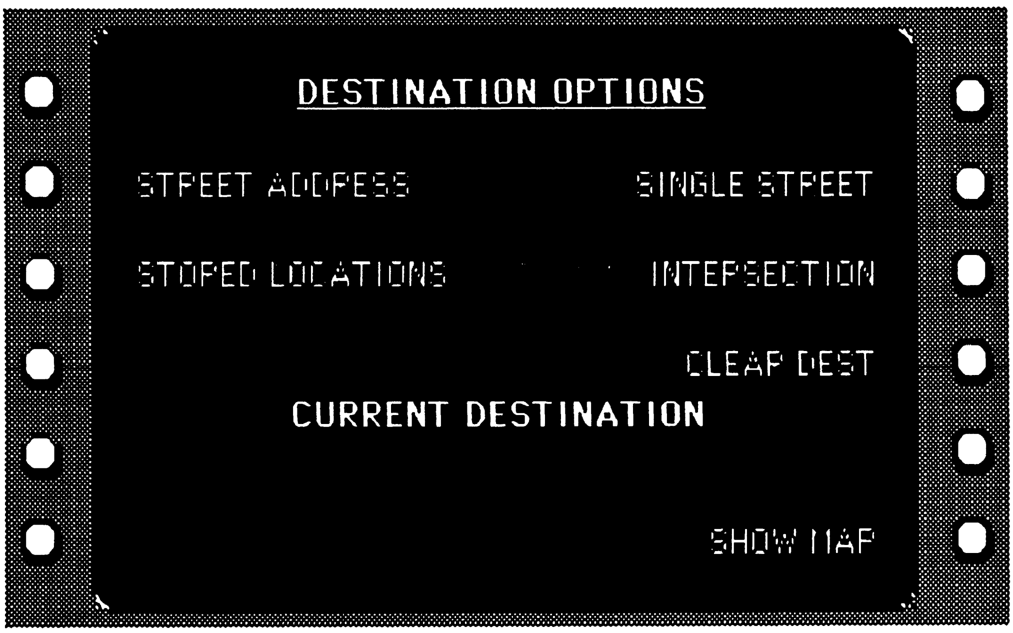


Figure 10. Typical ETAK Navigator Screens

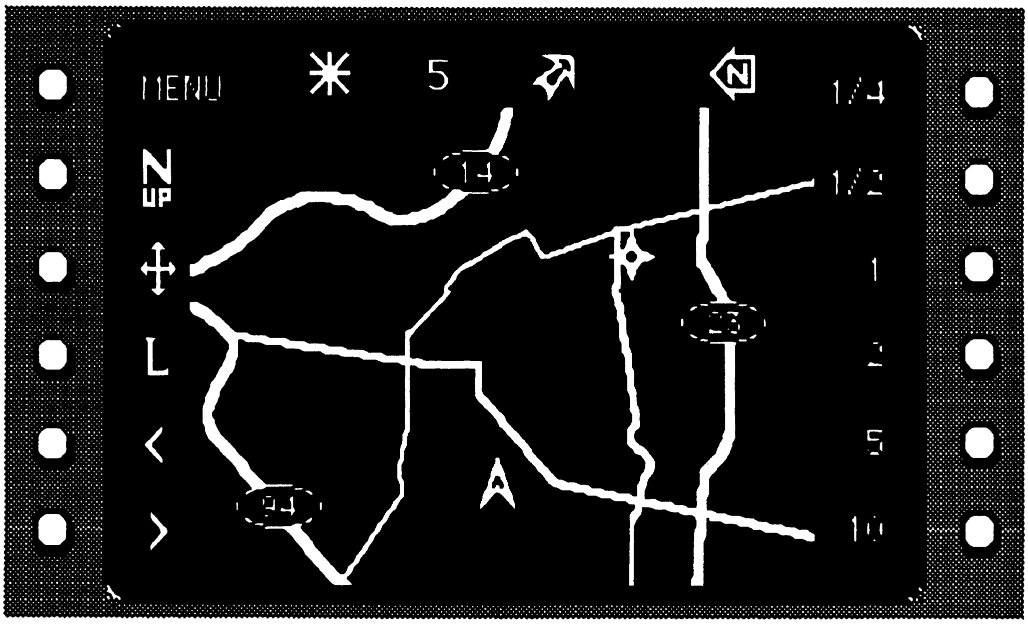


Figure 10 (continued). Typical ETAK Navigator Screens

To obtain reactions to it, a survey was given to 108 customers of National Car Rental in Los Angeles and San Francisco. These renters appear to be a select group, including a large number of executives (presidents and vice-presidents of companies) and various technical people, including eight engineers. Of the sample, 24 had requested a car with the Navigator and 98 used the unit during the rental period. It is not known how or how many people were solicited, nor how or when the survey was administered. Apparently they had all used the Navigator while driving. Half of them were given some training by National employees, but all apparently had access to printed instructions.

Table 13 shows how the Navigator was reportedly used. Locations for offices, hotels, restaurants, points of interests, and other destinations were commonly requested.

Table 13. How Was the Navigator Used?

Used to locate	Frequency	Median # Times (when used)
Office	49	2
Hotel	51	1
Restaurant	43	2
Point of interest	55	2
Other destination	55	2
Alternate route	20	2

Of the respondents, 83% found the Navigator to be useful, though 49% said they would use a map or written directions with it. Respondents indicated they would consider it for their own cars (53%). A typical respondent was to pay an extra $5-$9 per day for it in a rental car, and agreed that it was better than a map in an unfamiliar city. Their comments reflected some problems in learning how to use the unit ("very useful once I learned how to use it").

Thus, this study suggests that a select group of drivers found the system to be usable, though there were complaints about the ease of learning. Quite interesting is the relatively high value placed on having one in a rental car. For this audience, installing navigation systems can be profitable to the rental-car companies.

Wierwille and His Colleagues

To date, Wierwille and his colleagues have published the results from two sets of studies involving on-the-road evaluations of navigation systems. Part 1 of the first set was Dingus' dissertation (Dingus, 1988) which examined the attentional demand of using an ETAK Navigator. This research also was described in a technical report (Dingus, Antin, Hulse, and Wierwille, 1986), a proceedings paper (Wierwille, Antin, Dingus, and Hulse, 1988), and a journal article (Dingus, Antin, Hulse, and Wierwille, 1989). Part 2 (Antin's dissertation - Antin, 1987) concerned electronic navigation systems and alternatives. The dissertation also was printed as a technical report (Antin, Dingus, Hulse, and Wierwille, 1986), and a journal article (Antin, Dingus, Hulse, and Wierwille, 1990). An overview of both studies appears in a proceedings paper (Dingus, Antin, Hulse, and Wierwille, 1986).

The second set of studies was Hulse's thesis (Hulse, 1988). That research (two experiments) examined how anticipation for attentional demand affected the use of a navigation display. That thesis, along with an executive summary, was printed as a technical report (Wierwille, Hulse, Fischer, and Dingus, 1987). Summaries appear in three proceedings papers (Wierwille, Hulse, Fischer, and Dingus, 1988; Hulse, Dingus, Fischer and Wierwille, 1989; Wierwille, Hulse, Fischer, and Dingus, 1991).

More specifically, the initial experiment in the first study considered the visual/attentional demands and driving-performance changes associated with using a moving-map display. The second experiment addressed use of the electronic navigation system, paper maps, and memorized routes, as well as methodological issues. In both experiments, 32 drivers (16 men, 16 women; ages 19-73) operated an instrumented 1985 Cadillac Sedan DeVille fitted with an ETAK Navigator (with the smaller screen). They drove from 2,000 to 40,000 miles per year.

Three test routes near Blacksburg, Virginia included city streets, two-lane state roads, and expressways. With a few exceptions, each subject drove each route under either light (10 AM) or moderate (4 PM) traffic conditions. Each test route took about 20 minutes to complete. Prior to testing, drivers were given two to four hours of training on the use of the controls and displays in the vehicle, including the navigation system. In the test run, drivers were asked by an experimenter in the car to perform 1 of 26 tasks (8 navigational (e.g., determine distance to destination, next cross street) and 18 "conventional" (e.g., activate turn signal, adjust power mirror) while driving. There was about 15 to 20 seconds between requests. These tasks were selected to span the range of attentional demand. It should be noted the ETAK unit was not actually used for navigation.

To record driver eye fixations, two cameras were mounted on the vehicle, a hood-mounted camera aimed at the driver and a second aimed at the forward scene. When the driver was looking at an object, an experimenter in the back seat pushed a button. When the gaze shifted, the button was released until another object was fixated. Later analysis showed the fixation durations to be accurate as the experimenter's response time was constant. Thus, Wierwille was able to obtain fixation data without resorting to a head-mounted eye-fixation camera. In addition, steering wheel measurements, speed, and foot control use were all recorded automatically. When the vehicle was on or beyond a lane boundary, the front seat experimenter pushed a button.

Table 14 shows the total glance times for each task, ranging from 0.78 to 10.63 seconds. Many of the differences in task times were statistically significant. Three of the navigator tasks had particularly long durations: roadway name (road for next turn), roadway distance, and cross street (next). The only performance characteristic affected by individual differences was total glance time, and it was affected only by driver age. The difference was between the 50-years-old and over group (4.12 seconds) and younger drivers (ages 35-49, 2.80 seconds; ages 26-34, 2.86 seconds; ages 25 and under, 2.63 seconds).

