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On-the-Road Human Factors Evaluation of the Ali-Scout Navigation System

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HUMAN FACTORS

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This research was funded by RCOC and the Federal Highway Administration.

Two experiments examined the safety and usability of the Siemens Ali-Scout navigation system. The in-vehicle interface provides turn-by-turn visual and voice guidance. In the first experiment, 54 drivers varying in age drove to four destinations, twice using the Ali-Scout and once using experimenter verbal guidance. Subjects were tested in the afternoon, at rush hour, and in the evening.

There were no crashes or near misses using the Ali-Scout, but there were four critical incidents where drivers changed lanes in response to navigation voice instructions without checking traffic. Excluding the turns into destinations, the turn error rate was 8 percent, and uncertainties occurred at an additional 13 percent of the turns. Most of the errors and uncertainties occurred in autonomous mode in which only the distance and direction to the destination are shown, not turn-by-turn guidance. Most longitudinal control measures (trip duration, mean and standard deviation of moving speed, overall mean speed, mean throttle position, and the standard deviation of throttle position) reflected significant experimental differences.

Drivers rated the interface as reasonably safe for themselves but not as safe as the Rockwell PathMaster or the simulated UMTRI interfaces, primarily due to mistiming of the voice guidance.

In the supplemental experiment, eye fixation data at night for the Ali-Scout was collected for 10 drivers. An additional three drivers used the PathMaster. There were no crashes, near misses, or critical incidents associated with the PathMaster. In contrast to the first experiment, measures of lateral control (lane position) were most sensitive to experimental differences.

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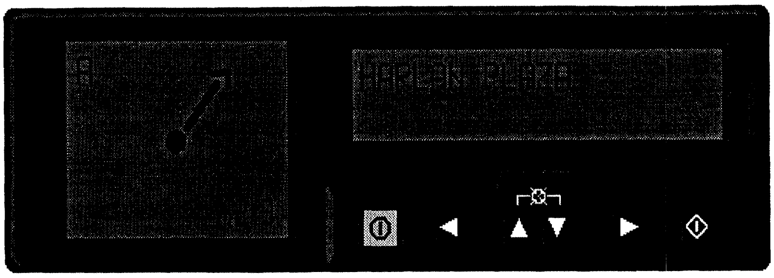
University of Michigan, Ann Arbor, Michigan, USA



1 ISSUES

1. How well did people drive?
   - navigation errors
   - speed, trip durations
   - throttle, headway
   - steering wheel angle, lane position
2: Was the Ali-Scout safe, usable, & useful?
   - accidents, near misses, critical incidents
   - driver ratings, comments
   - driving performance
   - willingness to pay
   - interface improvements
3. What should be done in future studies?
   - measures
   - experiment design
   - sensors, hardware
   - data reduction

2 METHOD

Experiment 1:

Session 1: Ali-Scout trip 1
Session 2: Ali-Scout trip 2, verbal guidance (baseline) (wk apart)

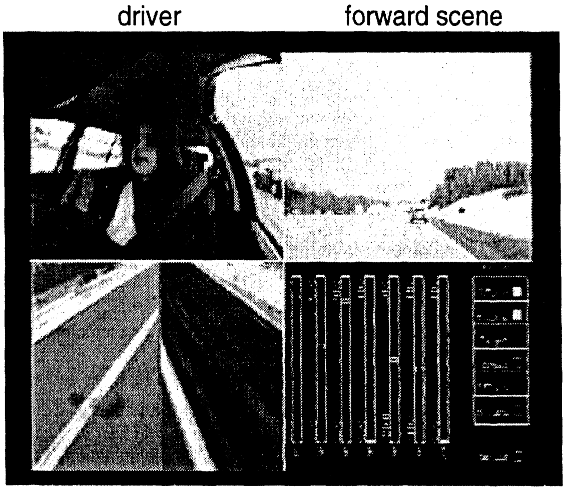
Subjects:

Time	Traffic	Age (# men / # woment)		
		19-30 (young)	40-55 (middle)	65-79 (older)
2-3 PM	moderate	3/3	3/3	3/3
5-6 PM	heavy	3/3	3/3	3/3
9-10 PM	light	3/3	3/3	3/3

Experiment 2:

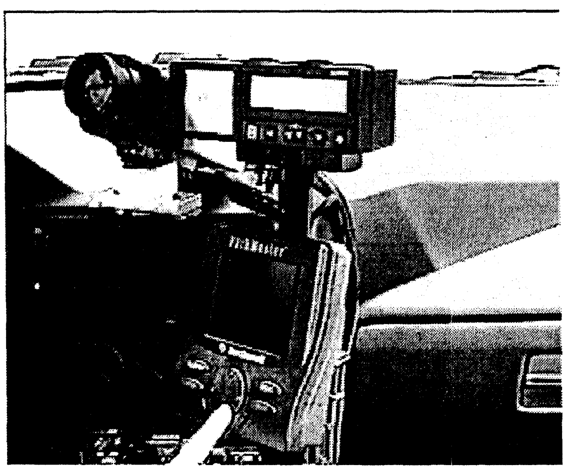
Session 1: navigation system trip 1, verbal guidance (baseline)	Subjects: 9 Ali-Scout (night), 4 PathMaster (rush hour)

driver forward scene



left lane tracker | right lane tracker | engineering data

Quad split image

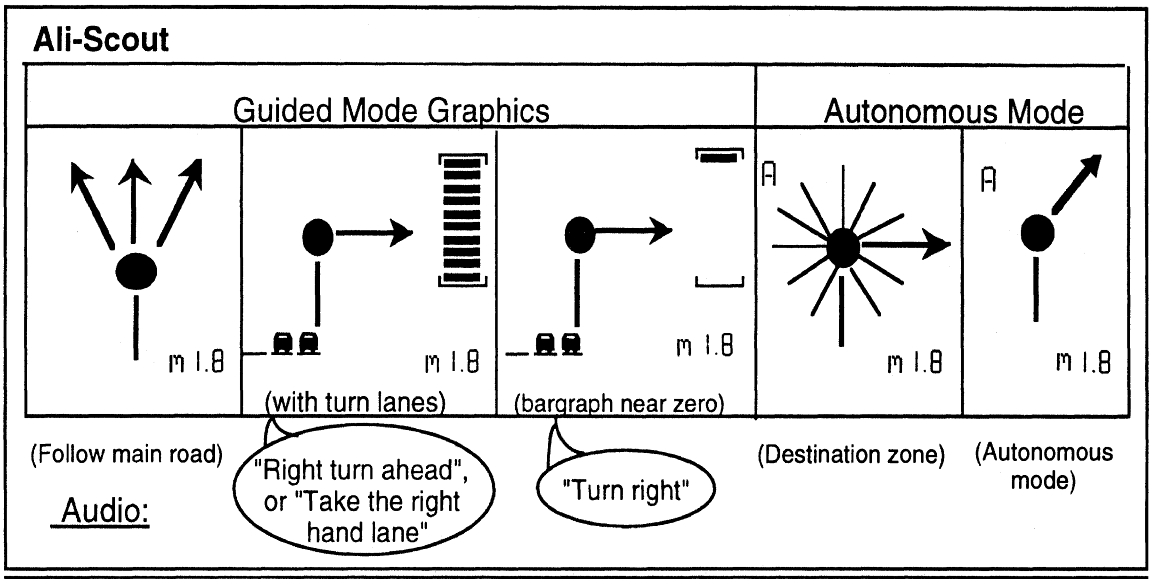


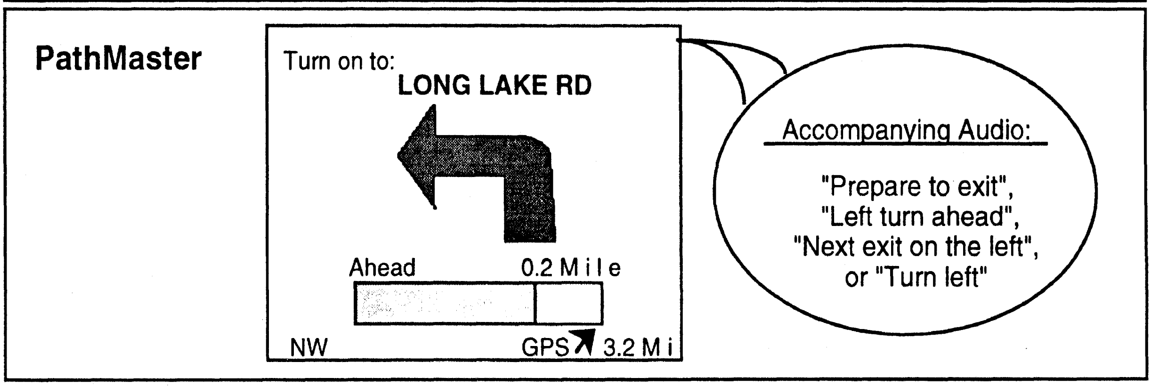
Navigation systems as installed
Ali-Scout top, PathMaster bottom

Route Description:

Start Point	Destination Number/Name	Turns/Maneuvers	Distance (mi)	Road Description (# of lanes)	Speed Limit (mi/hr)	Traffic
TOC Liberty Center	1. SOC Credit Union (exp)1 / Honeybaked Ham (exp 2)	•verbal instructions to I-75 North •guided right onto exit ramp •guided left onto Crooks Rd	•0.4 (•0.4) •2.9 (•2.9) •1.2 (•1.1)	•I-75 : 3 •Exit ramp: 1 •Crooks: 3 reduces to 2	•65 •25 •45	•heavy •moderate •heavy
SOC / Honey-baked Ham	2. Harlan Plaza	•verbal instructions to Crooks Rd •autonomous right onto Long Lake •guided right onto Rochester Rd •guided left onto Wattles Rd	•0.4 •0.1 •2.9 •1.0	•Long Lake: 2 reduces to 1 •Rochester: 2 •Wattles: 1	•45 •45 •40	•heavy •heavy •moderate
Harlan Plaza	3. Cumberland Dr.	•autonomous left out of parking lot •autonomous right onto John R Rd •autonomous right onto Cumberland Dr.	•0.1 •0.5	•Wattles: 1 •John R: 2 •Cumberland Dr.: 1	•40 •45 •25	•moderate •moderate •residential
Cumber-land Dr.	4. Maplewood Plaza	•verbal instructions to Wattles Rd •guided left onto Rochester Rd •guided right onto Rochester Rd split	•0.5 •1.0 •1.7	•Wattles: 1 •Rochester: 2 •Rochester Rd split: 2	•40 •45 •35	•moderate •heavy •moderate

→ Autonomous - shows "crow fly" direction and distance (mi) to destination
Guided - gives turn by turn directions





3 RESULTS

Turn errors and driver uncertainties / confusions from videotapes (54 subjects)

Route to Dest.	Ali-Scout Mode	Error Description	Number of turn errors by session		Number of uncertainties by session	
			1	2	1	2
2	A	Missed right turn at Long Lake	20	7	16	12
2	G	Turned into street prior to correct turn	2	0	3	0
2	G	Missed left turn at Wattles	3	1	8	4
2	G	Turned before intersection into shopping plaza	1	0	1	1
3	A	Turned right instead of left out of parking lot	3	1	5	0
3	A	Missed left turn onto John R	1	1	10	3
4	G	Missed right turn onto Rochester Rd	2	0	3	2
		total	32	10	46	22

A = autonomous, G = guided

Turn errors (session 1/2)

Sex	Age			Total
	young	middle	older	
women	7/2	7/1	2/1	16/4
men	6/1	6/2	4/3	16/6
Total	13/3	13/3	6/4	32/10

Turn confusions or uncertainties (session 1/2)

Sex	Age			Total
	young	middle	older	
women	12/2	5/3	10/7	27/12
men	6/4	8/3	5/3	19/10
Total	18/6	13/6	15/10	46/22

Subjective Ratings:

Ratings		Experiment 1		Experiment 2	
	Statement strongly agree (1) -----> strongly disagree (5)	Ali Scout (n=54)	Past study UMTRI interfaces Auditory/IP/ HUD (n=30+)	PathMaster (n=4)	Matched Ali-Scout (n=6)
Safety	safe for me to use while driving	4.0	5.0/4/7/4.6	4.5	4.0
	safe for an inexperienced driver	2.8	3.7/3.0/2.7	3.3	2.4
	was (not) distracting	3.9		4.3	4.1
System usefulness	would use for daily travel	3.2	4.6/3.4/3.2	3.3	3.6
	would use if in a hurry	3.7	4.5/3.4/3.2	4.0	4.0
	route guidance was helpful	4.3	5.0/4.8/4.0	4.5	4.3
	prefer over road map	4.3	4.8/4.6/4.6	4.3	4.1
	prefer over written instructions	4.1	4.8/4.8/4.7	4.5	4.1
	helpful in locating a new destination	4.6		4.8	4.7
	helpful in driving to familiar locations	2.6		1.5	2.4
Feature usefulness	autonomous mode was useful	3.5			
	guided mode was useful	4.4			
	arrow in autonomous mode was useful	4.2			
	miles to destination was useful	4.5		4.8	4.0
	auditory guidance was useful	4.6		4.3	4.4
	ample time for auditory turn messages	3.7		4.5	3.6
	turn countdown bars were useful	4.0		3.8	3.6
	guided mode turn graphics useful	4.4		4.3	4.1
	"follow current path" graphic useful	4.5			

Driving Performance Factors Significant at $p<0.05$ (in Experiment 1, 2, or both)

	Examined in		Lateral position		Wheel angle	Headway	
	Exp 1	Exp 2	mean	sd	sd	mean	sd
Age	y	n	1	-	-	1	1
Sex	y	y		1		-	-
Subject	y	y	both	1	1	1	1
Destination	y	y	both	both	both	both	both
Session #	y	y	-	-	-	-	-
Road section	y	y	both	both	both	both	both
Time of day	y	n	1	1	-	1	1
Dest*Time	y	n	-	-	1	-	-
Dest* Session #	y	n	-	-	-	1	-
Sex*Age	y	n	1	1	-	-	-
System	n	y	2	2	-	2	2
System * Section	n	y	2	2	-	2	2
System * Session	n	y	-	-	-	-	-