Table 14. Total Display Glance Time for Each Task

Task	Mean Time (sec)	Standard Deviation
under 1.0 seconds		
Speed	0.78	0.65
Following Traffic	0.98	0.60
1.0 to 2.5 seconds		
Time	1.04	0.56
Vent	1.13	0.99
Destination Direction	1.57	0.94
Remaining Fuel	1.58	0.95
Tone Controls	1.59	1.03
Info. Lights	1.75	0.93
Destination Distance	1.83	1.09
Fan	1.95	1.29
Balance Volume	2.23	1.50
Sentinel	2.38	1.71
Defrost	2.86	1.59
Fuel Economy	2.87	1.09
Correct Direction	2.96	1.86
2.5 to 4.0 seconds		
Fuel Range	3.00	1.43
Temperature	3.50	1.73
Cassette Tape*	3.23	1.55
Heading	3.58	2.23
4.0 to 8.0 seconds		
Zoom Level	4.00	2.17
Cruise Control	4.82	3.80
Power Mirror	5.71	2.78
Tune Radio	7.60	3.41
over 8 seconds		
Cross Street	8.63	4.86
Roadway Distance	8.84	5.20
Roadway Name	10.63	5.80

Note: For the cassette, 1.64 seconds and 0.59 seconds of the standard deviation was searching for and orienting the cassette.

Table 15 shows the durations for each glance with tasks listed in the same order as the previous table. Glance durations range from 0.62 to 1.66 seconds. Notice that the rank ordering of the two sets of times are similar (as expected) but not identical. The number of glances varied from about 1.25 seconds for speed to 6.5 seconds for roadway name.

Table 15. Display Single Glance Length

Task	Mean Length (sec)	Standard Deviation
Speed	0.62	0.48
Following Traffic	0.75	0.36
Time	0.83	0.38
Vent	0.62	0.40
Destination Direction	1.20	0.73
Remaining Fuel	1.04	0.50
Tone Controls	0.92	0.41
Info. Lights	0.83	0.35
Destination Distance	1.06	0.56
Fan	1.10	0.48
Balance	0.86	0.35
Sentinel	1.01	0.47
Defrost	1.14	0.61
Fuel Economy	1.14	0.58
Correct Direction	1.45	0.67
Fuel Range	1.19	1.02
Temperature	1.10	0.52
Cassette Tape	0.80	0.29
Heading	1.30	0.56
Zoom Level	1.40	0.65
Cruise Control	0.82	0.36
Power Mirror	0.86	0.34
Tune Radio	1.10	0.47
Cross Street	1.66	0.82
Roadway Distance	1.53	0.65
Roadway Name	1.63	0.80

The time for the three most time-consuming navigation tasks depended upon whether the driver needed to zoom to get the information required. (See Table 16.) Requiring the use of zoom roughly doubled the total glance time.

Table 16. Navigation Task Total Glance Times

	Mean Total Glance Time (sec)	
	Info Available	Zoom Required
Roadway Name	4.61	12.12
Roadway Distance	6.77	10.77
Cross Street	4.05	8.91

Table 17 shows the number of lane exceedences by task and their mean duration. In general, performance on this dimension was correlated with the total glance time and mean fixation duration. It is likely that the linkage would have been stronger if the dependent measure had been a continuous variable (e.g., lane deviation) instead of a binary value (in or out of the lane). The most exceedences were for operating a power mirror, inserting a cassette tape, and tuning the radio, followed by roadway distance, roadway name, and cross street. These tasks tended to "capture" attention. For example, once the drivers started to tune the radio, they continued until the task was complete. Roadway distance, roadway name, and cross street had a large number of exceedences because those tasks take a long time to complete.

Table 17. Number of Lane Exceedences and Mean Duration

Task	Number of Lane Exceedences	Mean Duration (seconds)
Following traffic	0	
Time	0	
Speed	0	
Vent	0	
Destination distance	0	
Destination direction	0	
Turn signal	0	
Fan	1	0.46
Remaining fuel	1	0.95
Tone controls	1	0.97
Correct direction	1	1.00
Sentinel	2	0.28
Balance	2	0.55
Defrost	3	0.67
Heading	3	0.62
Info. Lights	3	0.83
Fuel economy	3	2.25
Zoom level	4	0.94
Fuel range	5	0.84
Temperature	8	0.65
Cross street	8	0.93
Roadway name	8	1.38
Roadway distance	9	1.17
Tune radio	10	1.86
Cassette tape	13	0.99
Power mirror	21	1.10

Thus, as a whole, these data indicate that using an automotive navigation system is much more difficult than "conventional" driving tasks.

The objectives of the second part of the first study was to evaluate the relative effectiveness and navigation strategies used for three methods: (1) a memorized route (the control condition), (2) a paper map, and (3) the ETAK Navigator. The three routes were similar to those in the previous experiment. Participants were told to drive to each destination as "efficiently as possible." While navigating, they read aloud the names of any signs they used.

In the memorized route condition, drivers were shown the route on a map and drove the route repeatedly until they did so without an error (after which data collection commenced). In the map condition, the route was marked on a standard road map. No special training was provided. To train participants in the use of the Navigator, participants read the owner's manual, had its operation described while the car was parked, and then used it to get to an unknown destination.

The subject sample size, age groups, car, and instrumentation were identical to the previous experiment. Each driver drove three trips, seeing each route and each navigation condition once.

As Table 18 shows, the memorized route required the least total time. Overall, there was no significant difference between the paper map and the Navigator, though more time was spent studying it. On the other hand, when using the Navigator the average glance time to the roadway was much shorter, suggesting that it imposed higher visual demands. In comparing the distribution of eye-dwell times, drivers spent 90% on the road, mirrors, and driving-related instruments for the memorized route, 82% for the paper map, and 60% for the navigator. Time spent on the map or navigator was 7% and 33% for the last two conditions.

Table 18. Times Associated with Each Condition

Time (sec)	Paper map	Memorized Route	Navigator
Study	1.55	0.02	0.75
Drive	14.00	11.01	15.20
Total	15.55	11.04	15.95
Avg Glance to Road	4.25	5.09	1.85
Signs	1.34	1.30	1.85
Avg Glance to Map/Nav	1.52	0.00	1.37

An ANOVA of the eye fixation data showed that there were significant differences due to the navigation condition and traffic density for tasks directly related to driving, and due to gender for map related tasks. Antin, Dingus, Hulse, and Wierwille (1986) also provide data on mean glance durations and transition probabilities between objects, and analysis of other performance measures. Overall, these and other data show that an ordinary paper map is just as good, if not better, than the first version of the Navigator. However, 28 of the 32 drivers preferred the Navigator over the paper map.

The second set of studies in the series consisted of two experiments. The first experiment examined anticipated attentional demand. It used the same instrumented vehicle as in the initial study. A series of roads was selected for which the lane widths, curvature, sight distance, and so forth were known. Segments analyzed varied from 30 to 350 meters in length.

Based on an analysis of the literature, Wierwille and his colleagues proposed that attentional demand be equal to the equation shown below. Q has a range of values from 0 to 100 inclusive.

$$Q = 0.4A + 0.3B + 0.2C + 0.1D$$

where:

$A = 20 \log_2(500/Sd)$ (Sight Distance Factor)

where Sd = sight distance (m)
if $Sd > 500$, then $A = 0$
if $Sd < 15.6$, then $A=100$

$B = (100 * Rmax) / R$ (Curvature Factor)

where R = radius of curvature
$Rmax$ = maximum value of the radius of curvature
(set to 18.52 m (60.7 ft)
the turn radius for a city street)

note: $R = 360X / (2\pi a)$

X = arc length along the curve (m)
a = change in direction (degrees)

$C = -40So + 100$ (Lane Restriction Factor)

where: So = distance of closest obstruction to road (m)
(phone pole, fence, ditch, etc.)
if $So > 2.5$, then $C=0$

$D = -36.5W + 267$ (Road Width Factor)

where: W = road width for 2 lanes (m)
if $W > 7.3$ (24 ft, 12 ft lanes), then $D = 0$
if $W < 4.57$ (15 ft, 7.5 ft lanes), then $D = 100$

Five graduate students studying human factors engineering at Virginia Tech, who were well acquainted with the concept of attentional demand, participated in an experiment to validate the measure. They were shown a map of the route and then drove it twice, once to become familiar with it and a second time to rate it on a scale of 1 to 9. Ratings considered the extent to which drivers could look away from the road, the possibility of unanticipated traffic, intersections, and interactions with other vehicles. Specifically, 1 corresponded to being able to look away from the road for long periods (4 seconds or more), 5 was for being able to look away for periods of 1-1.5 seconds, and 9 corresponded to not being able to look away at all.

In the main experiments, 24 drivers participated (12 men, 12 women). The vehicle and its instrumentation were the same as before. Subjects were given extensive training in the use of the ETAK Navigator prior to data collection.

The first experiment (anticipated attentional demand) involved driving over two lightly traveled road sections (7 and 8 miles respectively). These two-lane roads had a mixture of sections with rolling hills and a high degree of curvature, and straighter sections with longer sight distances. They took about 20 minutes to drive using the ETAK Navigator. These routes were used in the previous preliminary calibration experiment.

The second experiment (unanticipated attentional demand) involved three routes on which traffic was moderate to heavy. Routes were about eight miles long and required driving past factories, shopping centers, and along main streets of small towns. These routes each took about 25 minutes to drive using the ETAK Navigator. The five runs for these two experiments were conducted in one session. As before, participants read aloud the names of street and highway signs they used to navigate.