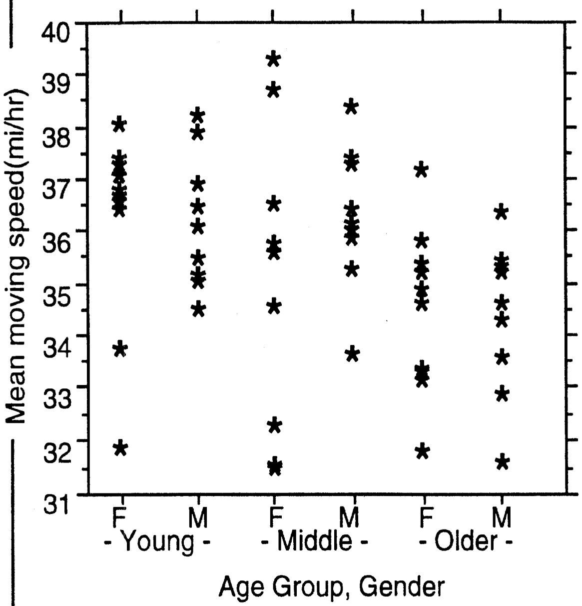
	Examined in		Duration	Moving Speed		Overall Speed	Throttle	
	Exp 1	Exp 2	mean	mean	sd	mean	mean	sd
Age	y	n	-	1	1	1	both	2
Sex	y	y	-	2	-	-	2	2
Subject	y	y	1	both	1	1	both	both
Destination	y	y	both	both	both	both	both	both
Session #	y	y	1	both	1	both	1	1
Road section	y	y	both	both	both	both	both	both
Time of day	y	n	1	1	1	1	1	1
Dest*Time	y	n	1	-	1	-	1	1
Dest* Session #	y	n	-	-	-	-	1	1
Sex*Age	y	n	-	1	1	1	-	-
System	n	y	2-	-	2	-	2	2
System * Section	n	y	2	-	-	-	-	-
System * Session	n	y	-	-	-	-	-	-

Experiment 1:

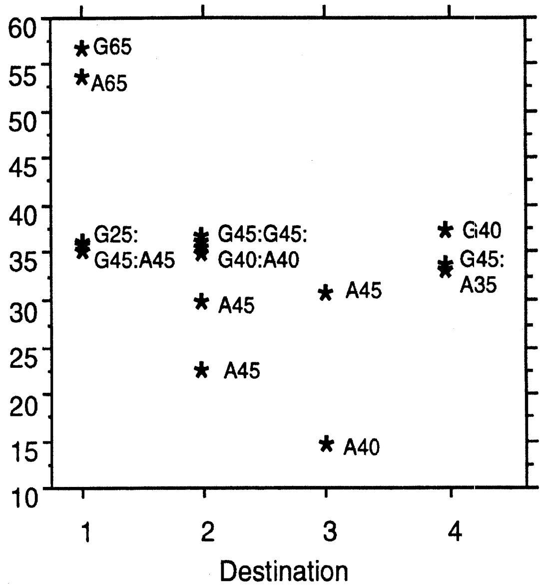
Example output for one dependent variable (see report for others)

Mean Moving Speed

Individual subject performance



Section within destination performance



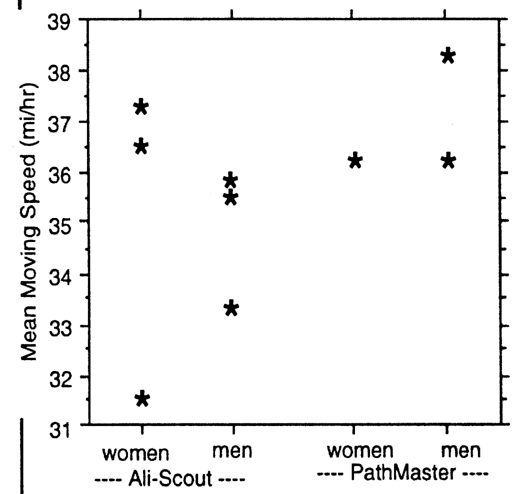
Note: G = guided, A = autonomous, # = speed limit

Experiment 2:

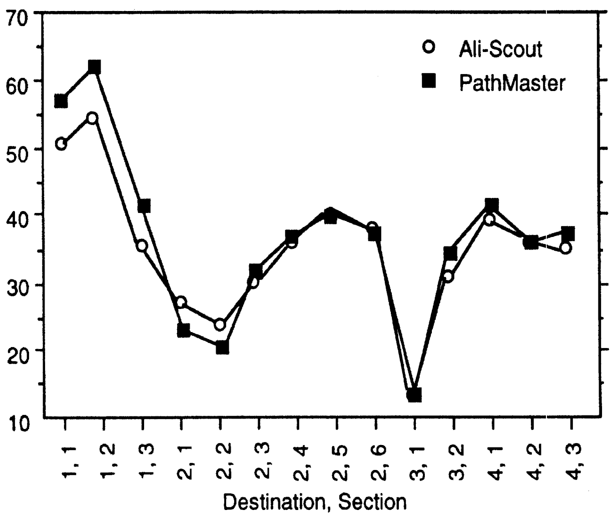
Example output for one dependent variable (see report for others)

Mean Moving Speed

Individual subject performance



Section within destination performance



4 CONCLUSIONS

Q: What factors affected driving with the Ali-Scout and the PathMaster?
A: Almost everything

- very large differences between sections (of test route) within destinations due to speed limit and road geometry
- 25% differences in trip times due to time of day (afternoon, rush hour, evening), mostly due to traffic
- larger headways when traffic density was lower (10% range)
- SD of lane position was lower at night (even though it was more difficult to see)
- middle-aged subject's driving behavior resembled younger subjects more than older subjects
- younger drivers drove faster, more variably, and had more headway (not less) than older subjects
- as drivers became more familiar with the route, speed variance increased

Q: How did the interface alter driving performance?
A: Ali-Scout was not as good as PathMaster or verbal guidance

- verbal (baseline) guidance led to trip times 6% faster than Ali-Scout
- PathMaster trips took 15% less time that Ali-Scout, but this may reflect a group difference, not an interface difference.
- PathMaster subjects were much less variable in lane position maintenance (1.0 vs. 0.4 ft)

Q: Were the Ali-Scout and PathMaster safe to use?
A: Ali-Scout-usually; PathMaster-possibly yes

- no crashes or near misses with Ali-Scout but 4 critical incidents (in response to auditory instructions, drivers changed lanes without looking)
- no PathMaster incidents (but the data set was small)
- drivers rated Ali-Scout as safe for themselves but not novices
- PathMaster was rated safer, but not as safe as UMTRI interfaces

Q: Were the Ali-Scout and PathMaster useful?
A: Yes, but there were many turn errors with the Ali-Scout

- drivers preferred the Ali-Scout over maps or written instructions for trips to unfamiliar destinations; however, other interfaces (UMTRI, PathMaster) were rated higher
- 8% of the Ali-Scout turns were wrong for the first session, 2% for the second (errors+uncertainties =21% for trip 1, 6% for trip 2)
- numerous errors when looking for destinations
- 3/4 of the turn errors were in autonomous mode
- error rates were lower for PathMaster and UMTRI interfaces

System	Mean Price Subjects were Willing to Pay
Ali-Scout	$593
PathMaster	$300
UMTRI IP/HUD/auditory	$1,125/$723/$937

Ali-Scout Problem	Lesson Learned
Late messages led to turn errors and uncertainties	Auditory message timing is more critical than any other feature
Subjects made lane changes without checking traffic	Voice messages may be interpreted as commands to be obeyed
Relatively more turn errors in autonomous mode; lack of understanding autonomous graphics and chime	All driving should be in a guided mode
Graphics were misunderstood (e.g. miles to destination, follow current path)	Pretesting of graphics is needed

PREFACE

This report is one of a series supported by the Road Commission of Oakland County, Michigan and the Federal Highway Administration, as part of the FAST-TRAC (Faster and Safer Travel through Traffic Routing and Advanced Controls) Project. (See Underwood, 1994; Eby, Streff, Wallace, Kostyniuk, Hopp, and Underwood, 1996; Taylor and Wu, 1995; Kostyniuk, and Eby, 1996 for related research.) This operational field test combines the SCATS (Sydney Coordinated Automatic Traffic Control System) equipment and software, the Autoscope video detection system, and the Ali-Scout (Autofahrer Leit und Information System Scout) dynamic route guidance system. The goals of this effort are to improve traffic flow and reduce traffic accidents in Oakland County and the surrounding area.

Ali-Scout is a second generation product developed by the Siemens Corporation. The product provides real-time, turn-by-turn guidance to drivers who have units installed in their vehicles. Ali-Scout vehicles communicate with infrared roadside beacons, which send travel times to the traffic control center and receive sequential routing instructions from the center.

If navigation products are to be produced, they must be safe and easy to use. The original program plan called for four human factors studies to examine safety and usability: (1) destination entry and retrieval in the laboratory, (2) route following on the road using the Ali-Scout in an instrumented car, (3) getting lost (where drivers are taken off route to see how they and the navigation system recover), and (4) a comparative evaluation of alternative navigation interfaces. Study 4 was canceled first, weakening study 2 (as it was intended to provide baseline data for the Ali-Scout). Subsequently, study 3 was canceled for lack of funding (midway through study 2). During the original definition of the project, the focus was on evaluation of the Ali-Scout interface, with comparisons occurring in study 4. However, as the project unfolded, it became clear that a beacon-based system with some of the limitations present in the Ali-Scout interface was not likely to represent future products in the U.S. Further, the cancellation of studies 3 and 4 meant that pilot comparison data had to be conducted in earlier studies so that the safety of the Ali-Scout interface could be assessed. As a consequence of these changes, emphasis was shifted towards a more general assessment of the desired qualities in navigation interfaces and protocols for assessing them. Such shifts occurred without compromising the intent of the project as it was initially framed.

Driver navigation-related tasks include (1) calibration and set up, (2) telling the system where the driver wants to go (destination designation), and (3) following the guidance instructions. The second and third tasks are more important. The human factors work carried out in the FAST-TRAC project is described in five reports. Matters related to destination designation are covered in Steinfeld, Manes, Green, and Hunter (1996) and a subsequent report that models the prediction of keystroke entry times (Manes, Green, and Hunter, 1996b). Research relating to following route guidance is covered in three reports: one concerning equipment used in the evaluation (Katz, Green, and Fleming, 1995), this report concerning driving performance and subjective ratings (Katz, Fleming, Green, Hunter, and Damouth, 1996), and a third concerning driver eye glances (Manes, Green, and Hunter, 1996a, in progress).

The intent of this report was to examine safety and usability in great detail by determining exactly how people drove when using the interface--how fast they drove, where they were in the lane, where they looked, etc., and how they felt about the interfaces--how safe they believed it to be and how much they would pay for it. Finally, as a result of this extensive effort, a great deal was learned about how to conduct future on-the-road experiments of navigation interfaces. Those ideas appear in this report as well.

Several individuals and organizations made important contributions to this effort and their contributions are gratefully acknowledged.

Mel Rode, Benny Reed (Siemens)	for coordinating installation of the Ali-Scout unit and other technical assistance
Amitaabh Malhotra (formerly of UMTRI)	for helping with installation of the equipment in the test vehicle and software development

Finally, the authors would like to thank Cale Hodder of Toyota for encouraging the authors to include Japanese-style A3 reports (the short summary prior to the Preface) in our technical reports.

TABLE OF CONTENTS

INTRODUCTION

There is considerable world wide interest in developing safe and easy to use navigation systems for motor vehicles. Navigation systems typically include a screen capable of showing maps of the route and display turn-by-turn guidance (usually in the form of arrows), and computer-generated speech to provide directions. Such products are quite popular in Japan (Treece, 1996). Efforts to market such products on a similar scale in the U.S. and Europe are just beginning.

From the driver's perspective, these systems reduce wasted travel, save time and save fuel. Also, by reducing the need to look at paper maps while driving, they can make driving safer. In terms of comfort and convenience, they are an attractive option for drivers. From the government's perspective, they are desirable because navigation systems support more efficient use of the existing road network, as well as reducing wasted fuel, and reducing air pollution.

There are two primary driver tasks involved in using these products: (1) entering and retrieving destinations, and (2) following the directions given by these systems (route guidance). Secondary tasks include setting and calibrating the system. Destination entry has been covered in a previous report (Steinfeld, Manes, Green and Hunter, 1996) and will be covered in a forthcoming report (Manes, Green, and Hunter, 1996b). This report covers how people utilize route guidance.

Previous Research

The selection of issues to be examined in this research project was molded by the human factors literature and by specific needs to evaluate and improve the Ali-Scout driver interface. While a number of driver studies involving route guidance systems have been conducted, there are many unanswered questions, both with regard to the merits of interface features and the methods for assessing the safety and ease of use of those interfaces. The U.S. literature is summarized in Green (1993a). Much of the non-U.S. literature is covered in Green (1993b). Other relevant material appears in de Waard (1996).

Some of the earliest research (Stephens, Rosen, Mammano, and Gibbs, 1968; Trabold and Prewitt, 1969) was associated with the development of ERGS, the Experimental Route Guidance System, a first generation interface developed by GM, Serendipity Associates, and the Federal Highway Administration (FHWA). Virtually all of the studies were carried out in the laboratory using choice response time tasks. Despite its simplicity, the research provided useful information to guide the design of the interface. Unfortunately, Congress did not fund the implementation of ERGS.

Subsequently, FHWA conducted several studies concerning voice messages. At issue was the relationship between recall and recognition rates, and the repetition of messages, the number of chunks in the message, and so forth (for example, see Gatling, 1977).

After being dormant for a time, research efforts were renewed in Europe as a result of the DRIVE and PROMETHEUS projects (e.g., Alm, 1990; Labiale, 1990). These studies focused on presentation format issues and the recall of information. They showed the need for keeping information simple and the merits of auditory presentation. Also occurring were major efforts to evaluate real products (e.g., West, Kemp, and Hack, 1989).

In the U.S. there were two independent efforts to examine auditory route guidance. Bell Labs, interested in providing a new phone service, conducted research that showed the superiority of voice-based guidance over maps (Streeter, Vitello, and Wonsiewicz, 1985). For his dissertation, Jim Davis developed a comprehensive auditory guidance system (Davis and Schmandt, 1989). While the supporting human factors testing was minimal, the design was nonetheless interesting.

In parallel, GM was supporting research on navigation systems at Virginia Tech (Wierwille, Hulse, Fischer, and Dingus, 1988; Antin, Dingus, Hulse, and Wierwille, 1990). That research compared the attentional demands of an ETAK Navigator with paper maps and memorized routes, developed an expression to predict driving workload, and examined the role of expectancy and the use of navigation systems.