From these data, four predictive equations were developed (shown below). In each case the regression was significant ($p<.0001$). The residuals do not suggest higher order effects (square, cube, etc.). Thus, fixations directly associated with driving increased while fixations to the navigation system decreased as both computed and rated attentional demand increased. Drivers were therefore adapting their behavior to the attentional demands of the task combination.

$$EYEDRIVE = .002Q + 0.56$$
$$EYENAV = -0.0026Q + 0.40$$
$$EYEDRIVE = 0.029S + 0.50$$
$$EYENAV = -0.032S + 0.46$$

where

EYEDRIVE = % of fixations on objects related to driving
EYENAV= % of fixations on navigation display
Q = Computed Attention Value (0-100) described earlier
S = Subjective (Rated) Attention Value (1-9)

Table 19 shows the correlations of the independent variables and the subjective and objective measures of attentional demand. Many of the independent variables are correlated with each other. Note the correlation of the subject and objective readings ($r=.72$). Sight distance was the best predictor of the subjective rating of attention ($r=.65$). The correlations of the various independent measures with EYEDRIVE and EYENAV were low, but that may be because the grain of the analysis was quite fine (very short segments).

Table 19. Correlations of Independent and Dependent Variables

	Sight Distance	Curv.	Lane Restrict	Road Width	Subj. Rating	EYEDRIVE	EYENAV
Objective Rating (Q)	.85	.52	.69	.48	.72	.13	-.14
Sight Distance		.25	.33	.25	.65	.10	-.11
Curvature			.21	.11	.39	.09	-.12
Lane Restriction				.41	.43	.07	-.10
Road Width					.29	.05	-.04
Subjective Rating						.17	-.18

The results of Experiment 2 were developed by examining the forward scene videotape for incidents of unanticipated attentional demand, which were compared with normal-, low-, and high-traffic situations. In all, there were 135 such incidents. Analysis of variance of the results indicated significant differences due to traffic conditions (low vs. high vs. incident). Table 20 shows some of the key differences. They clearly show that drivers are adapting to external demands. As more attention is required by the external environment, either by heavy traffic (anticipated) or by incidents (unanticipated), drivers respond by looking more often to the roadway than the navigation display, and for longer periods of time. There is, however, one important difference not reflected in these data. When the demand for attention is anticipated, drivers respond by sampling more often. When it is unanticipated, drivers respond by increasing the fixation duration.

Table 20. Results from the Unanticipated Demand Experiment

Measure	Light Traffic	Heavy Traffic	Incident
Probability Glance to road center	.51	.61	.63
Probability Glance to ETAK	.31	.26	.19
Mean Time (sec) Glance to road center	1.2	1.9	3.0

The research of Wierwille and his colleagues has been a significant contribution to the literature, in terms of performance data, theory, and research methods. The principal findings include:

1. In terms of performance, it is just as easy to use a paper map as it is the original version of the ETAK system.

2. Eye-fixation data seems to be the measure most sensitive to task factors, certainly more sensitive than binary measures of lane maintenance (in or out) or speed variations. Wierwille and his colleagues have developed an interesting method that does not require the use of an on-the-head camera.

3. Eye-fixation durations for in-vehicle tasks tend to be longer than those for conventional tasks (e.g., operating the defroster). The durations of navigation-related tasks double when use of the zoom is required. For the purposes of comparison, Wierwille's research provides a wealth of fixation and task-completion data for a variety of in-vehicle activities.

4. When driving demands are high, people respond by looking more often at the highway and less at the navigation display. When the attention demands increase unexpectedly, people look at the road longer, not primarily more often. Thus, people seemed to adapt their behavior of driving, protecting the driving task even when faced with increased in-vehicle attentional demands.

5. Wierwille proposes an objective measure of attentional demand (Q) which is correlated with subjective estimates of attentional demand. Q is calculated from data on the sight distance, road curvature, lane width, and roadside clearance.

WHAT ARE THE HUMAN PERFORMANCE CHARACTERISTICS OF AUDITORY SYSTEMS?

Gatling's Research

Gatling (1975). Not only has there been research concerning solely visual systems, but some studies have focused on only auditory route-guidance as well. FHWA conducted several studies to examine the human performance characteristics of auditory messages in vehicles.

Gatling (1975) describes four experiments. In these and other studies, a 1966 Oldsmobile driven on a limited-access highway (Dulles Airport Road) at 45 miles per hour was the loading task. At no time did the drivers follow the navigation instructions given. In the car was an audio recorder and a slide projector on the back seat shelf aimed at a projection screen just to the left of the mirror (4.5 inches high x 11 inches wide). This is a simple and clever way to simulate presentation of messages of a wide field-of-view HUD. When this research was conducted, it was thought that local radio broadcasts would provide drivers with route alternatives at decision points. This series of studies considered whether information should be presented visually or auditorily, if it should be repeated, how likely it was it would be forgotten, and other related issues.

The first experiment examined retention of auditory navigation information. At random times 30 drivers were given a warning signal followed by recorded messages containing one to six chunks of information. ("Next right exit/for Boston/via route 213/3 miles" would be a four-chunk message.) Messages were given either once or twice. During a 5-15 second delay drivers read aloud 1 of 15 unrelated messages (e.g., "slow - automobile accident in right lane") that interfere with rehearsal of the to-be-remembered message.

Figure 11 shows the route-error data (one chunk of the message was incorrect). As expected, there was no effect of the delay on recall since the duration of the interfering task was fixed. Card, Moran, and Newell (1983) state that the half-life for working memory (middleman) is 73 seconds for one chunk and 7 seconds for three chunks. Using a 4 second interference period (to read the message), the predicted values are 96% and 67% correct, reasonably close to the 97% and 46% measured.

Presenting test messages a second time improved recall by about 15%. However, notice in Figure 11 the reversal in performance between two and three chunks, which does not make sense and suggests that the data for older participants is noisy. (Only 9 of the 39 drivers were old and each driver responded to only five messages for each chunk.)

In the second experiment two to nine chunk messages were presented auditorily once or twice to 36 drivers, mostly young. Drivers were then shown slides (of text) and asked which piece of information (if any) was in the preceding auditory message. Slides were exposed for 5 seconds, with a new slide appearing every 15 seconds.

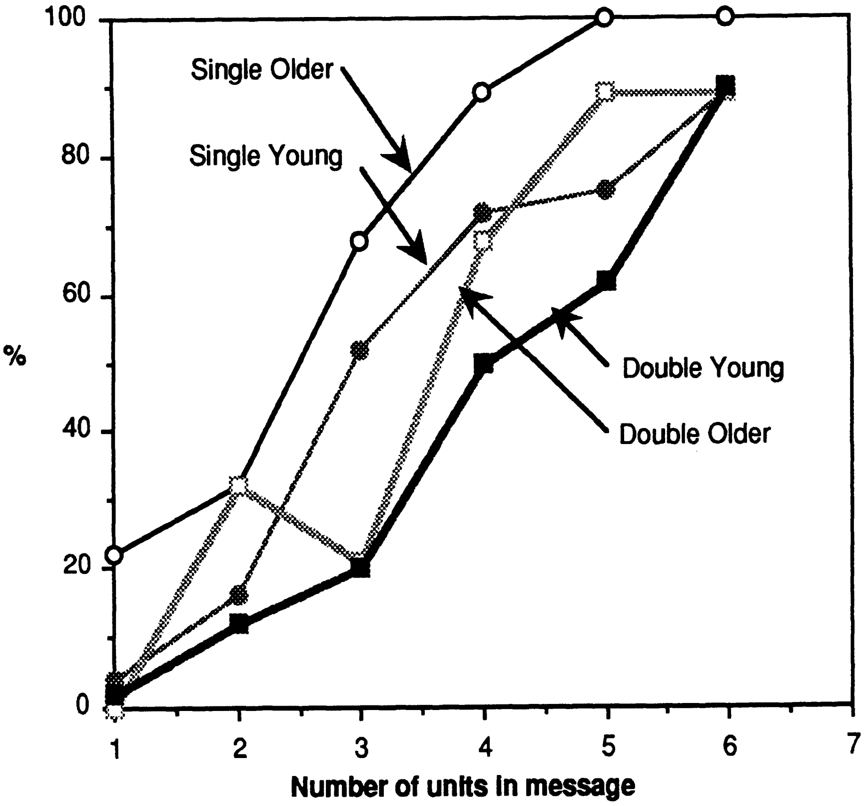


Figure 11. Percent Error vs. Message Size, Experiment 1 (Gatling, 1975)
Note: Single or double refers to presentation of the message once or twice.

Figure 12 shows the percentage of route errors as a function of the message length. Because this experiment concerned recognition rather than recall, route-error rates were considerably lower than in the previous experiment. (See Table 21.)

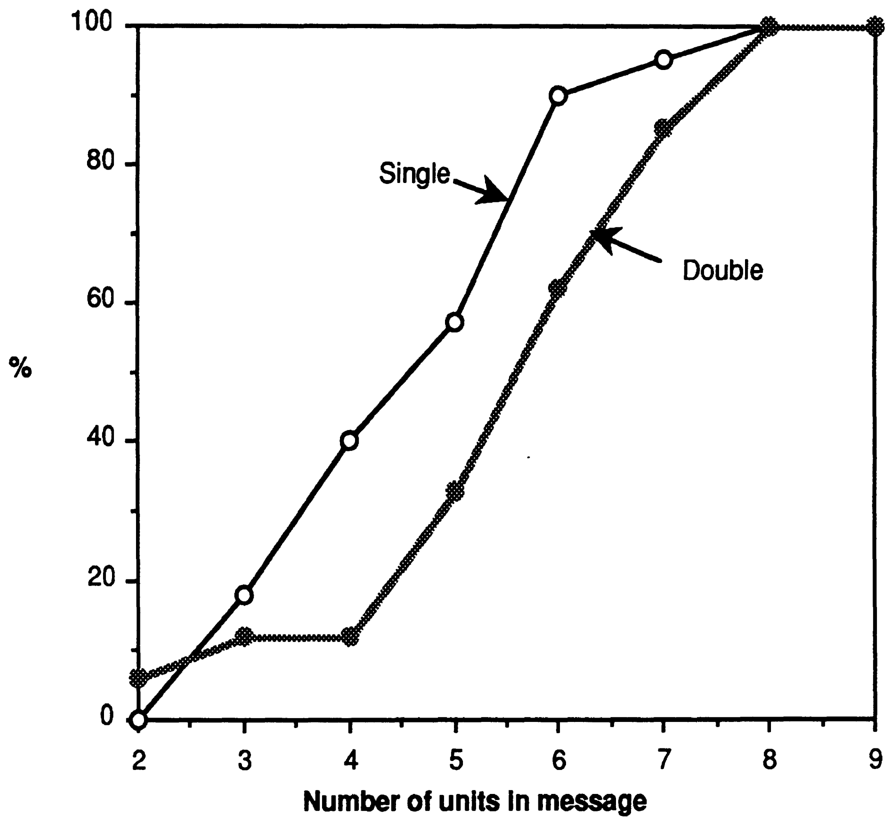


Figure 12. Route Error Rates vs. Message Length, Experiment 2 (Gatling, 1975)

Table 21. Route Error Rates As a Function of Measurement Method (for Single Presentation only)

	Message Length (chunks)				
Experiment	2	3	4	5	6
1 (Recall)	17	53	73	77	90
2 (Recognition)	0	17	39	56	89

Particularly important, however, are the differences in recognition as a function of information type. For single presentations, average recognition was 88% for exits, 86% for streets and towns, 81% for distances and turns, and 51% for three-digit route numbers. Hence, in attempting to predict memory for route instructions, all chunks should not be treated as equally likely to be remembered.

The third experiment concerned the likelihood that information would be recalled as a function of its content. Some 36 people were presented auditory messages that contained information about both lodging and fuel, but the lodging part contained more numbers. Immediately thereafter, drivers recalled what it said about either lodging or fuel. In agreement with the previous study, recall of the message with the numeric data was significantly poorer.

The last experiment was concerned with the time to tune a radio to an advisory message. While driving, 36 people were shown a slide that instructed them to tune the radio to 1606 kHz for further information. (The pointer started at 550 kHz (the other end of the AM band) and the presets were of no use.) Tuning times ranged from 9.4-36.6 seconds depending upon the bandwidth to the station and whether the radio was on or off. The 95th percentile time to tune the radio (starting with it off) would be 53.3 seconds (which translates into 4688 feet at 55 mph).

Gatling (1976). This study concerned whether navigation messages should be presented visually or auditorily. In the visual condition, slides of two to seven chunk navigation messages were shown for 20 seconds. In the auditory automatic condition, people pressed a button (traffic advisory) for the radio to present a message. In the auditory manual condition, the driver tuned the radio to a station in response to a slide. Fifteen seconds later 54 drivers were asked to recall if the probe items (e.g., Exit 1 East) were in the message to be remembered.

As shown in Figure 3, people made fewer errors when the presentation was auditory and automatic. Also notice that the shape of the function is more ogival than found in previous experiments.

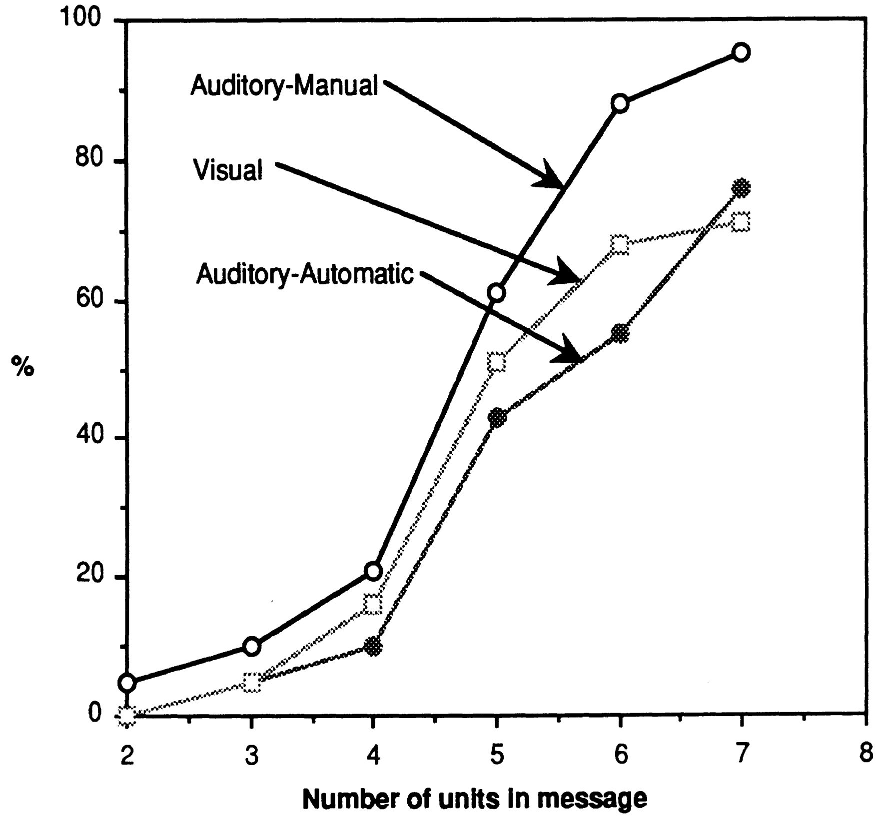


Figure 13. Recall of Messages in Gatling (1976)

Gatling (1977). Some sixty people, mostly young, participated in this experiment. Messages of two to seven chunks were either presented visually (on the screen) or auditorily in 2 formats. Visual messages were spread across multiple slides. Each slide was shown for 10 seconds with a 10 second delay between slides. For auditory messages, the short form duplicated exactly the visual message (e.g., "Construction ahead", "stay in lane", reduced speed 35 mph", "use shoulder 800 feet"). In the long form, the message was embedded in prose. ("This is a warning message that..."). Unlike the visual messages (with each slide shown once), each auditory message was repeated before recall was requested.

As shown in Figure 14, recall was best for long auditory messages and worst for visual messages, a finding consistent with the previous study. Apparently the elaboration aided recall more than the additional delay in retrieval hindered it. Of course, this difference is confounded with the number of presentations. Durations for the auditory messages are not given but could be computed. (The text examined appears in the appendix to Gatling, 1977).

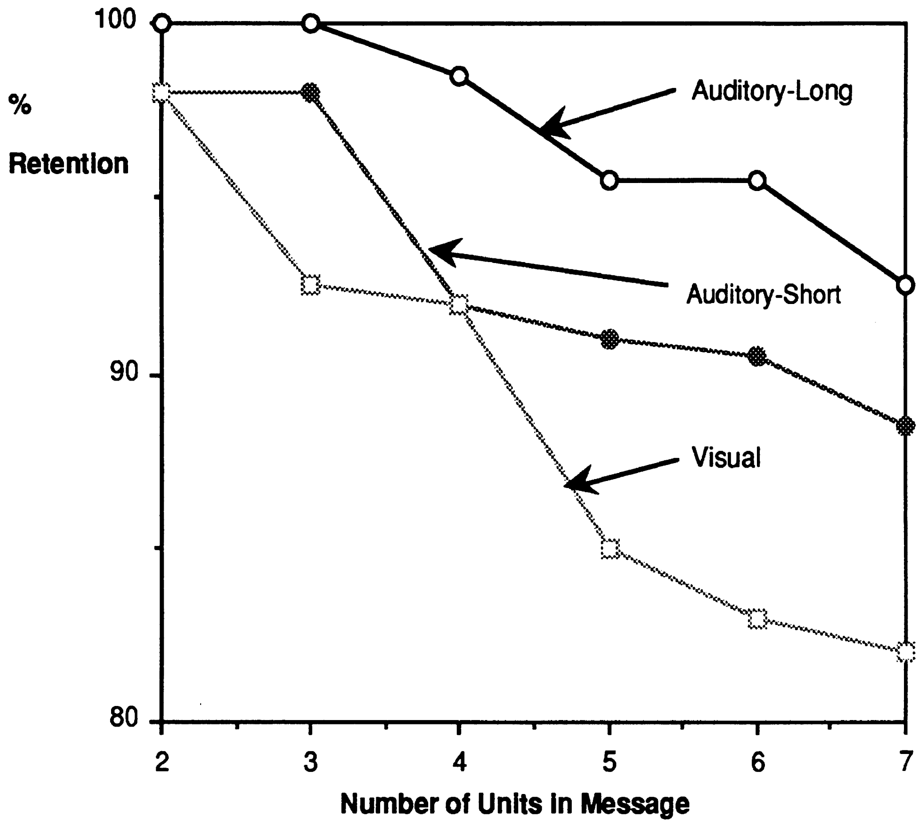


Figure 14. Recall as a Function of Message Length in Gatling (1977)

In the last experiment in this series, messages of two to seven chunks were presented to a sample of 50 drivers, mostly young. Messages were presented either visually or auditorily (short format). In the visual condition the navigation instructions were shown for 20 seconds. Fifteen seconds later, the slides with the information to be recalled were shown, one every fifteen seconds. In the auditory condition, probes were also shown once every fifteen seconds. The auditory navigation information was not repeated (as it was in previous experiments).