A third parallel effort was conducted for the FHWA on alternative presentation schemes (Walker, Alicandri, Sedney, and Roberts, 1992). That laboratory research showed that drivers performed best with simple visual (turn arrows) and auditory displays.

In the 1990s the emphasis of the research changed from laboratory studies of concepts to on-the-road evaluations of real systems or preproduction prototypes. Overviews of research conducted in Europe are found in Parkes and Franzen (1993) and Michon (1993). Similar detailed overviews of Japanese research have not been identified. There were also a number of simulator and laboratory experiments (e.g., Green and Williams, 1992; Green, Hoekstra, Williams, Wen, and George, 1993). However, the rest of this review will concentrate on recent on-the-road experiments, studies having the most direct bearing on the research reported here.

In the first of two experiments, Parkes, Ashby, and Fairclough (1991) had 20 participants drive a local road while either guided by a highlighted route on a paper map or by computer text on an instrument panel display. Subjects took significantly longer to complete the route using the map, made more errors (34 with the map, 18 with the computer text), and had higher heart rates. Furthermore, subjects spent 12 percent of the time looking at the computer display versus 22 percent of the time for paper maps (as recorded by video cameras). Glance durations for the maps were both longer (1.8 versus 1.3 seconds) and more frequent (234 versus 160 glances). Subjects commented that the map gave them a better overview of the trip (e.g., distances between junctions and landmarks) but required more concentration. Thus, this experiment highlights the value of glance duration and frequency and, heart rate (also recorded) as measures of interface usability. It also indicates that text may be a viable presentation format, something that others have not followed up.

In experiment two, 24 subjects drove a test vehicle in urban Berlin either using the LISB/Ali-Scout or TravelPilot navigation system. Measures recorded were glance location (8 zones) and NASA TLX subjective workload ratings.

Subjects took less time to reach destinations using the LISB/Ali-Scout system, because it chose a better route. Table 1 shows the glance data. The most critical difference is that with LISB/Ali-Scout there were more glances to the road ahead. With regard to workload, the TLX values reflected lower demands of the LISB interface. Overall, subjects rated LISB as easier to use, more comfortable, simpler, and less distracting. Thus, this experiment showed that both glance data and TLX measures can detect differences in interface design. In addition, this research shows the superiority of turn-by-turn guidance (Ali-Scout) over point-on-a-map interfaces (TravelPilot).

Table 1. Percentage of glances while moving.

	Both trips		Similar routes	
	LISB	TravelPilot	LISB	TravelPilot
road	81.7	75.7	80.5	76.1
display	7.9	14.5	9.2	12.9
inside mirror	2.4	1.9	2.4	1.9
instrument panel	1.1	0.7	0.9	0.8
left side	1.5	1.9	1.5	2.5
right side	1.3	1.7	1.4	1.8
left mirror	2.1	1.7	2.2	1.8
right mirror	0.5	0.4	0.5	0.4

Burnett and Joyner (1993) described a related experiment in which subjects drove a test route using either an unspecified electronic map-based route guidance system or experimenter guidance. (See Appendix A for a summary.) They report differences in turn errors and TLX workload ratings between interfaces. Particularly interesting are the statistics for the number and frequency of glances to the locations described by Parkes, Ashby, and Fairclough (1991). The percentages are quite different, so different that the possibility of inconsistent definitions or measurement protocols needs to be considered.

Parkes and Burnett (1993) explored the design of turn graphics for a hypothetical interface. The key findings were that glance frequency, TLX scores, and Modified Cooper-Harper scores all reflected differences in interface design, suggesting their usefulness in future studies.

Daimon (Daimon, 1992; Daimon and Kawashima, 1996) has conducted several experiments concerning the use of verbal protocols for evaluating navigation interfaces, an idea that has not been pursued by others. In addition, these studies support the use of heart rate variability for examining interface differences as well as eye fixation data. Since the interfaces are not described in detail, comparisons of the data from these studies with others is difficult.

The best known and largest evaluation of navigation systems in the U.S. is the TravTek operational field test. This project examined the use of a navigation system with both auditory and visual elements (Fleischman, 1991; Inman, Fleischman, Dingus, and Lee; 1993; Perez, Fleischman, Golembiewski, and Dennard, 1993).

Several experiments were conducted that involve detailed analysis of driver actions ("camera car experiments"), pairs of drivers (with and without navigation) going to and from the same place at the same time (yoked driver experiments), and others involving rental car drivers.

In the camera car experiments subjects drove an instrumented vehicle under six different conditions: turn by turn guidance (with and without voice), map (with and without voice), paper directions, and a paper map. Performances sensitive to interface differences included eye fixations (mean glance duration to the road and the nav display), speed (mean and variance), number of lane deviations, variance of lateral acceleration, variance of steering wheel angle, variance of longitudinal acceleration, and time if the brake is pressed. Also sensitive to differences were several workload measures (both overall and with respect to time stress, visual effort, and psychological stress) and trip measures (planning time, driving time, number of stops, and mean duration of stops). Further information on this and other TravTek experiments appears in Appendix A.

Another major program to collect data on the usability of navigation and other interfaces is described Green, Williams, Serafin, and Paelke, 1991 and Green, 1993a. In that program some 20 experiments were conducted. Two series of experiments involved on-the-road tests of navigation and other interfaces to examine the safety and ease of use. The interface rating protocol developed in this previous project along with the classification of turn errors and driving performance measures examined also severed as a basis for the Ali-Scout evaluation. Hence, these previous experiments are described in some detail.

In the first experiment in the first series (Green, Williams, Hoekstra, George, and Wen, 1993), a pilot test to find flaws in the experiment, pairs of drivers drove an instrumented car over a 19-turn, 35-minute route aided by an experimental route guidance system. The route included sections through residential neighborhoods, on city streets, and on expressways. The route guidance was provided on a head-up display (HUD), on the instrument panel (IP), both without a voice element or, strictly by voice.

In the second experiment, 43 drivers followed the same route using the same route guidance system and other information systems. (Only the data from 30 drivers was analyzable due to problems with weather, software, and hardware.) Each driver only used one of the three navigation interfaces.

Use of the navigation system seemed to change driving behavior very little from the baseline condition. Measures collected included mean and standard deviation of steering wheel angle, throttle position, lateral position, and speed. Of these, the standard deviation of steering wheel angle seemed to be among the most sensitive to attentional demands, showing significant differences between interface types (0.9 for auditory, 1.0 for HUD, 1.1 for IP). Except for throttle position, there were no other significant differences between measures due to interface design. This is in sharp contrast to the TravTek results. This may be because subjects nested with age and sex was not included as a factor in the model, inflating the error estimates, and because the experiment design was between groups. In addition, the lane tracker only tracked a single edge marking, the left. In subsequent efforts it was observed that lane widths (as indicated by where the painted lines are located), commonly vary by as much as a foot. Only tracking one edge add considerable error into position estimates, decreasing the likelihood that lateral position measures will be significant.

Also examined were turn errors. Turn errors were classified as either "near misses" (where the driver expressed confusion or hesitated) and "execution errors" (where drivers missed a turn or made a wrong turn). Overall, there were 11 errors for the auditory interface (6 near misses, 5 execution errors), 8 for the IP interface (4 near misses, 4 execution errors), and 6 for the HUD (5 near misses, 1 execution error). This corresponds to an error rate of 4.4 percent for all types of mistakes and 1.8 percent for execution errors, both very low values.

To obtain a better sense of the visual demands of navigation, glance data were obtained from 8 drivers who used the IP version. Younger drivers glanced at the navigation display every 2 to 4 seconds, older drivers every 1 to 3 seconds. In part, this relatively frequent rate was due to the short distance between turns (30 seconds to 4 minutes). For the HUD version, glance data were difficult to obtain because the HUD was close to the line of sight. Since there was no display for the auditory interfaces, there were no display-related glances.

In terms of the ease of use, ratings for the auditory route-guidance interface were slightly lower than those for the IP and HUD implementations. However, ratings for other nonnavigation tasks were also slightly lower, suggesting the difference was due to the subject group, not the interface design. (Drivers only experienced one of the three implementations of the route guidance interface but the same implements of the interfaces for other systems.) Overall, drivers rated the route guidance interfaces as easy to use.

Green, Hoekstra, and Williams (1993) describe a third experiment in which 8 drivers drove a 19-turn, 35-minute route. The route was an enlargement of the route used in the previous experiment. Subjects were guided by a modified version of the IP interface used in previous experiments.

There were 8 navigation errors made by the 8 drivers in this experiment, comparable to the 25 errors from 30 drivers in a previous experiment. Significant differences in mean steering wheel angle, mean throttle position, the mean and standard deviation of throttle position, and mean speed were found. It is unclear why more measures were statistically significant in this experiment than in the previous one.

Foley and Hudak (1996) describe a field test of an unspecified route guidance system that provided turn-by-turn guidance. The interface consisted of a monochrome screen with a voice supplement. Each of 45 drivers drove a vehicle for approximately one month (either in Orlando or San Francisco) and reported their experiences in a post-drive briefing. Destination designation was via an infrared keyboard.

No driving performance data was collected. In the post-test response to at least 45 questions, subjects were generally satisfied with the system (1 to 6 scale, mean 4.0), and reported it did not interfere with driving safely (mean 5.0). The navigation interface was active on 15 percent of the trips, of which 63 percent were successful (in terms of reaching the destination). The actual success rate was probably greater, and in some cases, the car was shut off at the destination before the system indicated arrival. In terms of entries, 45 percent involved a street address, 38 percent intersections, and 17 percent were from memory.

To gain a better understanding of what to measure to identify the safety impacts of in-vehicle information systems, Verwey and his colleagues have conducted a series of experiments. See Verwey, Brookhuis, and Janssen (1996) and Verwey (1996a) for a description of the problem, and Verwey (1996c) for a related experiment on a traffic congestion display. Verwey (1996b) describes an experiment in which 12 drivers drove an instrumented van over a fixed urban route. The route was driven twice, the first time using a map-based route guidance system (Bosch TravelPilot), the second time using verbal guidance from the experimenter. Subjects drove to six destinations in Amersfoort in the Netherlands. Each of four situations occurred three times on the route: (1) turning right from a main road on to a minor road where bicycles and mopeds were present, (2) approaching an intersection for which motor vehicles (including the subject) have the right of way, (3) approaching a main road intersection (from a minor road) where other vehicles had the right of way, and (4) driving straight on a major inner-city artery.

Table 2 lists the dependent measures examined and the level of significance achieved to the effect of navigation guidance. Subjective safety ratings were scored by a driving instructor (the experimenter) as either satisfactory, acceptable, or unsafe. Looking behavior and deceleration were determined from video recordings. Time-to-Line Crossing (TLC) and lane excursions were assessed by a special purpose lane tracker.

Table 2. Dependent Measures Examined by Verwey (1996c)

Situation	p-value	Measure
right turn	<.05	subjective ratings
	>.15	frequency of looking over the shoulder
	>.20	hypothetical deceleration (safe braking maneuvers)
intersection with right of way	<.05	subjective ratings
	>.20	looking at priority traffic
	no diff	frequency of critical Time-to-Intersection (TTI)
yield intersection	<.05	subjective ratings
	>.20	frequency of critical Time-to-Intersection (TTI)
straight	<.001, .01	subjective ratings (2 measures)
	>.20	standard deviation of speed
	>.20	frequency of critical Time-to-Line Crossings (TLC)
	>.15	line crossing frequency

Verwey claims these data suggest that the subjective ratings are more sensitive to interface differences than objective performance measures. While that may be true, most of the objective measures were experimenter interpretations of objective outcomes, not direct measurements.

Conclusions from the Literature

What should be measured?

1. Measures of driving performance that have been successfully used to detect differences between navigation interfaces include turn errors and near errors, glance behavior (frequency and duration), measures of driver lateral control input (mean and standard deviation of steering wheel angle), measures of longitudinal control input (mean and standard deviation of throttle angle), measures of vehicle lateral behavior (mean and standard deviation of lane position, number of lane excursions, time to line crossing, lateral acceleration), and measures of speed control (mean and standard deviation of speed, various measures of acceleration), workload ratings, subjective assessments of driver errors, crashes, critical incidents, and heart rate variability.

2. Driver input measures of longitudinal and lateral control have received the most attention in UMTRI studies (Green, Williams, Serafin, and Paelke, 1991 and Green, 1993a; Green, Hoekstra, and Williams, 1993). Generally, those measures were not sensitive to interface differences, but that may be because of possible flaws in the speed sensor and because subjects were not included as a factor in the ANOVA, inflating the error estimate. In addition, all of the interfaces examined were fairly well designed, so differences may have been too small to detect.

3. Turn errors, glance behavior, and workload ratings have indicated interface differences in every study in which they have been used. The NASA TLX scheme or variations of it are favored.

4. Of the longitudinal output measures, both mean speed and speed variance (along with trip duration) seem to be sensitive to some interface differences (except in the UMTRI studies for the reasons noted previously).

5. Of the lateral output measures, the standard deviation of lane position seems to be more sensitive than the number of lane excursions, mainly because there are often so few excursions in real experiments.

6. There are never enough crashes in navigation experiments (in fact, there usually are not any) to be able to assess interface differences. Backing off in severity, there are also usually too few near misses to identify differences. One step removed are driver errors, which seem to reflect interface differences. Unfortunately, there is no accepted scheme for classifying driver errors.

6\. Verwey's research suggests that subjective measures may be more sensitive than objective measures. However, the objective measures were derived from visual observation of driving, not direct performance measurement.

7\. Only one study has examined physiological measures, namely heart rate variability, a measure popular with Japanese researchers.

8\. None of the studies to date have examined headway.

What leads to a good navigation interface?

Designs examined include paper maps, point-on-a-map electronic systems, crow-fly interfaces, text displays, turn-by-turn visual (arrow-based) guidance, and voice-based systems.

1. Generally paper maps and point-on-a-map based-electronic do not provide good guidance. A major problem with paper maps is reacquiring the current location after looking away from the map.

2. Only one study has examined text-based guidance, a study in which that interface performed fairly well. Text-based guidance has yet to be compared with turn-by-turn arrow displays.

3. Drivers do fairly well with turn-by-turn guidance, especially when it is supplemented by voice. In the U.S., performance with turn-by-turn guidance is superior to electronic map-based guidance, even when a highlighted route is shown.

4. Performance differences between alternative versions of a particular format (e.g., different turn-by-turn displays, are less than those between formats (turn-by-turn versus paper maps).