Figure 15 shows the percentage of route errors as a function of the number of route numbers in the message. Notice that error rates were lower for auditory presentation when the number of route numbers was small. Visual presentation was superior in other cases.

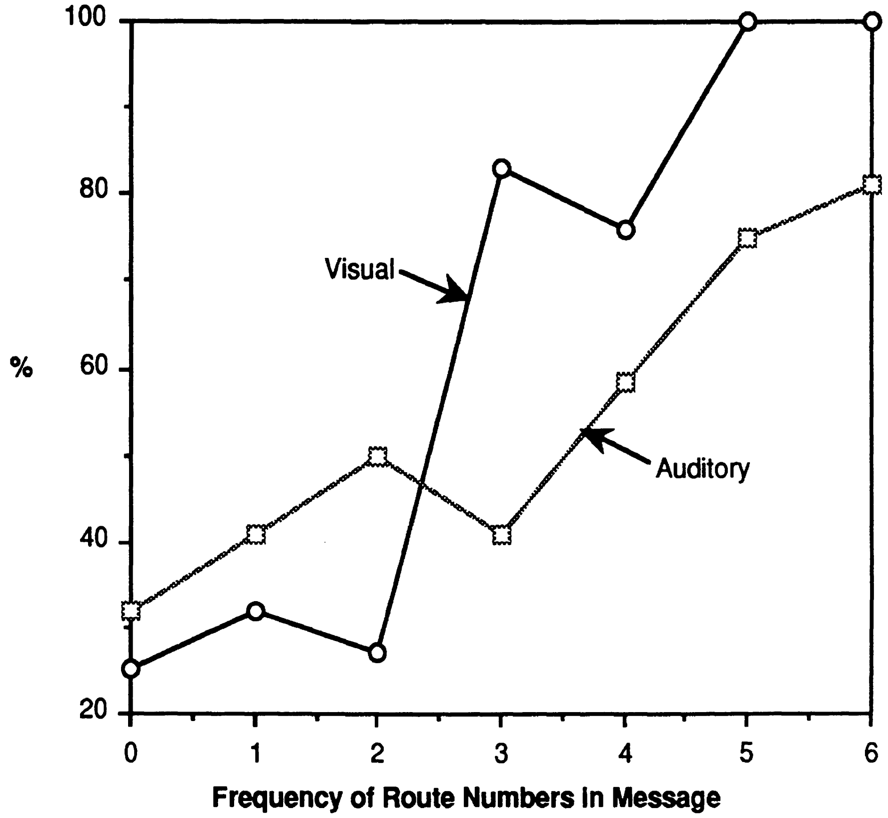


Figure 15. Frequency of Route Numbers in Message vs. Percentage of Route Errors (Gatling, 1977)

The Gatling research comprises an interesting set of experiments concerning memory of route information. Notable is the use of on-the-road context to assess recall. It is unfortunate that the nature of the interfering task was not more precisely defined and the duration of interfering task varied, so the results could be linked more closely to other research in the psychological literature.

As is normally the case, performance in these tasks (route errors, percent correct, etc.) decreased as the number of items to be remembered increased (about 20% per chunk). It is not clear if the relationship is linear or ogival. The results reported here are consistent with those in the literature, with performance depending upon the test method. Here, recognition performance was superior to recall on average by 27% for five chunks or less. Differences due to age were about the same size.

With regard to the key factor of interest, memory for route information was not consistently better for visual or auditory presentation, with differences being due to implementation details (e.g., manual vs. automatic presentation). Repeating messages improved recall by about 15%. These findings suggest that either modality could be used for route-guidance and traffic-advisory systems. However, it is clear that the amount of information to be remembered should be held to a minimum, one or two chunks, if recall performance is to be satisfactory. This recommendation, of course, depends on the nature of the information as memory of route numbers was far worse than memory for town names.

A highly desired extension of these data consists of equations to predict recognition and recall performance as a function of the parameters given here. To develop a full set of equations, some additional data are required.

Back Seat Driver

The most significant contributions on voice-navigation-system design have come from Davis and Schmandt, when Davis was at the MIT Media Laboratory. The original effort concerned a program to generate directions in fluent English for a section of Boston (Davis and Trobaugh, 1987). (See also Davis and Hirschberg, 1988.) The input device was a phone keypad. Unique aspects of this work include the development of a vocabulary for describing the road network and a set of rules by which the merits of alternative sets of directions could be compared. This was an expansion of the work of Elliot and Lest (1982). In brief, the shortest route was not always the best route, for these have too many turns, and consequently are difficult to describe and follow. In computing the utility of a route, there were penalties for turns whose amount depended on the direction of the turn, if the street was one-way, and if the turn was forced ("left turn only"). In addition, utilities were adjusted if the street was "good" or "bad," if landmarks were available, and so forth.

This work was expanded upon and described in greater detail in Davis's dissertation on the Back Seat Driver, a voice-based route-guidance system (Davis, 1989). (See Davis and Schmandt, 1989 and Schmandt and Davis, 1989 for a summary.) They put considerable thought into what drivers do and how to make an interface compatible with human behavior. The initial design of the interface was based on a short study of natural direction-giving. Further revisions emerged from an iterative design process. ("When the design was wrong, drivers complained, or just got lost, and I changed the design until they stopped complaining." (Davis, 1989, p. 17)). While this research does not contain much human-performance data, their interface was a good first cut at a strictly auditory route-guidance system.

In his direction-giving experiment, Davis had six people give instructions on how to get to randomly selected destinations while they were passengers in a car. The conversations were recorded on a cassette recorder and transcribed (except for the personal comments). Table 22 shows the 10 most commonly used verbs. The verb "take" was usually associated with turns, though not always, while the word "turn" was not always associated with turning ("Fulkerson turns into (becomes) Binney"). The angle of road changes was important information, both in the context of hard turns (more that 90 degrees) vs. ordinary turns and bends in the road (bear to the right).

Table 22. Verbs Used for Giving Directions

Rank	Verb	Frequency
1	take	35
2	bear	22
3	go	22
4	keep	13
5	stay	8
6	turn	4
7	follow	4
8	make	3
9	get	3
10	continue	2

Davis identified several other results of his research:

1. Subjects in his studies did not use absolute distances but used qualitative terms ("in a while," "up ahead") and immediate locations ("here").

2. People used street names as place markers only 25% of the time. Commonly, markers included road structures (bridges) and traffic lights. Drivers did not make widespread use of famous landmarks.

3. Time permitting, people said each instruction twice: once as advance notice and once at the decision point. Advance instructions often refer to a landmark.

4. Good subjects gave additional information to make driving safer, especially information about which lane to drive.

5. There were differences in style (simple imperative-"Take a right"; second person - "You're gonna take a right", "You're gonna wanna take a right"; first person plural - "We're gonna turn right"). No style was preferred.

6. Good subjects were not always silent when turning was not required. At many decision points (major intersections) and where streets widened, drivers need instructions to continue.

The Back Seat Driver was designed based on these and other findings. The interface is much more complex than that of Streeter et al. described elsewhere, as it included a wider variety of intersections. The interface is very chatty and many regard it as excessively so. It was structured as follows.

The system consists of an audio speaker, a car phone with a numeric keypad, and a remote computer. Not much effort was put into optimizing the keypad interface. The table below shows the key assignments.

Table 23. Key Assignments

Key	Pre-trip	While driving
1	start a trip	"what now"
2	repeat previous utterance	repeat
3	find closest provider of service	"what next"
4	nothing	total length & percentage complete
5	hear location	current location
6	nothing	"I can't do it"
7	resume trip	suspend trip
8	internal debugging statistics	internal debugging statistics
9	hang up	hang up
*	help	
0	nothing	
#	nothing	

Note: The suspend trip function stops presentation of instructions for a while. Hitting the resume gives instructions from the current location.

There are 10 driver actions (continue, forced turn, turn around, enter, exit, onto rotary, exit rotary, fork, turn, stop) described in detail in the following table.

Table 24. Back Seat Driver Actions

	Action	Explanation
1	Continue	Driver stays on "same" road, taking "obvious" path. (bends under 30°, continuation of painted centerline)
2	Forced Turn	No decision to be made, road bends more than 10° that are "worth mentioning."
3	Turn Around	Heading is opposite of what it should be. (used for dead end streets)
4	Enter	"Drive onto <Name of Expressway>"
5	Exit	"Take exit 23" or "Take the exit for Somerville"
6	Onto-Rotary	"Drive onto the rotary"
7	Exit Rotary	Move off of rotary onto street
8	Fork	None of the branches is obvious. If one branch is stronger than the others it is a continue or a turn. (All must be access ramps or none must be access ramps.)
9	Stop	Designates destination
10	Turn	Anything that doesn't fit above (taking "non-obvious" path, at a decision point)

Instructions were of two types: those spoken once, and those spoken twice (once ahead of the decision point and once at the decision point). For example, "go straight through the lights" did not need repeating, but "take a left at the next light" was reiterated with "take a left here" when the decision point was reached. If an instruction was needed twice in a row (e.g., two right turns close together) the word "another" was used so driver did not think the system was repeating itself ("Take a right here" followed by "take another right here").

Back Seat Driver would describe the next instruction as soon as the previous instruction was completed. When the instruction was restated as the decision point was close, the system would begin speaking at $v * (ts + tr)$ where v was the velocity of the car, ts was the time required to speak the instruction, and tr was the time needed for the driver to react to the instruction. The voice synthesizer spoke at 180 words/minute, and reaction time was set at 2 seconds.

A cue was used to describe the next decision point. The system used a landmark when possible or a distance otherwise. Some drivers liked distance information, others did not. Distance was better given for farther decision points than closer. (This was modifiable.) Landmarks included commercial buildings (e.g., gas stations), underpasses, bridges, tunnels, bends in the road, railroad crossings, and end of road (T intersections). Street names were only used when the driver was familiar with the road network because landmarks can be seen at a greater distance than street signs. Street names were stated last in the instruction only as confirmation (e.g., "At the next light, turn left. It is Maple Road."). Whether street names were provided was a modifiable parameter.

The location cue was always stated before the instruction verb, otherwise drivers tended to follow the instruction verb without waiting to hear where the instruction should be followed. For example, the system didn't say, "turn left at the next light", it said, "at the next light, turn left."

If a feature was closer than 1/10th of a mile, it was considered to be visible. The system considered the car to be at an intersection when it was 30 yards away, unless the car was stopped at an intersection with a light, then 50 yards away was considered the intersection. This distance was the point at which the system changed from saying, "Turn left at the next lights" to "Turn left here."

Back Seat Driver gave advice on lanes and speed, if the information was critical to either accomplishing the next instruction, or staying on the road. It would inform the driver of what lane to be in before the turn, what lane to get into after the turn, and sometimes what lane to stay out of. It would also advise drivers of a drop in speed necessary for an approaching turn or curve.

The system used a neutral tone when mistakes occurred. When the system used the message, "You made a mistake. You should have taken a right..." drivers complained. The message of choice was of the type, "Oops, I meant for you to take a right." Drivers could make use here of a "can't do that" button if the route the system was trying to follow was impassable or illegal, so the system could plot a new route, avoiding that segment of the route.

The system also inferred certain dangers from the database of the road network and informed the driver of them. These included speed restrictions on straights and curves, one-way streets, merging traffic, blind driveways, speed traps, poor road conditions, and dangerous intersections.

Reassuring phrases ("good" or "nice work") were provided after completing desired maneuvers to help drivers. While this feature was very popular with test drivers, it was modifiable. Though some found the choice of words patronizing, they preferred them over no response.

While Davis's research contains little quantitative or qualitative evidence to support the design decisions made, the decisions nonetheless seem reasonable. It is surprising that others have not tried to test the design and that it is not a product by now. This may be because of the complexity of the system. As will be shown later, chatty systems such as Back Seat Driver tend to be distracting and not as useful as auditory interfaces that say less.

COMPARISONS OF AUDITORY AND VISUAL SYSTEMS

Streeter, Vitello, and Wonsiewicz (1985)

Streeter and her colleagues conducted several studies (e.g., Streeter, Vitello, and Wonsiewicz, 1985) examining the merits of auditory route-guidance. At the time, AT&T was considering providing a mobile phone-based electronic route finder and was interested in the driver interface to the service.

A significant part of their research was devoted to reviewing the psychological literature on human memory and navigation, and descriptions from colleagues on how they drove from work to home. Extracted from that material were recommendations for the design of auditory guidance systems shown below (Table 25). A key recommendation was the preference for landmarks over street names for turn instructions.

Table 25. Instructions Used by Streeter et al.

Instruction Type	Instruction
Critical direction: Left or right instruction	Drive {x.x} miles to {street_name} and turn {left|right}.
Critical direction: Continue instruction	{street_name 1} changes name to {street_name 2}. At {x.x} miles turn {left|right} onto {street_name 3}.
When to turn instruction: If a landmark is available, then	{landmark} is on the {left (corner)|right (corner)|straight ahead}.
When to turn instruction: If a landmark is not available, then	{street_before_name} is the street before {street_name}.
Too far instruction	If you come to {landmark|major str_street}, you've gone too far.
Summary instruction	If you come to {landmark|major str_street}, you've gone too far.
Summary instruction	Remember it's {x.x} miles to your {left|right} turn onto {street_name}.
T-junction	Omit the "too far" instruction.
Junctions of more than two streets	the tricky intersection of street {street_name_1}, street {steet_name_2}, and street {street_name_3}.
Turns separated by 1/10 mile or less, combine the 2 instructions.	a quick {left|right} onto street {street_name}.

In an on-the-road experiment, guidance was provided by taped instructions (which could be played once or repeated), a customized map (with a highlighted route), a combination of the two, or a standard New Jersey map and an address. The customized map was similar to a AAA Triptik.

Participants were 57 ordinary and professional drivers unfamiliar with Monmouth County, N.J. Each participant drove four routes (one practice and three test) from a set of seven. These seven routes were actually used by Bell Labs employees to get from a Holmdel, N.J. site to their homes. The routes varied in difficulty (6, 7, and 13 turns).

Participants took less time and drove shorter distances with the auditory instructions than with a standard map. (See Table 26.) Providing both a map and a tape was not better than providing just a tape, implying that providing more information is not always better.

Table 26. Performance from Streeter et al. (1985)

Measure	Tape	Custom Map	Custom Map + Tape	Std Map (Control)
Miles	11.4	12.7	12.0	15.8
Turns	7.3	7.3	7.3	12.7
Time (min)	24.2	26.4	25.5	34.2
Errors	1.1	1.9	1.6	

The preference data led to the same conclusion. Auditory presentation was preferred followed by custom maps and then standard maps. This research suggests route-guidance should be auditory only.

Table 27 shows the kinds of errors drivers made. Notice that most of the differences occur in the last four categories ("turned wrong way", "turned on wrong road", "missed location and not aware", "and never found correct road").

Table 27. Errors Reported by Streeter et al. (1985)

Error Type	Tape	Cust. Map	Map + Tape
Unable to find location while searching	33	35	23
Saw while driving past	18	19	14
Didn't go far enough	0	2	2
Thought on wrong street but OK	1	0	0
Turned wrong way	1	10	1
Turned on wrong road	9	31	18
Missed location and not aware	8	15	11
Never found correct road	1	8	2

Participants in the control group used a variety of ways to obtain directions. One of the sixteen control group participants, who located people for the Internal Revenue Service, purchased a county road map showing all the streets. From the others there were 85 inquiries: 47 at garages, 14 at municipal buildings (post offices, police station, etc.), 4 at shops, 4 at toll booths, and 10 of passers-by (including 4 postal carriers and 2 police officers).

The Streeter, et al. work is one of the few studies in the literature to examine both the design and performance of auditory guidance systems. They found drivers did better with auditory displays than visual ones, and what was most interesting was that providing more information (both visual and auditory displays) could be worse than either alone.

Walker, Alicandri, Sedney, and Roberts (1990, 1991, 1992)

This research was conducted by the FHWA using FHWA's highway driving simulator (HYSIM) with assistance from the staff of COMSIS Corporation. This fixed-base simulator consists of a 1980 Ford Fairlane in front of a large projection video projection screen. The scene shown was fairly bare, though regulatory, warning, and guide signs were included. For some conditions, a superimposed image from a video camera of a model car or truck (lead vehicle) was shown.

This experiment examined six generic electronic guidance units, three visual and three auditory. The complex unit consisted of a 7-1/4-inch diagonal CRT display showing the local area at its highest level of magnification. (See Figure 16.) (The display appears similar to that used in the ETAK Navigator/Blaupunkt TravelPilot.) The map was always oriented head up with the vehicle symbol (arrow) in the center of the display. The medium complexity display was a modification of the ERGS design. To make a left turn, the sequence shown was "TAKE THIRD LEFT <-," "TAKE SECOND LEFT <-," and "TAKE FIRST LEFT <-" at three, two, and one blocks before the turn. In the simple version, arrows modified from the ERGS mimic appeared the block before a turn (↱, ↰).

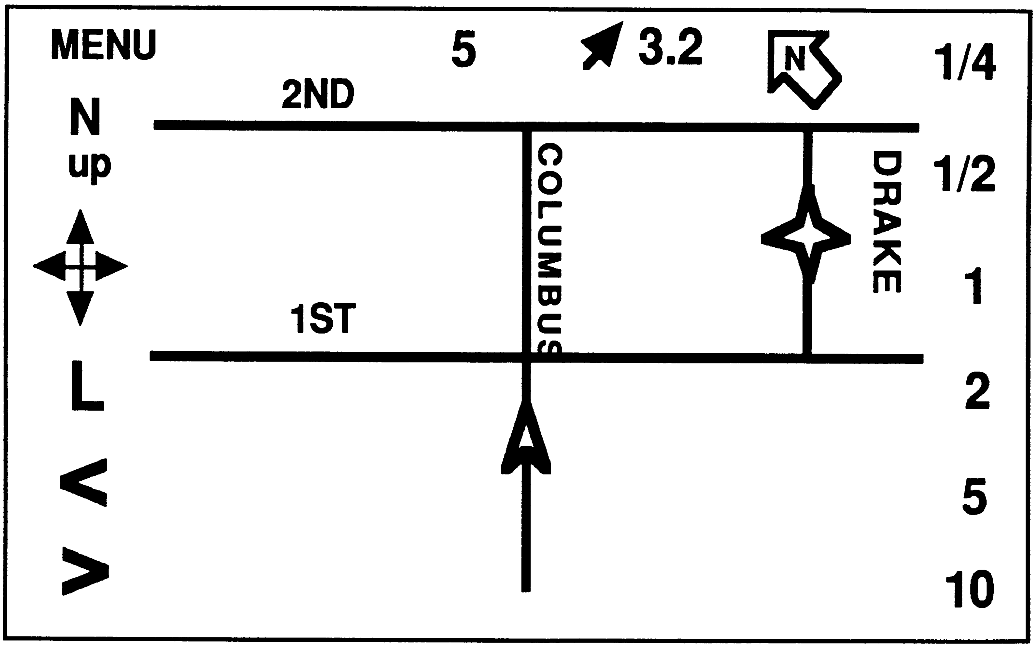


Figure 16. Complex Unit Display

In the complex auditory system a tape-recorded woman's voice provided detailed instructions, such as the following: "You are heading southeast on Oakland." "You are crossing Ferris." "The next 4 streets are LaBelle, Manchester, Victor, and Gerald." "Your next turn is a left (northeast) onto Caniff in approximately 1.8 miles.") In the medium complexity condition, the recorded messages were identical to that shown by the visual unit. The simple auditory unit said either "left, left, left" or "right, right, right" a half block before the turn.