5. Performance with guidance on a HUD is superior to presenting information on an instrument panel.

6. The ultimate form of guidance is that provided by an experimenter in the test vehicle providing context-sensitive voice guidance.

Issues Examined

The literature review and sponsor interests influenced the issues to be investigated. As was noted in the preface, changes in the project direction led to adjustments in the emphasis given to particular issues. This project addressed three issues, all restatements of the issues identified in the project proposal.

Issue 1: How well did people drive with the Ali-Scout?

Issue 2: Was the Ali-Scout safe, usable, and useful?

Issue 3. What should be done in future driving studies?

More specifically, those issues can be stated as follows.

Issue 1: What were typical values for driving performance and behavior while using the Ali-Scout interface? How did those values change with driver age, sex, time of day, traffic, and experience with the system?

- How well did drivers navigate using the Ali-Scout interface?

- What were typical values for speed and trip durations?
- What were typical values for direct measures of longitudinal control (throttle position, headway)?
- What were typical values for measures of lateral control (steering wheel angle, lane position, etc.)?

Issue 2: Were there safety and usability problems associated with the Ali-Scout interface? How does the Ali-Scout interface compare with other navigation systems and information sources?

- How successful were the various navigation aids in getting drivers to destinations?
- Were there any crashes, near misses, or critical incidents, or other problems observed by experimenters?
- What comments did drivers make?
- Was the interface rated as safe and easy to use by drivers?
- What was the effect of using the Ali-Scout (or other navigation aids) on driving performance?
- How often did drivers look at the display, when did they look, and was looking distracting?
- How much were drivers willing to pay for the navigation system?
- How can the interface be improved?

Issue 3: What should be measured in future studies and how?

- Which safety and usability measures (e.g., navigation effectiveness, observations of driving risk, driver ratings, driving performance) were most sensitive to differences in interface design?
- How can experiments be designed to minimize the impact of route variations and individual differences?
- What should be measured and what hardware problems are likely to occur?
- What were the data reduction and analysis problems and how can they be overcome?

All of these issues are addressed in this report except the question pertaining to glance data, which is examined in Manes, Green, and Hunter (1996a, in progress).

MAIN EXPERIMENT - TEST PLAN

Test Participants

A total of 57 licensed drivers participated in the experiment. They were either friends of the experimenters, respondents to a newspaper advertisement or patrons of the Troy Community Senior Center. As shown in Table 3, 18 subjects were recruited equally from three age groups: young, middle-aged, and older, and tested at three different times of the day, each corresponding to a different traffic condition. Each age group contained an equal number of men and women. The mean age in each group was 21, 48, and 72 years, respectively. Corrected visual acuity ranged from 20/15 to 20/30.

Table 3. Subjects.

		Age (# men / # women)		
		19-30	40-55	65-79
Time	Traffic	(young)	(middle-aged)	(older)
2-3 PM	moderate	3/3	3/3	3/3
5-6 PM	heavy	3/3	3/3	3/3
9-10 PM	light	3/3	3/3	3/3

Three additional subjects either did not complete both sessions or had incomplete data sets: two young men and one older man, all in the 2-3 PM session. The data for these subjects was replaced. However, surveys were completed by all 57 subjects after the first session, regardless of whether or not the subject completed the second session of the experiment.

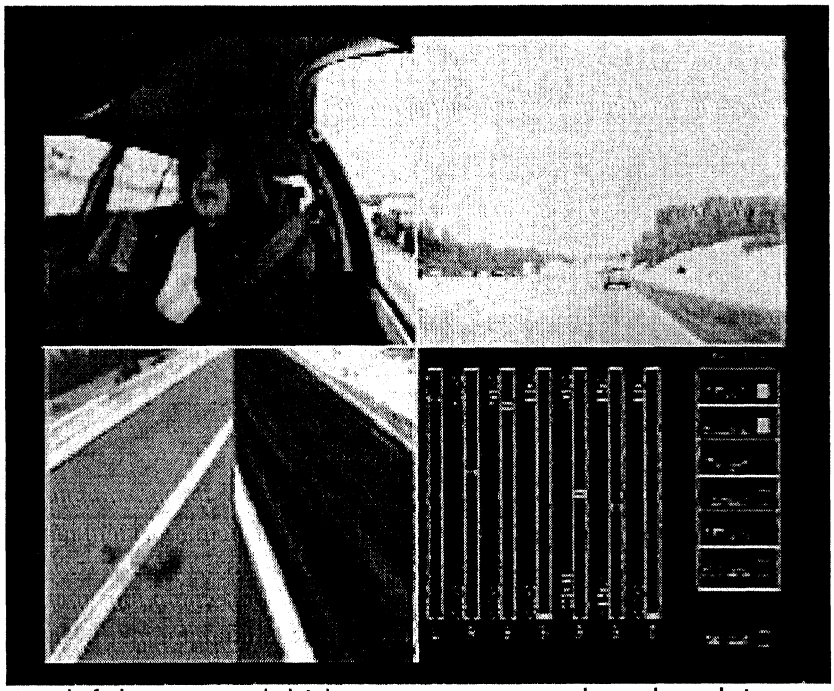
Participants reported that they drove between 1,000 and 61,000 miles per year (mean = 16,800), which is slightly greater than the average for the U.S. The annual mileage tended to be less for the young drivers and older drivers. Subjects rated their familiarity with driving in the city of Troy as 3.1 (mean) on a scale from 1 to 5 (1 = not at all familiar, and 5 = very familiar). On the same scale, subjects rated their familiarity with the FAST-TRAC project in Oakland County as 2.0, and pretest familiarity with the Ali-Scout navigation system as 1.2, indicating little to no familiarity. Only one subject had driven a vehicle with a different in-vehicle navigation system, a prototype developed by UMTRI (Green, Williams, Hoekstra, George, and Wen, 1993), and then only for a single experimental session. Both before and after experimentation subjects were asked if they knew the location of any of the destinations on the test route prior to testing. Four subjects had prior knowledge of SOC Credit Union (destination 1), 3 knew of Harlan Plaza (destination 2), 8 knew of Cumberland Dr. (destination 3), and 4 were familiar with Maplewood Plaza (destination 4).

Instrumented Car

The UMTRI Driver Interface Research Vehicle is a highly instrumented, left-hand drive 1991 Honda Accord station wagon. This car has sensors for all major driver control inputs (steering wheel angle, throttle and brake position, turn signal), vehicle responses (speed, lateral position), and cameras for recording the forward scene and driver.

The video recording system consists of three bullet (lipstick) cameras (one to record the forward scene mounted below the inside rear view mirror, a second aimed at the driver and mounted on the A-pillar, a third aimed at the driver and mounted below the Ali-Scout navigation unit to record eye fixations), and two small cameras located in the outside mirrors to record the lane markings on either side of the vehicle (lane trackers). Camera outputs are combined, along with a summary of the data collected by the computer (described below) by a quad splitter, displayed on a monitor, and recorded on a VCR. The two lane tracker images are combined by a two-image splitter and fill one quadrant of the quad splitter image. (See Figure 1.)

driver forward scene



left lane tracker right lane tracker engineering data

Figure 1. Typical quad-screen image.

Note: The capital letters L,R,S,R,R,S,T at the bottom right of the screen are labels for the bar graphs for the left lane tracker, right lane tracker, speed, range (headway), range rate, steering, and throttle.

Sound is picked up by two miniature lavaliere microphones, one mounted on the A-pillar, a second mounted on the inside rear-view mirror. An audio mixer combines the two microphone outputs for recording on one of the VCR's audio channels.

Engineering data is collected by a 486 computer via a custom-made signal conditioner (both located in the cargo section of the car). Sensors include a potentiometer mounted below the steering wheel (to measure steering wheel angle) and a headway sensor mounted to the front bumper. The engine computer located under the passenger's feet provides the speed, throttle, and brake signals. Lane position is determined in real time by the 486 by processing video images from the lane trackers. The 486 gets the majority of its data from the custom-built signal conditioner that receives the signals from both the engine controller and the steering-wheel-angle sensor. The data are stored on an external hard drive and then copied to a Bernoulli drive for analysis.

The data-collection and video equipment can be either powered by the car, or when stationary, by a 110-volt AC wall outlet source. During on-road tests, a 400-watt, 110-volt AC power converter connected to the car's electrical system supplements the 12-volt supply drawn from the car's battery. The stock Honda Accord alternator is used and there are no supplemental batteries to power the equipment. Figure 2 shows most of the engineering data equipment and the power supplies in the rear of the test vehicle.

All equipment is operated by an experimenter seated in the right-rear passenger seat. Using the video display showing the quad splitter output (Figure 1), the experimenter monitors the camera output, making adjustments as necessary, as well as checking the proper operation of all engineering data sensors. A keyboard is in the equipment rack next to the experimenter (and behind the driver). This rack also contains all the camera controls, a VCR, audio mixer, and a video display. Figure 3 shows the arrangement of most of the equipment operated by the experimenter. The CRT on the top shelf of the rack was not present during testing. Not shown is the quad splitter (behind the driver's seat) and the cellular phone (used in emergencies and stored under the equipment rack). Appendix B shows a plan view of the test vehicle and the model numbers of all equipment in the vehicle.

Figure 2. Data collection equipment and power supplies.

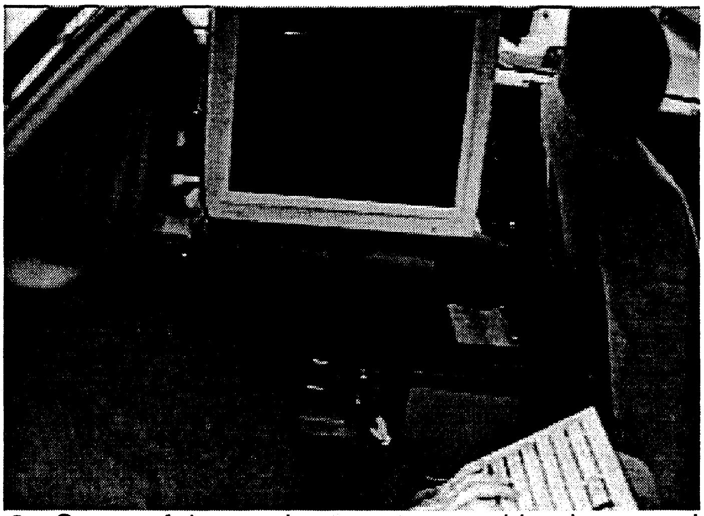


Figure 3. Some of the equipment operated by the experimenter (looking from right to left across the back seat).

The measures collected by the instrumented car are summarized in Table 4.

Table 4. Measures collected.

Measure	Units	Sampling Rate (Hz)	Type	Comments
left lane distance	ft	10	vehicle response	from center of edge marking to centerline of vehicle
right lane distance	ft	10	vehicle response	from center of edge marking to centerline of vehicle
speed	ft/s	10	vehicle response	from wheel pulser, later converted to mi/hr
range	m	30	vehicle response	to lead vehicle (if detected)
range rate	m/s	30	vehicle response	change in range to lead vehicle (rate of closure)
steering wheel angle	deg	30	driver input	position of steering wheel, plus is clockwise
throttle position	percent	30	driver input	angle of accelerator, 0 is no depression, floored is 100
left lock	none	10	status	does the left lane tracker see a lane marking (yes/no)
right lock	none	10	status	does the right lane tracker see a lane marking (yes/no)
headway target	none	10	status	does the headway sensor see a target (yes/no)
brake	none	10	driver input	is the brake pedal being pressed (yes/no)
left turn	none	10	driver input	is the left turn signal on (yes/no)
right turn	none	10	driver input	is the right turn signal on (yes/no)

Ali-Scout Operation

The Ali-Scout navigation system provides directions to specified destinations using voice and visual instructions via equipment installed in the test vehicle. The central Ali-Scout computer at the traffic operations center (TOC) determines the best route for each vehicle to take. Via line-of-sight infrared beacons, it communicates that information to a transceiver near the inside rear-view mirror of the vehicle. The only onboard, vehicle-location equipment is a wheel pulser and electronic compass (though a driver interface consisting of a keyboard and display is also present). There is no local map database or GPS receiver. Unlike other systems, the Ali-Scout in-vehicle system must periodically encounter beacons to update vehicle location and navigation instructions. As a consequence, the system is very limited in dealing with drivers that leave the specified route. Beacons are located at major intersections (approximately 1 mile apart) and on highways in Oakland County, Michigan. At the time of experimentation, 18 beacons were operational within the city of Troy, Michigan. Of the 18, 5 were used on the test route of this experiment. (See Appendix C.)

Figure 4 shows the Ali-Scout unit as it normally appeared to drivers in autonomous mode (indicated by an "A" in the upper right corner of the display screen). While operating in this mode, an arrow points in the direction of the destination and the "crow fly" distance (in miles) is continuously updated and displayed in the lower right corner of the guidance window. (See Table 5.)

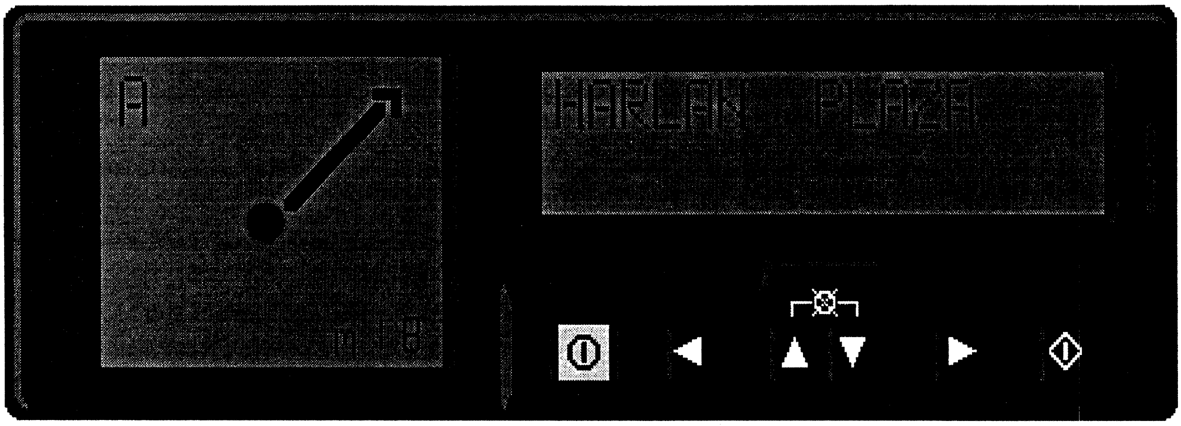


Figure 4. Ali-Scout system in Autonomous Mode

Once the vehicle enters the vicinity of a beacon, communication between the in-vehicle transceiver and the beacon begins, and the letter "I" (interaction with beacon) is displayed in the upper right corner of the guidance window. A chime sounds when the in-vehicle unit has been updated by the beacon and the system changes into guided mode. In guided mode, the Ali-Scout provides specific route guidance to the destination, including auditory messages and visual cues on the display unit. Visual cues include the driving distance (miles) to the destination, and maneuver graphics. The maneuver graphics shown to drivers during the test route of this experiment are given in Table 5.