In the control condition, drivers were given a AAA-like strip map showing all intersecting streets and turns. Drivers could look at the map only at stop signs or lights.

Because the road scene was simple, three types of loading tasks were provided while driving to improve the simulation. The perceptual loading task involved monitoring two gauges on the instrument panel (oil--upper left and temperature--upper right). When the oil gauge was low or the temperature gauge was high the subject pushed associated buttons to correct the problem.

The cognitive task consisted of tape-recorded arithmetic problems involving the distance to the next gas station and remaining fuel. The easy and moderate difficulty question was (slightly rephrased), "You have gas to go X miles, but you need to go Y. How far will you walk?" In the easy condition X and Y were multiples of 5 and differed by 10. In the moderate condition two-place subtraction was required. In the hard condition the question included the number of gallons of fuel left, so multiplication was also required. Table 28 shows how load factors were combined.

Table 28. How Load Factors Were Combined (Walker et al., 1990)

	Zone		
Load Factor	Easy	Medium	Hard
Lane width	12 ft	10 ft	8 ft
Cross winds	none	light	heavy
Lead vehicle	none	sedan	truck
Gauge change	none	gross	small
Mileage questions	easy	moderate	hard

Upon arriving at the test site each of the 126 subjects drove the simulator for at least 9 miles of a 14 mile loop in downtown Detroit. Concurrently, drivers responded to easy gas mileage questions, moderately difficult gauge changes, and the guidance system. Each subject then drove the main route once (12 turns, 26 miles), participating in one of the seven test conditions. The speed limit was 25 mph. All of the intersections were T's or crosses, though not all turns were 90 degrees. There were no expressway entrances or exits and no traffic circles. When drivers made a wrong turn, the street ended in a cul-de-sac, a clever way to avoid experimental complexities in recovering from navigation errors.

Data were collected for 15 zones (5 at each of the 3 levels of difficulty). Each zone was partitioned into four subzones, varying in distance before and after intersections. Dependent variables included heart rate, speed, lateral placement, and response time to gauge changes.

With regard to heart rate, there were no differences due to the navigation device. There were also no main effects due to devices in the gauge response times, though there was a device by turn interaction. Response times for the complex visual display were substantially longer in turn sections (38 seconds) than in straight sections (just under 20 seconds), and for maps in both sections (30 seconds--straight, 40 seconds--curve), than other devices. It is thought that the added visual demands of these conditions reduced the time available for drivers to look at the gauges.

With regard to average speed, participants tended to drive slower (by about 1 mph) when using visual navigation devices. There were slight differences in speed between the easy and moderate difficulty conditions. (Moderate was slower.) People drove about 2 mph slower in the complex condition than in the moderate one.

It is interesting to note that the navigation device had no impact on either average lane position or lane variance. It is believed that lane maintenance was a "protected" task. Drivers made sure that performance on that dimension was good, even if performance on other dimensions degraded as a consequence.

Table 29 shows the frequency of navigational errors by device. Differences due to both complexity and modality were significant. Performance was better for auditory displays than visual ones. The largest number of errors was associated with the simple visual navigational device, which performed well on other measures, but may not have provided enough information for drivers to navigate effectively.

Table 29. Frequency of Navigational Errors

Modality	Simple	Medium	Complex	Map (control)
Visual	16	3	12	14
Auditory	0	1	8	

Thus, the primary difference was between the complex visual device and other alternatives. People missed more gauges, had longer response times, and drove more slowly than other devices when using it except for the strip map. The results suggested that simpler devices are preferred for route-guidance.

In considering these data, the authors caution that the road scenes were spartan, the added workload was somewhat artificial, and there may have been sampling problems, particularly with older drivers who were more likely to experience simulator sickness.

CONCLUSIONS

As was noted earlier, this review concerns research done only in the U.S., not research carried out in Japan or Europe. Even though the research cited here is only part of the picture, and in fact does not include research presented at the 1991 VNIS (Vehicle Navigation and Information Systems) Conference, there is still a great deal than can be gleaned from it. Following are answers to some of the more commonly posed questions.

What information should be shown in driver information and navigation systems?

The information desired for navigation depends upon the mode the driver is in, for example, trip planning vs. orientation vs. route-guidance. In guidance, simple information about what to do seems adequate though there are times when other information is desired (for example, the distance to some point ahead as suggested by Cross and McGrath).

In terms of other information such as destination assistance, it is evident that the kinds of information drivers might want is widely varying. (Cross and McGrath cite over 30 categories.) That information is linked with the trip purpose and time of year. If someone is going on a fishing trip, it is unlikely they will be interested in race tracks, cemeteries, or libraries, but they might be interested in boat launches and fish hatcheries. Some of the hierarchical menu systems that have been developed to retrieve information have not utilized this to reduce the search space.

How should electronic maps be designed? What should be shown?

What an electronic map should show depends upon the task. For planning, one needs lots of details. As is suggested elsewhere, planning tasks should be pretrip tasks (Dingus, 1991). There seems to be good evidence that for planning trips, maps should be oriented north up. For orientation and route-guidance, the map view should be compatible with the scene outside the windshield, namely, heading up. To provide additional orientation information, one interpretation of Adeyemi's research is that north and the other cardinal directions should also be shown.

Detail on maps, especially for route-guidance, should be minimized. Walker, et al. show that complex maps are more demanding (as assessed by secondary task performance) than simple arrow displays. The Stilitz and Yitzhaky research suggests that each additional street shown adds almost 0.4 seconds to search time. Their data are for situations where more than three streets are shown and might not apply to a simple display. Many of the details regarding map design (should streets be single or double line, what should the line width be, etc.) have not been examined but are needed to improve display design.

There is some disagreement concerning what constitutes a landmark and when they should be provided. Davis considers landmarks to be road specific markers that are highly visible--underpasses, bridges, street lights, and stop signs. However, drivers also use highly visible buildings with signs as landmarks, especially gas stations and fast food restaurants.

How should auditory systems be designed?

The main issue is how verbose systems should be. Davis's work argues for providing lots of information. Although he reportedly conducted usability tests of Back Seat Driver, they were very informal. On the other hand, Walker did conduct them and his research argues for systems that minimize verbiage. The difference may not be the thoroughness of the tests, but the driving environment. Back Seat Driver was examined in Boston, in the area near the MIT campus. The area is congested and there are streets coming from all directions. Turns could be in close proximity and drivers needed information about lane changes. Streets signs were often hard to see because of their small size, disrepair, and blockage. As noted earlier, Walker considered basically a grid system with widely spaced turns and highly visible street signs. The only traffic was a lead vehicle (which was not always present). It may be that the design depends upon these factors, and possibly an auditory guidance system should sense them and alter its output accordingly.

Should route-guidance information be visual or auditory (or both)?

The U.S. data do not show a clear advantage for either sensory modality, at least for the systems examined. Driver performance depended very much on how much information is presented. Walker's simulator study showed that moderate complexity systems (both visual and auditory) led to minimal and almost equal (three vs. one) navigational errors, though their systems involved driving a simple grid network with widely spaced turns.

On the other hand, Streeter's research showed that drivers performed the best with a simple auditory system (when compared with a map) but did not examine use of a good visual guidance system such as the simple or moderate complexity units examined by Walker. When provided with both auditory information and the customized map, drivers did worse than when just given the tape alone. Those unfamiliar with human factors engineering often argue that more information is better and drivers should be provided with both visual displays and voice data. In this case, the more information drivers are given, the more they must process, even when it is redundant. The added information can detract from performance.

Readers interested in this topic should pay close attention to research done in Europe (for example, Labiale, 1989; 1990; Pauzie and Marin-Lamellet, 1989, Verwey, 1989; Verwey and Janssen, 1988). Because of their size and context (on the road), it is likely that the Camera Car Study and Orlando Test Network Study being conducted as part of TravTek will do much to resolve this question. (See Burgett, 1991 and Fleischman, 1991 for a summary of the work planned.)

How have and how should navigation systems be tested?

Methods for examining navigation systems can be partitioned into laboratory and on-the-road methods, with slight variations depending upon whether the information is visual or auditory. In Rothery's work on ERGS, subjects were shown a slide of a road scene and then a navigation display showing either a lane change or an exiting instruction. They acted upon it by actuating the turn signal in the appropriate direction. Response times and error rates were the dependent measures.

A second method employed by Rothery was to have a driver approach an intersection and to get navigation information by pressing a button that held a projector shutter open (showing a slide of a navigation display). The dependent measure was the exposure duration, which corresponds to how long the driver looked at the display and not at the road. The tendency in simple experiments such as this would be to not collect detailed driving-performance measures (speed, lane position, etc.) but possibly to collect navigation-performance data (turn errors). This method is fairly simple, and, since a working prototype is not required, can be done using sketches of preproduction prototypes and any car, not an instrumented vehicle.