Table 5. Ali-Scout maneuver graphics and auditory messages.

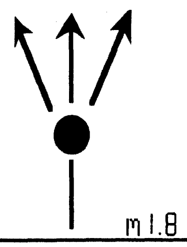
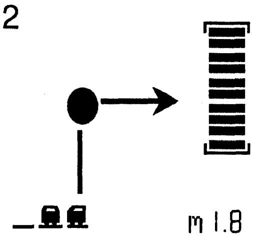
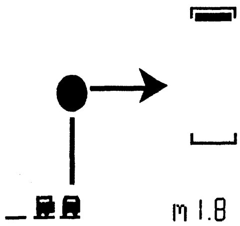
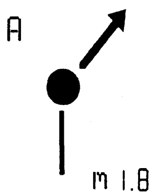
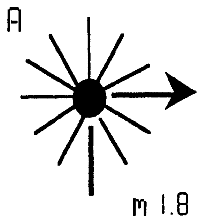
Graphic	Meaning	Auditory message
1 	Follow main road	
2 	Prepare to turn right Bargraphs display relative distance to the right turn Lane recommendation for turn	"Right turn ahead" or "Take the right hand lane"
3 	Execute right turn Bargraph near zero	"Turn right"
4 	Autonomous mode	
5 	Destination zone Operating in autonomous mode	Chime indicating change from guided to autonomous mode

Figure 5 shows the Ali-Scout display unit while in guided mode.

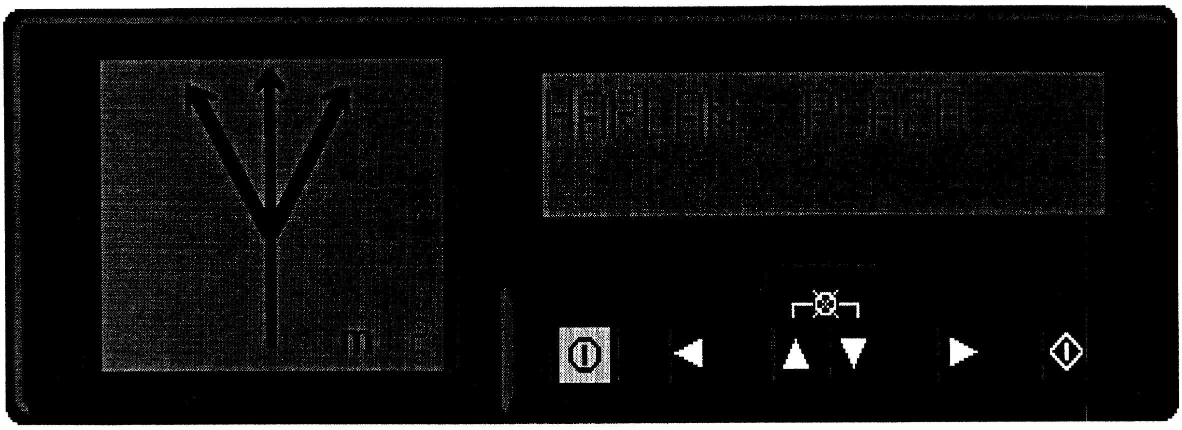


Figure 5. Ali-Scout navigation unit in guided mode.

Generally, the Ali-Scout will guide drivers to within a quarter mile of the desired destination, at which time it switches back into the autonomous mode. (See graphic 5, Table 5.) At this point, drivers are expected to follow the crow-fly arrow to the specified destination.

remove page break

Destinations and Test Route Overview

All experimentation took place in Troy, a suburb of Detroit, Michigan. Four different destinations were chosen based on criteria described in Appendix D: SOC Credit Union, Harlan Plaza, Cumberland Dr., and Maplewood Plaza. Pictures of each destination, and its sign (if detached from the building), as well as the destination attributes (building type, height, distance from road, etc.) are in Appendix E. The full test route (along with major roads in the area) can be seen in Figure 6. A description of the test route (turns, road description, speed limits, and traffic density) is given in Table 6.

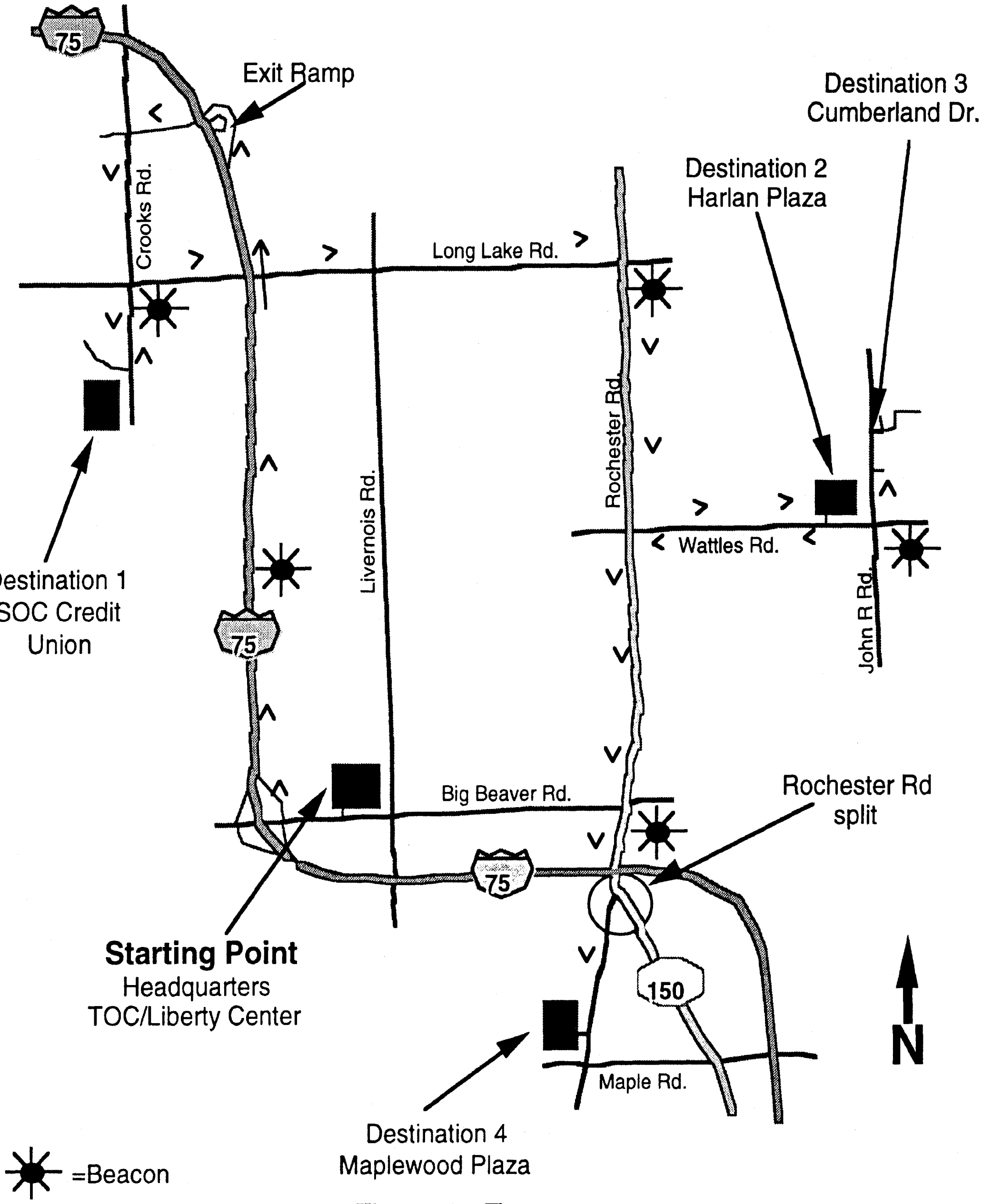


Figure 6. Test route.

Table 6. Test Route Description

Start Point	Destination Number/ Name	Turns/Maneuvers	Road Description (# of lanes)	Speed (mi/hr)	Traffic
TOC/ Liberty Center	1. SOC Credit Union	•verbal instructions to I-75 N. •guided right onto exit ramp •guided left onto Crooks Rd. •autonomous right into destination	•I-75: 3 •Exit ramp: 1 •Crooks: 3 merges to 2	•65 •25 •45	•heavy •light •heavy
SOC Credit Union	2. Harlan Plaza	•verbal instructions to Crooks Rd. •autonomous right onto Long Lake •guided right onto Rochester Rd. •guided left onto Wattles Rd. •autonomous left into destination	•Long Lake: 2 merges to 1 •Rochester: 2 •Wattles: 1	•45 •45 •40	•heavy •heavy •moderate
Harlan Plaza	3. Cumber-land Dr.	•autonomous left out of parking lot •autonomous right onto John R Rd. •autonomous right onto Cumberland Dr.	•Wattles: 1 •John R: 2 •Cumberland Dr.: 1	•40 •45 •25	•moderate •moderate •residential
Cumber-land Dr.	4. Maplewood Plaza	•verbal instructions to Wattles Rd. •guided left onto Rochester Rd. •guided right onto Rochester Rd. split •autonomous right into destination	•Wattles: 1 •Rochester: 2 •Rochester Rd. split: 2	•40 •45 •35	•moderate •heavy •moderate

More detailed descriptions of each of the four test routes, as well as maps of each individual destination, appear in Appendix F.

Test Activities and Their Sequence

Each subject participated in three test runs. Runs one and two involved using the Ali-Scout to drive to four destinations in a fixed sequence. The same four destinations were used in all sessions. The third run (baseline) provided comparison data on how subjects would drive to a reasonably familiar destination when provided close to ideal guidance (voice guidance from the experimenter). Trial one was conducted in the first session. Trials two and three were completed in the second session (approximately 1 week apart). Driving differences between Ali-Scout guided runs and the experimenter-guided run should reflect the workload associated with using the Ali-Scout unit.

Session One

The experimenter met the subjects in front of the Liberty Center office building (northwest corner of Livernois and Big Beaver Rd.) and escorted them upstairs to the Road Commission of Oakland County where the FAST-TRAC project office was located. Subjects watched a brief 10-minute video concerning the FAST-TRAC project and the operation of the Ali-Scout unit as well as providing information about the Traffic Operations Center and SCATS. Participants were told that the experiment involved two separate sessions, approximately 1 hour and 1-1/2 hours, respectively. (A copy of the instructions is found in Appendix G.) Subjects were informed that they would be paid $15 for the first session and $35 for the second session, a total of $50. Subjects completed a biographical form and a consent form and then had their visual acuity measured using a Titmus Vision Tester. (Copies of the biographical and consent forms are in Appendices I and J, respectively.) Subjects were then escorted downstairs to the test vehicle.

While the subject adjusted the vehicle mirrors, etc., the experimenter, seated in the right back seat of the vehicle, initialized the test equipment, and then reinforced key points concerning the Ali-Scout's use. (See Appendix G.) After initializing the video equipment, the experimenter verbally guided the subject to the beginning of the test route. The experimenter then began saving data and told the subject to "use the Ali-Scout" to get to SOC Credit Union.

While the subject drove the test route, the experimenter in the back seat monitored the data collection software and entered comments as necessary. (See Table 7.) At significant places during the route, codes were entered to signify events such as turns and changes in the Ali-Scout mode. There was some inconsistency between the two experimenters as to when to mark turns (e.g., just before turn, in the middle of the intersection, towards the end, etc.). A more serious problem resulted from the data entry software marking the turn in the data as soon as the key code was typed, instead of waiting for a carriage return to signify entry. This idiosyncrasy of the program caused variability in code times, since one experimenter developed the habit of typing in the code early, and waiting to hit the return key when the event actually happened. Due to experimenter error, a small percentage of events were not coded.

Table 7. Event codes.

Letter	Meaning	When Used
C	Change mode	entered when the Ali-Scout switched between guided and autonomous modes
T	Turn	entered when the subject began a turn
P	Problem	entered when a traffic or equipment problem occurred during testing

The specifics of the test route used to reach all four destinations (including the instructions provided by the Ali-Scout, and the mode segments) are given in Appendix H.

At SOC Credit Union, the subject parked the car, so the experimenter could save the data, enter new test parameters into the data collection computers, and enter the next destination into the Ali-Scout (Harlan Plaza). To begin the second test route, subjects were instructed to make a right turn from the parking lot, pull all the way into the left lane and make a U-turn in the median. (This is otherwise known as a Michigan left turn.) Once the subject was headed north on Crooks Rd. he/she used the Ali-Scout to get to Harlan Plaza. The specifics of the test route used to reach Harlan Plaza are given in Appendix H.

At Harlan Plaza, the subject parked the car, again to allow the experimenter to save the data, reinitialize the data logging software, and enter a new destination in the Ali-Scout (Cumberland Drive). Because the Cumberland Drive destination was so close, the Ali-Scout never entered into guided mode. Subjects were told the unit would remain in autonomous mode for the entire trip to the third destination and were told to use their best judgment (aided by the Ali-Scout) to reach Cumberland Drive. Accordingly, experimenter guidance for exiting the parking lot was not provided. A description of the this link is provided in Appendix H.

After making a right turn onto Cumberland Drive (the destination), the subject was instructed to make a quick left turn onto Lancashire Court, drive around the cul-de-sac, and pull over. The experimenter then saved the data that was collected, entered new test parameters into the data logging computer, and changed the destination in the Ali-Scout to Maplewood Plaza.

To begin the fourth link of the route, the subject was verbally guided to Wattles Road, heading west. ("Make a right turn from Lancashire Court onto Cumberland Drive. Make a left turn at the traffic signal at John R Road and then a right turn on to Wattles Road.") Ali-Scout guidance was then used to get to Maplewood Plaza. Appendix H describes the guidance provided by the Ali-Scout unit.