There is only one study in the U.S. literature in which surveys have been used to obtain driver reactions to a route-guidance system. In that case, drivers responded to the survey after they had used the system, not just seen it, which is important. It is very difficult for the public to accurately assess the usability of something they have never used. Because of the nature of surveys, they can be useful in identifying problems but not their solution or measures of the scope of problems. Engineers need all three types of information. As a footnote, surveys have been used successfully to examine the information provided by existing navigation aids and driver information requirements (Cross and McGrath, 1977; Petchenik and Clawson, 1984).

Both the work of Walker, et al. and Wierwille, et al. have used more complex procedures. In the case of Walker, an instrumented simulator was used. It is not known how many people were required to staff the simulator, but presumably several. Dependent measures included heart rate, speed, lateral placement, response time to instrument panel gauges, and navigation errors. Of these measures, speed and lateral placement, as well as navigational errors were most sensitive to the design differences, while heart rate was relatively unaffected. It is difficult to assess the usefulness of the lateral placement data. An artifact of this simulator is that intersection corners were square, not round, which altered how people drove through turns.

Wierwille's research involved an instrumented car driven on the highway. The vehicle required considerable modification to be used for research purposes and when testing was in progress, two experimenters were required. Wierwille measured navigation performance (turn errors, again a discriminating measure), as well as speed, lateral placement, and driver eye fixations. Both speed and lateral placement, while indicative of design differences, at times could be insensitive. In the case of lateral displacement, that is probably because scoring was binary (in or out of lane). A lane tracker was not available. Eye fixations proved to be quite sensitive to design differences and changed both in frequency and duration in response to external and internal demands. It should be noted that Wierwille had a camera pointed at the drivers and had the data reduced manually. While the results were quite reliable, data reduction was tedious and time consuming. In some environments where inexpensive labor is not available, reduction could be very expensive.

An interesting alternative proposed by Rothery is to use a Senders helmet to limit the viewing time available. Today, such research might be conducted using LCD eyeglasses, such as those developed by Translucent Technologies, instead of a bulky motorcycle helmet. However, Human Subjects Review Committees are not likely to approve studies in which people drive down public highways and effectively close their eyes from time to time to see how long they can do it and still keep the car on the road.

One significant gap in the literature is the lack of comparisons of methods. It is not clear when the laboratory data will predict on-the-road performance, in particular fixation times, durations, or most likely, total look times. One would expect, however, there would be reasonable correlations.

Are navigation systems safe? When won't they be?

There is still no definitive evidence on the safety of navigation systems and the only definitive evidence will come from on-the-road use and subsequent accident statistics. Risk, which is being assessed, is a combination of exposure and the number of accidents. Currently, market penetration is insufficient to make judgments about risk and it will be some time until penetration is sufficient. Further, such information will be difficult to obtain because accident data bases do not code any information about the use of in-vehicle equipment. A simple comparison of accident statistics is not appropriate because likely users of route-guidance systems will be those who drive a great deal. Further, without these systems, users would have accumulated more mileage (and potentially been exposed to more accidents).

The best evidence in the literature now, the research of Wierwille and his colleagues, suggests these systems can be safe, but how safe and if they are safe enough will depend on the implementation. A major concern is that these systems will demand attention and that drivers will stop looking at the road. The evidence from Wierwille's work is that drivers respond intelligently to navigation-system demands. When traffic gets dense or there are demands that require drivers to look at the road, they do. Where drivers can get into trouble is with unanticipated demands, situations when they are looking at the navigation system and unexpectedly a highway situation arises that they do not attend to quickly. This is primarily a problem where an in-vehicle operation captures drivers' attention and they pursue that task to completion. Wierwille's work shows that many of the tasks associated with the ETAK Navigator take much longer to complete than current ("accepted") in-vehicle tasks. Presumably, future navigation systems will be easier to use than the Navigator, which was a second generation system. Some feel that using a cellular phone is at the limit of what is acceptable. It is unfortunate that that task was not in his test battery.

What should be measured when people use navigation systems?

The dependent measure desired depends upon the experimental paradigm. In laboratory experiments, response time and error rates are typically considered, though in some cases exposure duration might also be measured. In simulator or on-the-road studies, both navigation performance and driver performance measures are considered.

Navigation measures of interest include the number of turns, the number of turn errors, the distance driven, the average speed, and the trip time. Obviously, distance, speed, and time are perfectly correlated. Of these measures, the number of errors is the most inidcative of between system differences, though time and distance are of interest because they provide measures of navigation waste than can be converted into costs (lost work time, excess fuel).

Of the driver-performance measures, eye fixations seem to be the most sensitive to design differences. (See, for example, Wierwille's research.) However, eye fixations are also sensitive to many other variables as well (momentary attentional demands from traffic, variations in road geometry, variations due to individual differences, and so forth.) Eye fixations require considerable equipment to collect and are laborious to analyze.

Lane position and speed variations have also been recorded by Wierwille, and Walker has considered speed. Wierwille examined only if drivers were in or out of a lane. Lane position might have been more sensitive if it was measured more precisely. Also, Walker points out that performance measures need to be zone specific. They should only be considered in the area near where the driver uses the route-guidance system.

What kinds of drivers will have the most problems?

Both the work of Wierwille and Walker show that the primary individual difference affecting performance with navigation systems is driver age; drivers roughly 65 and above have more problems than middle aged and younger drivers. (Differences related to map reading skill have also been documented by Adeyemi and Wierwille.) There are no apparent differences between men and women. This is important because older drivers are more likely to have the income to acquire vehicles Distinctions among older drivers (65-75 vs. those over 75) is a topic that still needs to be explored. While there is no evidence of large-scale interactions between display format and age, it should be considered. Certainly, deficits in hearing or sight are like to affect the use of these systems.

Where is the literature weak?

The literature on human factors and automotive navigation systems is not different from the automotive human factors literature in general in terms of weaknesses.

1. The literature lacks theory. Except for Wierwille's Q value for workload and Adeyemi's work on map search there have been no attempts to predict performance, which is information that engineers need to design systems. However, even in those cases, reasons have not been offered as to why the equations should be structured as they have been. There is a genuine lack of understanding of the mental processes involved in navigation. This problem is less acute for auditory systems where some attempt was made to consider evidence from the psychological literature (e.g., Streeter's work, Back Seat Driver).

In other contexts, data on visual search time, memory scanning, and the like have been used to build useful, predictive models of human behavior that identify how long it will take a person to complete a task, sometimes how often they will do it incorrectly, and why problems will occur. (See, for example, Card, Moran, and Newell, 1983; Polson, and Kieras, 1984; Polson and Lewis, 1990.) Ongoing collaborative work between the University of Michigan Transportation Research Institute and Bolt, Beranek and Newman (Green, Williams, Serafin, and Paelke, 1991) is designed to address this concern.

2. A second, more practical area needing additional research is that of complex intersections and successive maneuvers. In brief, the emphasis of route-guidance studies has been on simple intersections and grid networks (e.g., Walker) but it is suspected that route-guidance systems are likely to have the greatest benefit for maneuvers in heavy traffic, at complex intersections, and for difficult maneuvers, especially those involving expressways. These situations are where accidents are most likely (which good information could prevent). These situations have not been given much examination, though both Streeter and Wierwille have considered expressways.

3. Except for the work on auditory navigation, U.S. research on route-guidance has not examined the role of landmarks in electronic systems because they are not in the system databases. When people naturally give directions, they refer to underpasses, traffic lights, gas stations, and so forth. The extent to which they improve navigation performance, and the time to process them, should be examined. There is likely to be an interaction between the value of landmarks and the ambient illumination level (day vs. night), as landmarks remain visible when street signs and curb edges become difficult to see. There have been no tests of route-guidance systems conducted at night in the U.S. (though such tests are being considered in the ongoing TravTek project).

4. All of the drivers in these tests have been given careful instructions in the operation of the in-vehicle navigation systems being tested. But this is not how drivers become acquainted with cars. When they buy a new car, rent a car, or borrow a car from a friend, they put the key in the ignition and go. They generally do not read the manual or attend an introductory class. The reactions of drivers unfamiliar with these systems needs study.

Thus, the U.S. literature shows that, in general, simple auditory and visual systems can provide useful route-guidance information and, when properly designed, can be superior to paper maps. The usability of these systems by older drivers, novice drivers, and under difficult conditions needs to be explored, as does the usability of third-generation systems. If those systems should be easy to use (and safe) then more thought needs to be given to modeling driver behavior and using that information to engineer improved route-guidance systems. Again, readers are reminded, that the evidence reported here is only part of the picture. It will be more complete when European and Japanese data are included. In addition, work is ongoing at The University of Michigan, at the University of California-Berkeley (PATH project), and in Orlando (TravTek) on the safety and ease of use of these systems. For additional information on current research, readers are advised to see the following papers and reports: Allen, Stein, Rosenthal, Ziedman, Torres, and Halati, 1991; Burgett, 1991; Carpenter, Fleischman, Dingus, Szczublewski, Krage, and Means, 1991; Dingus, Hulse, Krage, Szczublewski, and Berry, 1991; Fleischman, 1991; Fleischman, Carpenter, and Dingus, 1991; Green, Serafin, Williams, and Paelke, 1991; Green, Williams, Serafin, and Paelke, 1991; Krage, 1991; and Rillings and Lewis, 1991.

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