At Maplewood Plaza, the subject parked the car so the experimenter could save the data from the final link. The experimenter then drove the test vehicle back to TOC/Liberty Center, the starting point of the experiment, with the subject as a passenger. In the FAST-TRAC office the subject completed a survey concerning their familiarity with the project, the destinations, etc., as well as survey concerning the usability and usefulness of the Ali-Scout unit. (Copies of the Route Knowledge and Usability Surveys appear in Appendices K and L, respectively.) Subjects were then paid $15 cash after paperwork was completed (see Appendix M for payment form) and a time and date for the second session of the experiment was scheduled.

Session Two

The protocol used in session two was identical to that of session one for all destinations except destination three, for which subjects were not reminded the Ali-Scout would remain in autonomous mode for the duration of travel to destination three (Cumberland Drive). Subjects were directed onto the test route for the given destination and used the Ali-Scout to arrive at the destination. Upon arrival at each destination, data was saved and test parameters were changed. Accordingly, the Ali-Scout's destination was also changed by the experimenter.

When subjects arrived at destination four, they were told that the final trial, or baseline trial, would begin from that point. The baseline run involved driving the then familiar test route a third time, without the aid of the Ali-Scout navigation system. (The experimenter turned it off.) To ensure that subjects would reach each destination, the experimenter provided explicit directions. Subjects were also told that they should feel free to ask questions concerning the route, or where to turn, whenever they liked. (See Appendix N for a complete listing of the directions to each destination.) At each destination, data was saved by the experimenter. As in the first session, the experimenter drove the test vehicle from the fourth destination back to TOC/Liberty Center where the subject was paid $35 cash.

MAIN EXPERIMENT -- RESULTS

Crashes, Near Misses, Critical Incidents

In the literature the terms "accidents", "near accidents", and "critical incidents" are sometimes used to describe situations of varying severity. In this report the terms *crashes*, *near misses*, and *critical incidents* are used. A crash is a situation where the test vehicle collides with another object such as another vehicle, fixed objects (e.g., telephone poll), a pedestrian, etc. Damage of some sort usually occurs. Not all crashes are accidents because some can be deliberate. A near miss is a situation where a crash almost occurs but it is avoided by some drastic maneuver (sudden lane change, panic braking, etc.) to avoid it, either by the subject, other drivers, or both. Critical incidents are situations where the driver does something drastically wrong (passing a stop sign without slowing or noting it was there) but because of the traffic situation (no vehicles were present), no harm occurred.

Fortunately, no accidents or near misses were experienced during experimentation. There were several critical incidents in the seven months of experimentation (both original and supplemental testing). Most critical incidents occurred while the driver was not using the Ali-Scout (either during baseline trial, or when guided onto the test route by the experimenter). For instance, one subject drove through a red stop light, and another drove over a curb while maneuvering around stopped traffic. In addition, one older female subject in particular was considered by both experimenters to be a poor driver. A poor driver is defined as someone who did not maintain consistent lane position, speed, or did not complete maneuvers with confidence. For example, at one point during testing the poor driver put on her brakes (driving 20 mi/hr in a 40 mi/hr zone) during heavy rush hour traffic after being told that she had missed the right turn onto Long Lake Rd. The semi driving behind the test vehicle honked at the driver and was also forced to brake due to her reduced speed. The experimenter had to provide explicit instructions to the subject in order to avoid crashes.

During the initial exposure to the Ali-Scout (trial one), four critical incidents were created when drivers were given an auditory command to either take the right- or left-hand lane. Four drivers responded to the command by immediately changing lanes (neglecting to check their blind spot and ignoring surrounding traffic). Other drivers honked at the test vehicle, causing the subject to swerve back into the original lane. This occurred with two subjects traveling to destination two (before the intersection between Rochester Rd. and Wattles Rd.) and another two subjects traveling to destination four (before the split between Rochester Rd.). Had the experimenter not been present and vehicles in adjacent lanes been in slightly different positions, these events could have led to crashes.

Turn Errors

Not including the turn into the destination itself, the trip to destination one had one guided mode right turn and one guided mode left turn. Destination two involved one autonomous mode right turn, one guided mode right turn, and one guided mode left turn. Destination three involved two autonomous mode left turns. Finally, the test route to destination four included one guided mode right turn and one guided mode left turn. Thus, there were a total of eight turns during the entire test route, excluding the four turns into destinations.

Turn errors were determined by reviewing videotapes and notes of the sessions involving the Ali-Scout navigation system. En-route errors occurred where the driver actually made a wrong turn, or missed the correct turn. (See Table 8.) This table does not include errors made when subjects missed the entrance for the parking lot at each destination. (See Table 11.) In addition, uncertainties and confusions (when a subject shows clear apprehension about a maneuver) are included in Table 8. For example, one subject commented "So, if it's in autonomous mode it's not going to tell me to turn, but I probably should? Oh no...okay, I'm going to do it." This is typical of the uncertainty apparent in many subjects at different intersections.

Table 8. Turn errors for each destination.

Test Route to Dest. Number	Ali-Scout Mode	Intersection		Error Description	Number of Subjects to make Error by Session		Number of Subjects showing Uncertainty or Confusion	
		Driving On:	At:		1	2	1	2
2	A	Crooks Rd. (north)	Long Lake Rd.	Missed right turn onto Long Lake Rd.	20	7	16	12
2	G	Long Lake Rd. (east)	Rochester Rd.	Turned into street prior to Rochester Rd.	2	0	3	0
2	G	Rochester Rd. (south)	Wattles Rd.	Missed left turn onto Wattles Rd.	3	1	8	4
2	G	Rochester Rd. (south)	Wattles Rd. (shopping plaza)	Turned before intersection into shopping plaza parking lot	1	0	1	1
3	A	Harlan Plaza parking lot	Wattles Rd.	Missed left turn out of parking lot, instead turned right	3	1	5	0
3	A	Wattles Rd. (east)	John R Rd.	Missed left turn onto John R Rd.	1	1	10	3
4	G	Rochester Rd./ Stevenson Hwy. (south)	Rochester Rd. split	Missed right turn onto Rochester Rd. split	2	0	3	2
				Total	32	10	46	22

The most common turn error made by subjects was on the test route to destination two. While driving north on Crooks Rd., subjects often missed the autonomous right turn onto Long Lake Rd. The Ali-Scout's crow-fly arrow was clearly pointing due east at this intersection but, because subjects were not provided with an auditory cue, they did not turn right. Although time of day effects were not given in Table 8, it was found that, over both trials with the Ali-Scout, nine turn errors occurred during the afternoon session, eight during the rush hour session, and 10 during the night session (27 total over all three session times, and both session numbers). Therefore, time of day did not influence errors made.

In addition, at the intersection between Rochester Rd. and Wattles Rd., a total of four subjects missed the guided left turn and 12 more showed confusion or apprehension. While approaching this intersection the Ali-Scout gave a command to "take the left-hand lane," which many subjects did not interpret as the left-turn lane, or as a warning to prepare for a turn. When the second command, "turn left," followed, some subjects did not have enough time to slow down and turn. This problem could easily have been eliminated by substituting the "take the left hand lane" command with a "left turn ahead" audio command.

Similarly, during destination four (before the split at Rochester Rd.) a command to "take the right-hand lane" was also misunderstood. Two subjects missed the turn completely while five others showed apprehension regarding the turn.

No turn errors were made during the baseline trial because subjects were corrected before making any wrong turns. Subjects took advantage of opportunities to ask questions when they were unsure of the experimenter's directions during the baseline trial.

Table 9 shows the total number of turn errors by driver age and sex for both sessions. The predominant difference was session number (familiarity), with the number of turn errors in the first session being triple that of the second session. Older subjects made fewer turn errors, but no clear distinction can be made between the two sexes. Table 10, similarly, gives the total number of subjects showing uncertainty or confusion by subject age and sex. Again, there was clearly more uncertainty concerning turns during session one. Notice there was not a large effect due to age, though middle-aged drivers did slightly better. In terms of sex, men appeared somewhat less confused. Together, these data suggest that there are few age or sex differences affecting whether drivers correctly navigate.

Table 9. Number of turn errors using the Ali-Scout (session 1/session 2)

Sex	Age			Total
	young	middle	older	
women	7/2	7/1	2/1	16/4
men	6/1	6/2	4/3	16/6
Total	13/3	13/3	6/4	32/10

Table 10. Instances of confusion or uncertainty while using the Ali-Scout (session 1/ session 2)

Sex	Age			Total
	young	middle	older	
women	12/2	5/3	10/7	27/12
men	6/4	8/3	5/3	19/10
Total	18/6	13/6	15/10	46/22

It is assumed that a large number of subjects made turn errors or expressed confusion due to unfamiliarity with the Ali-Scout's autonomous mode. In fact, 33 of the 42 turn errors and 46 of the 68 near misses occurred in the autonomous mode, even though a minority of the driving was in this mode. Even with practice, errors predominated in the autonomous mode (9 of the 10 turn errors and 15 of the 22 turn confusions for the second session). A compilation of all maneuvers and features of the Ali-Scout that subjects found confusing is given in Appendix Q.

In addition to turn errors made during the test route, subjects often missed destinations. Table 11 gives the number of subjects (out of 54) who missed each destination during the first and second session of testing. When subjects missed a destination they usually drove past it without even noticing, though in some cases the subject saw the destination too late to turn. Destinations were always approached in the autonomous mode. Turn confusions and uncertainties were not included for turns into destinations; subjects generally turned into the destination only when they were able to clearly identify it.

Table 11. Destinations missed by subjects.

Destination	Number of subjects to miss destination	
	Session 1	Session 2
1. SOC Credit Union	27	11
2. Harlan Plaza	4	1
3. Cumberland Dr.	3	3
4. Maplewood Plaza	14	2

The first destination, SOC Credit Union, was by far the most missed destination. (Half of the subjects missed it during their first session.) This was probably due to subjects' unfamiliarity with the Ali-Scout navigation system and their failure to realize (no matter how much it was stressed by the experimenter) that they would have to look for the destination once they neared it.

Subject Comments Concerning Ali-Scout Features

During the course of experimentation several comments or questions concerning various features of the Ali-Scout system were posed to the experimenters. By analyzing the videotapes, comments were compiled by session number, subject age, subject sex, and Ali-Scout feature. (See Table 12.) All of the subject comments are listed in Appendix AC.

Table 12. Questions and confusion surrounding Ali-Scout features.

People were confused or unsure about these features or maneuvers	Session One						Session Two						Total
	YF	YM	MF	MM	OF	OM	YF	YM	MF	MM	OF	OM	
Chime signifying change from autonomous to guided or from guided to autonomous modes	2		2	4	6	1	1			1	4		15/6
Destination area graphic	1			1	1	1	1						4/1
Thought miles were meters				1		1				1			2/1
Thought miles were minutes					4								4/0
Miles to destination readout, in general	1	2		1		1							5/0
"follow current path" graphic	2	2		2	4								10/0
Asked if 'turn right' meant exit the highway	2	1			2	2		1			1		7/2
A in top left corner (signifying autonomous mode)	1	1	3			1							6/0
Lane position graphics			2	1					1	1			3/2
Total	9	6	7	10	17	7	2	1	1	3	5	0	

One of the most frequently asked questions (15 subjects during session 1) concerned the chime that the Ali-Scout provides when changing between autonomous and guided modes. Questions concerning the chime included: "That means I passed it, or I didn't find it?", "Does that mean you're there?", "Does that indicate that we get off at the exit?", and most regularly "What does that mean?."

Another common problem for subjects was the distance to destination readout at the bottom right of the Ali-Scout's screen. Two subjects asked if the readout was given in meters, one added, "That's not the international symbol for miles, that's the international symbol for meters." Four older, female subjects thought that the readout was given in minutes. In addition, another seven subjects asked what units the readout was given in.

Additionally, subjects asked several questions concerning the graphics presented by the Ali-Scout. Four subjects asked what the destination zone graphic meant, six subjects asked what the "A" in the upper left of the screen meant, and three subjects asked what the lane position graphic meant. Another frequently confused feature was the follow current path graphic (10 subjects). The most common misconception was that this graphic indicated that there were three lanes available to the driver.

Analysis of Post-Experiment Questionnaires

The post-experiment questionnaires contained questions concerning the overall safety (three questions), system usefulness (eight questions), and usefulness of Ali-Scout features (eight questions), along with other questions related to common driving task difficulty. Data was analyzed from all drivers who participated in the on-the-road experiment (57 drivers), not just those for whom there were reasonably complete driving performance data sets (54 drivers). Within each age-sex category there were 9 or 10 drivers in the 57 driver data set.

The first group of questions dealt with task difficulty for common driving tasks. After the first on-the-road test session, participants rated the difficulty of four driving tasks, based on lifetime driving experience (not just what occurred during the experiment). These ratings provide a baseline for the relative difficulty of the navigation tasks. The mean difficulty ratings are shown in Table 13 along with ratings from Green, Williams, Hoekstra, George, and Wen (1993), another on-road experiment concerning navigation system usability. The tasks that were rated least difficult were those that involve simple in-vehicle operations (reading the speedometer, or adjusting the fan speed). The more difficult tasks involve handling an object in the car (beverage), or reading information (street names). The two sets of ratings were highly similar, with the task of looking at street numbers to locate an address (used previously) being rated as more difficult than the task of reading street names (used here).

Table 13. Mean difficulty ratings for common tasks performed while driving.

	Mean Overall Rating	
Common driving task Not difficult 1 -----> 10 Extremely difficult	This Experiment	Green, et al, 1993
Reading the speed on the speedometer.	1.7	1.7
Drinking a beverage.	3.5	3.3
Reading street names.	3.2	
Looking at street numbers to locate an address.		4.4
Adjusting the fan speed on the car heater or air conditioner.	2.3	1.6

For the safety ratings, ANOVAs were performed to examine differences. The factors in the model were time of day, sex, age, subject (sex*age), sex*age interaction, and question. The ANOVA tables generated using these three variables (safety, system usefulness, and feature usefulness) appear in Appendix P.

Overall safety questions concerned the risk of using the interface while driving. Prior to the analysis, the scores for the third safety question were transformed (new rating = 5-original rating) so that positive values on every scale would be associated with safer systems. (The original statement was "The Ali-Scout was distracting.") In the ANOVA of the transformed ratings, there were significant differences due to age group (p=0.0052), and question concerning safety (p=0.0001), as well as subject nested within age and sex (p=0.0001). Older drivers, especially older men, were more likely to feel the system was safe than younger or middle-aged drivers (ratings of 3.8 versus 3.3 and 3.6, respectively). Drivers felt that it was safe for themselves to use the Ali-Scout while driving, but not necessarily safe for inexperienced drivers. They generally agreed it was not distracting. (See Table 14.)

Also shown in Table 14 are the means from a previous study (Green, Williams, Hoekstra, George, and Wen, 1993) in which some of the same questions were asked, but agree/disagree scale was reversed. The transformed data are shown in the table. Three values are given because in that previous experiment three interfaces were tested: (1) voice only, (2), instrument-panel visual display only, and (3) HUD only. The route used in that experiment was somewhat more difficult than that of the FAST-TRAC project, and the number of subjects rating each interface was small (11 on average). Nonetheless, these data suggest the Ali-Scout was not as safe as other interfaces described in the literature.

Table 14. Mean ratings of safety.

Ali-Scout evaluation Strongly disagree 1 ----> 5 Strongly agree	Mean Overall Rating This Experiment	 Green, et al, 1993 (aud/IP/HUD)
1. It is safe for me to use this system while driving.	4.0	5.0/4.7/4.5
2. It is safe for an inexperienced driver to use this system while driving.	2.8	3.7/3.0/2.7
3. The Ali-Scout was (not) distracting.	3.9	

Means for each subject based on all three safety questions are plotted by age group and sex, as shown in Figure 7. Nine or ten data points are present in each age, sex category, however, some points on the graph overlap. Figure 7 shows that older subjects generally reported higher safety ratings than younger subjects.

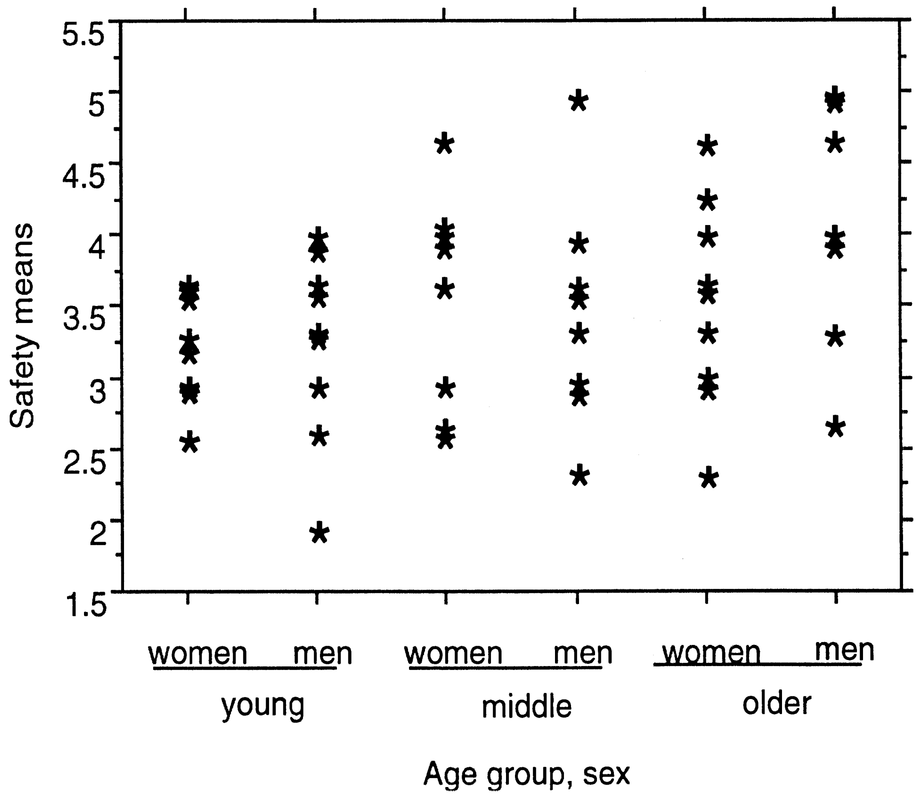


Figure 7. Subject mean safety ratings

System usefulness concerned the benefit of the system as a whole towards improved navigation. Table 15 gives the means for the seven questions concerning that topic. Neither sex, age group, nor time of day had a significant effect on subject ratings. Differences between subjects and questions were significant (both p=0.0001). According to the overall mean ratings, users strongly agreed that the information provided by the Ali-Scout was useful. Responses show that subjects would rather use a navigation system similar to the Ali-Scout than a standard paper road map, or written instructions to find their way. Overall, users felt that the Ali-Scout would be more helpful in locating a destination they had never visited than driving to a familiar location.

Table 15. Mean ratings of system usefulness.

Ali-Scout evaluation Strongly disagree 1 ----> 5 Strongly agree	Mean Overall Rating	Green, et al, 1993 (aud/IP/HUD)
1. I would likely use this system for my daily travel.	3.2	4.6/3.4/4.1
2. I would use this system if I were in a hurry.	3.7	4.5/3.4/3.2
3. The route guidance information provided is useful.	4.3	5.0/4.8/4.9
4. I would rather use a route guidance system similar to this one than use a standard paper road map to find my way.	4.3	4.8/4.6/4.5
5. I would rather use a route guidance system similar to this one than use written instructions to find my way.	4.1	4.8/4.8/4.7
6. The Ali-Scout would be helpful in locating a destination that I have never visited before.	4.6	-
7. The Ali-Scout would be helpful in driving to familiar locations.	2.6	-

The table above also provides comparison data for the UMTRI-designed interfaces used on a different route in a different experiment. Notice that ratings for all three interfaces (auditory only, instrument panel, HUD), tend to be greater than those for the Ali-Scout. Readers are reminded that the UMTRI interfaces were preproduction representations of how an easy-to-use interface might function.

Means for each subject based on all seven system usefulness questions appear in Figure 8 plotted by age group and sex. No patterns between age group and sex are apparent.

The usefulness of features concerned the value of display elements (e.g., countdown bars) and system modes. Ratings of the usefulness of Ali-Scout features appear in Table 16. There were significant differences due to subject age (4.1 for young drivers, 4.1 for middle-aged drivers, 4.5 for older drivers), subject nested within age and sex (Figure 9), and questions (all p=0.0001), but not time of day or sex. Time of day and sex were not significant for all three rating categories.

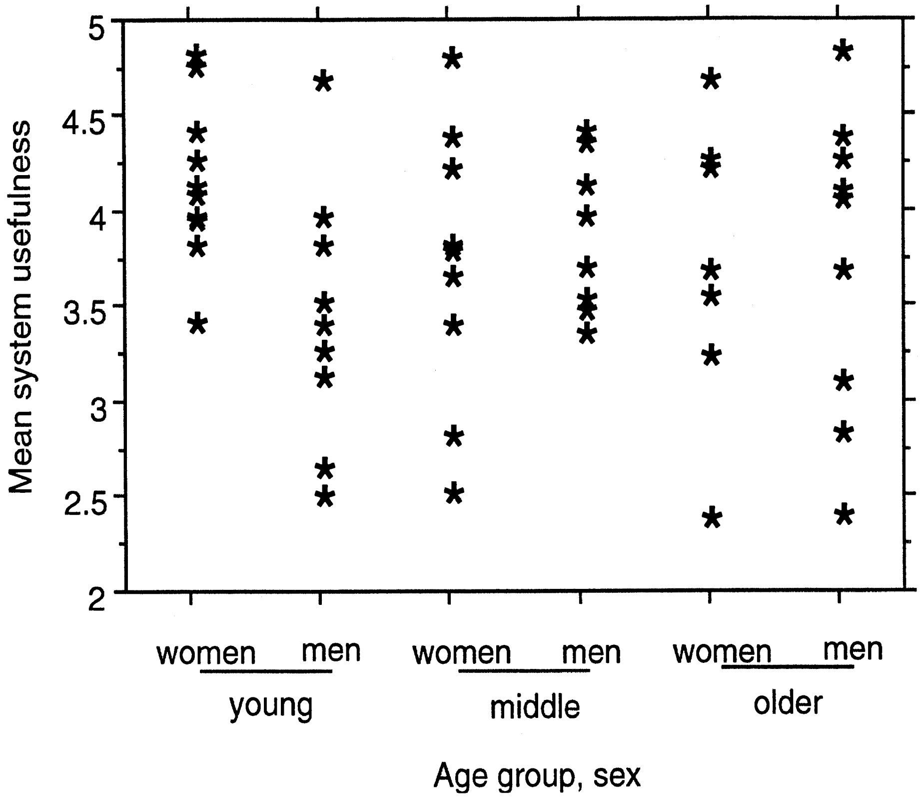


Figure 8. Subject mean system usability ratings.

Table 16. Mean ratings of usefulness of Ali-Scout features.

Ali-Scout evaluation Strongly disagree 1 ----> 5 Strongly agree	Mean Overall Rating
1. The Ali-Scout's autonomous mode was useful.	3.5
2. The Ali-Scout's guided mode was useful.	4.4
3. The arrow given in autonomous mode was useful.	4.2
4. The miles to reach destination readout was useful.	4.5
5. The auditory messages given in guided mode were useful.	4.6
6. The auditory messages are given in ample time before a turn is to be made.	3.7
7. The countdown bars to a turn in guided mode were useful.	4.0
8. The turn graphics in guided mode were useful.	4.4
9. The "follow current path" graphic in guided mode was useful.	4.5

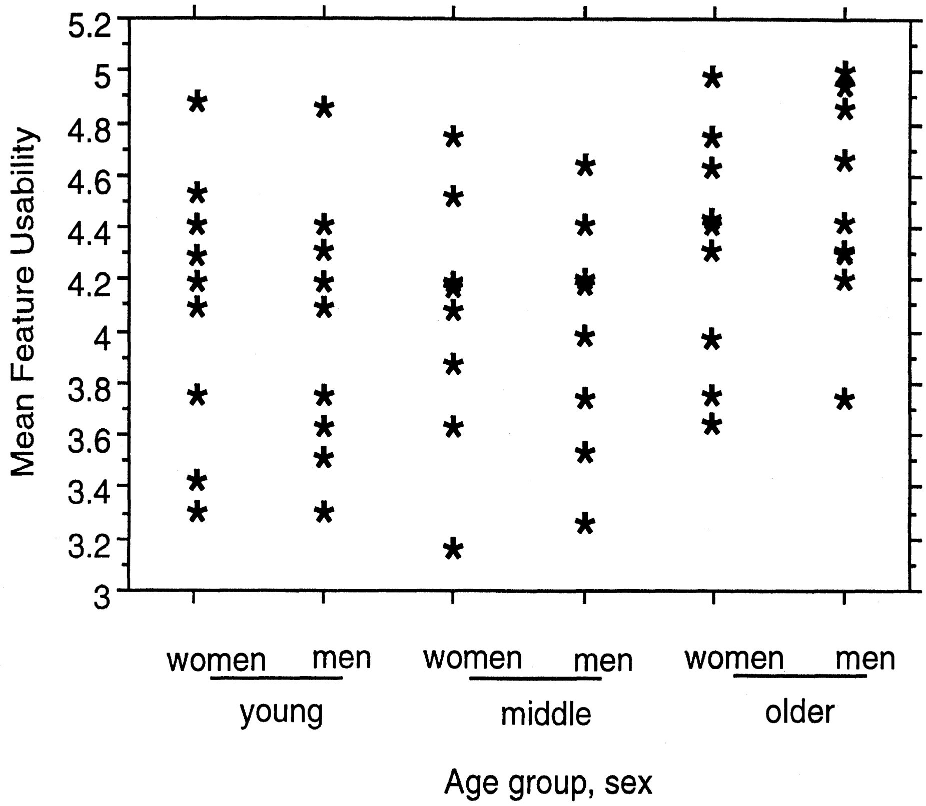


Figure 9. Subject mean feature usability ratings.

Overall, subjects found the auditory messages to be most useful, followed closely by the miles to reach destination readout and the "follow current path" graphic in guided mode. The feature rated least useful was the Ali-Scout's autonomous mode, which provided no turn directions or auditory instructions.

Participants were asked how much they would be willing to pay for a route guidance system (such as the Ali-Scout). Nine subjects left this question blank on their questionnaire. Of the subjects who did respond to the question (45 subjects), the mean amount was $593.22 with a range from $0 to $5,000. Figure 10 shows the distribution of how much subjects are willing to pay for a navigation system similar to the Ali-Scout. Notice that some subjects were not willing to pay anything, while a few were willing to pay very large amounts ($3,000 or $5,000).

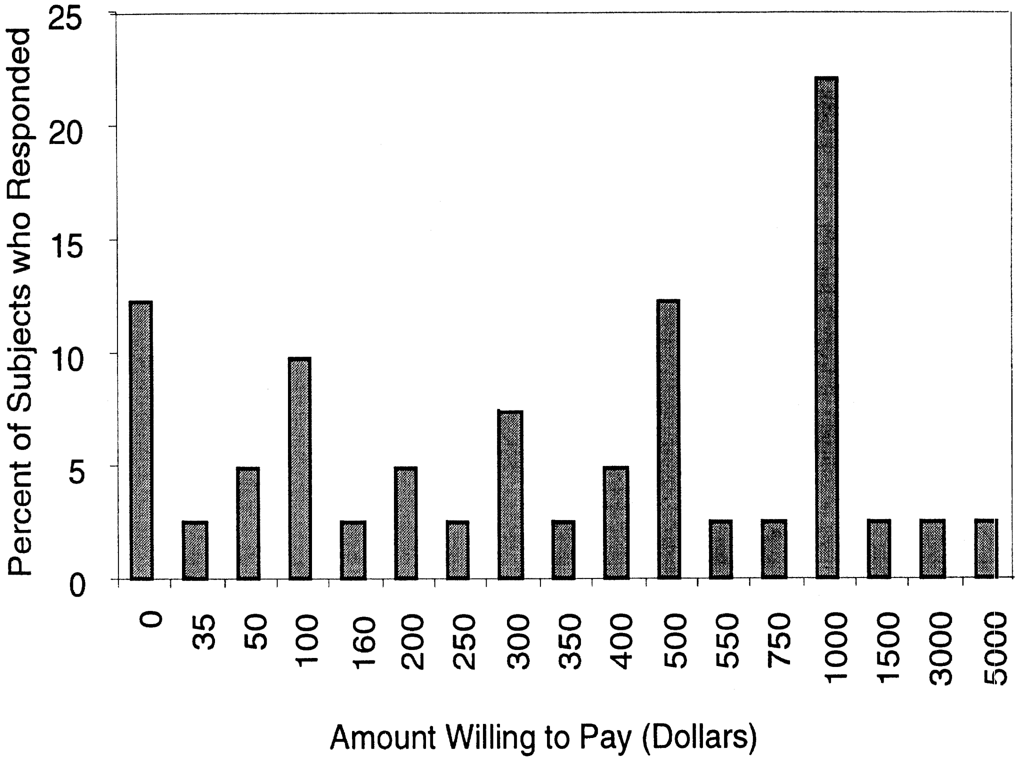


Figure 10. Amount subjects were willing to pay for a navigation system similar to the Ali-Scout.

Additional space was given on the questionnaire for subjects to make any general comments concerning the experiment and/or the Ali-Scout. Some of the comments provided by subjects are given in Table 17.

Table 17. Subject comments concerning their exposure to the Ali-Scout system.

Session Time	Age	Sex	Comment
Night	21	F	"On one of the turns the system told me at kind of the last minute to turn - I had to slam on the brakes - I saw the arrow pointing left but was confused when the system didn't give vocal instructions (until the last minute)."
Day	46	F	"The directions (audio) on Ali-Scout need to come a little sooner."
Night	44	M	"It needs to give directions right up to the point of destination. It needs to be more specific when giving directions. Example: get in the left turn lane instead of get in the left lane."
Rush Hour	51	M	"Very interesting system."
Day	77	M	"Very interesting. Seems practical."
Day	77	M	"Good start on a system."
Night	66	F	"It was fun, exciting and helpful."
Day	48	M	"Price dependent on area covered and options such as night readability, choice of voice, peripheral equipment available."
Day	75	F	"I especially liked the arrows so I know I'm going in the right direction when in a strange area."
Night	27	F	"This system is very interesting and useful."
Night	65	F	"Excellent system, but one I don't need."
Day	49	M	"This would be great in the real estate business if you could pinpoint down to house number or at least block."

Driving Data Reduction

All data channels were sampled at a fixed rate, either 10 or 30 Hz. Hence, each data point describes the status of the vehicle for 1/10 or 1/30 of a second. For channels sampled at 10 Hz, the "missing" data was filled in by assuming that every three successive samples were identical. Since the channels sampled at 10 Hz were of low bandwidth, this assumption is reasonable.

Each run (about 30 minutes) for each driver generated four data files, one per destination consisting of 30,000 lines of data (plus several header lines) for 13 measures (averaging just over 4 MB/run). These files were too large to analyze using statistical programs currently available for the Macintosh. Across the 54 subjects (3 runs/subject), almost 750 megabytes of raw data was collected. Consequently, the task of handling and subsequently reducing the data was a major undertaking at least equal in effort to running subjects.

To compute means and standard deviations for each measure of interest for subsequent statistical analyses, custom software was developed. The unit of analysis was a road section, a segment for which Ali-Scout mode (autonomous versus guided) and road (geometry and speed) were fixed. The actual partitioning of trips into sections was based on a combination of the ease by which the parser could identify changes in driving behavior, road details (i.e. turns, speed, induced stops), subjects' actual driving behavior, and common mistakes. Because the beginning and end of turns were difficult to determine, no turns are included in any of the sections. Instead, a section may either begin after a turn has been completed, and/or end before beginning a turn. There were 16 sections, five sections in destination 1, six sections in destination 2, two sections in destination 3, and three sections in destination 4 (sections are described in Appendix O).

When driving at a steady 55 mi/hr (though this also occurs at other speeds), a wheel pulse signal was occasionally missed, causing the recorded speed to drop by 2 mi/hr and then return to the previous speed on the next sample. If these changes actually occurred (a 2 mi/hr decrease and then increase of 2 mi/hr in 1/30 of a second), they would be very noticeable to drivers. An algorithm to smooth over these drop outs was built into the data parser.

The original plan was to use experimenter-entered codes to partition the data into sections for analysis. As was noted earlier, there were inconsistencies in coding among experimenters. Second, deviations from the route were common enough that manual correction of the data files would have been prohibitively time-consuming. The most common driver error was turning at the wrong place or missing a turn that was supposed to have been taken. In these cases, the drivers were directed back onto the proper route before the location at which they had originally deviated from it, and the experiment was continued. Since data collection was continuous throughout, irrelevant data due to turn errors was entered into the file. Therefore, the parser was written to automatically detect deviations by classifying the data into maneuvers and comparing the sequence of detected maneuvers to ideal sequences and actual (measured) distances along the route. Distances were computed from the speed and time data. Unfortunately, variance in calculated distances along known segments revealed that the speed signal was not entirely reliable. The sections of data representing the time in which the driver was not on the proper route were then left out of the parser's final output.

Since the route had not been designed with this process in mind, not all proper route divisions occurred near an easily-detectable vehicle maneuver. For example, some of the mode changes occurred in the middle of straight sections. To provide these divisions, the parser was modified to insert the mode-change break in the proper place, as measured by the ratio of distance from the previous maneuver to distance to next maneuver. In this way, the proper division would be found even if the speed reported was consistently either high or low.

Finally, to assure the accuracy of lane position calculations, only situations where both lane trackers were locked (detecting edge markings) were considered.

Once the data parser was working properly, each data file from each run for each subject for each destination was processed separately. As was noted earlier, data from three subjects was replaced because of missing data. Of the 54 subjects remaining (9 drivers in each age-sex category), a total of 41 sections (out of 864) were lost due to hardware, software, or experimenter error. The 41 sections were associated with 8 runs (out of 216). In no case were more than a few runs missing from a single subject (typically the data for one section or one destination), though for one subject 5 of 6 sections (for destination 2) were missing. Thus, there were very few cases of missing data, and because they were well distributed in the data set, were unlikely to result in any biases in the analysis.

Once parsed to generate means and standard deviations, files from successive runs were combined into a single output file. Subsequently, codes for age group, time slot, and subject within age-sex group were all added to the combined output file to supplement codes for sex, subject number, destination, section, session, and time of day already present. This enhanced version of the compiled data file was imported into StatView (version 4.5) and SuperANOVA (version 1.11) for analysis.

The data for each dependent measure were examined using an ANOVA model which included subject-related effects and their interactions (age group, sex, subject nested by sex and age group, and the sex by age interaction), trip characteristics (destination, road section within destination, session time), navigation system differences (trial) and selected interactions likely to be significant (destination by session time, destination by trial number). The ANOVA tables for all performance measures can be found in Appendix R. In addition to significance levels, means and standard deviations are reported in great detail for various roads, speed conditions, and guidance modes. This normative driving data does not appear elsewhere in the literature and is essential for building a knowledge base of how people drive.

To ensure an adequate amount of data was collected, an analysis of the straight driving points and stopped driving points was performed. (See Appendix S.)

Speed-Related/Longitudinal-Control Measures

Measures of driving performance were divided into two categories: longitudinal control (the position of the vehicle along the length of the road) and lateral control (lane position). Longitudinal measures include duration, overall speed, moving speed, throttle position, and headway with means and standard deviations for each. While several of these measures are highly correlated (duration, overall speed, moving speed), all were examined to facilitate comparison with other studies in the literature.

Duration

Duration is the time (in seconds) subjects required to drive a section of a road, to a destination, or the entire test route. It is a measure of considerable interest to drivers. (How long will it take to get there?) Means of duration are given by section. Therefore, to compute the destination or trial duration, the section mean must be multiplied by the number of sections within a destination or trial.

A significant difference was found between subjects when nested within age group and sex ($p=0.0022$) but not age or sex alone. Figure 11 shows the subject mean durations. Notice, that within each age-sex category (nine drivers), the times between the fastest and slowest drivers differ by 50 to 100 percent. This is largely due to the different time periods during which subjects were run.

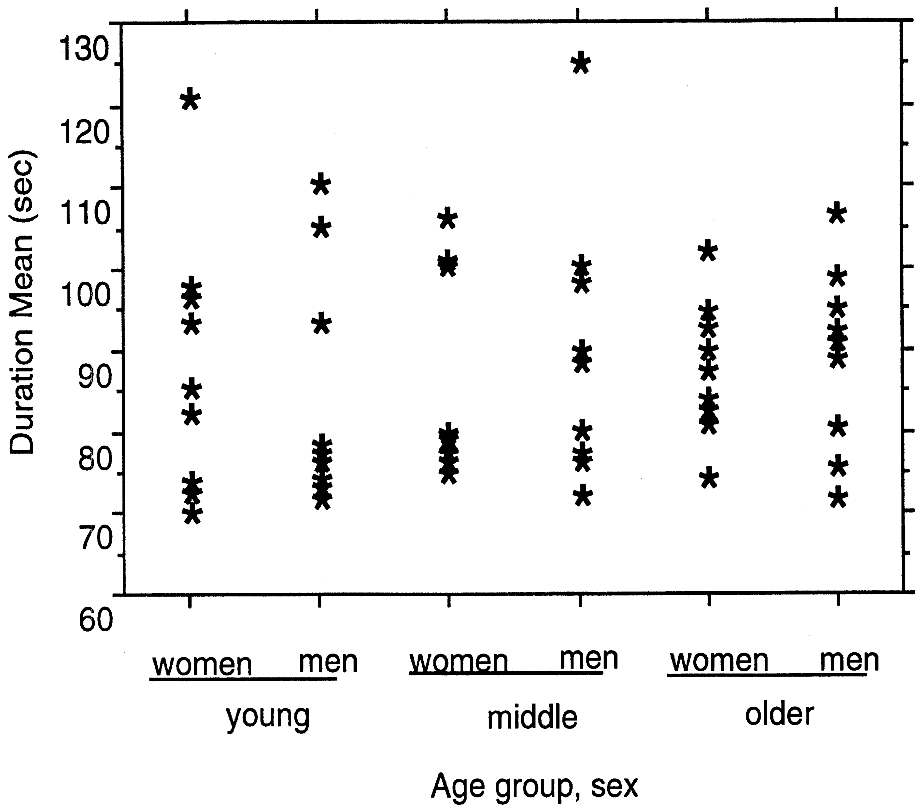


Figure 11. Mean duration for subjects by age group and sex.

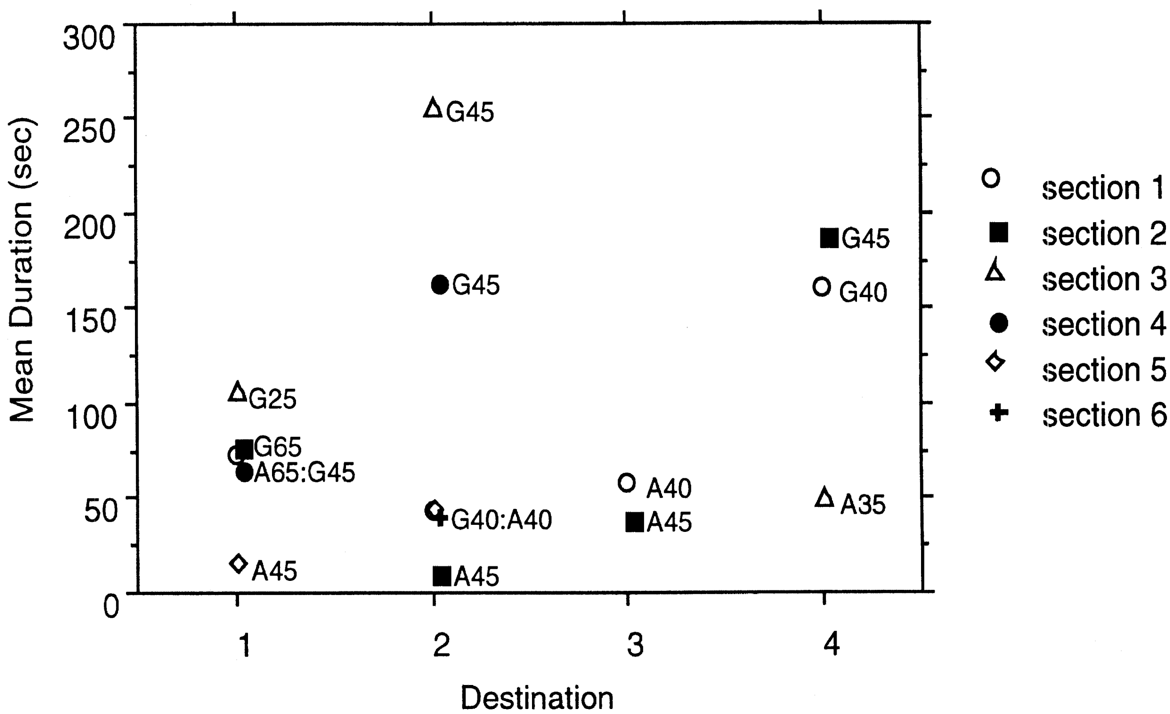


Figure 12. Mean duration for each section.

Duration by destination number (p= 0.0001) and duration by section within destination (p=0.0001) were found to be significant. (See Figure 12.) The mean section durations for destination 1, 2, 3, and 4 are 69 seconds, 95 seconds, 50 seconds, and 134 seconds, respectively. The respective total mean durations were 346 seconds, 569 seconds, 101 seconds, and 403 seconds. These differences occur because the routes lengths, road types, and traffic densities to each destination vary.

In addition, duration by trial was also found to be significant (p=0.0043). Mean section durations are 90 seconds for trial one, 91 seconds for trial two, and 85 seconds for the baseline trial. These lead to total mean durations of 1442 seconds for trial one, 1458 seconds for trial two, and 1355 seconds for the baseline trial. The difference between trial one and trial two is probably due to random variation. The shorter duration for baseline trial (by almost 10 percent) suggests that experimenter guidance is superior to that provided by the Ali-Scout interface. If familiarity was a factor, then the duration for run two would be much less than the duration for run one, which was not the case. This suggests that the Ali-Scout interface has room for improvement.

The time of day at which the experiment was run (afternoon, rush hour, or night) was found to be significant (p=0.0001). The mean section durations were 86 seconds for afternoon, 104 seconds for rush hour, and 77 seconds for night session. Therefore, the mean total durations for afternoon, rush hour, and night were 1360 seconds, 1656 seconds, and 1234 seconds, respectively. There is roughly a 30 percent difference between session times, reflecting the influence of traffic.

In addition, the interaction between destination and session time was significant (p=0.0001). Figure 13 shows that the rush hour session consistently had a longer duration over all four destinations. On the other hand, the night session had the shortest duration for all destinations. Destination two had an unusually long duration during rush hour, due to a merge from two lanes to one lane. This merge had less of an impact on duration in lighter traffic (e.g., afternoon and night).

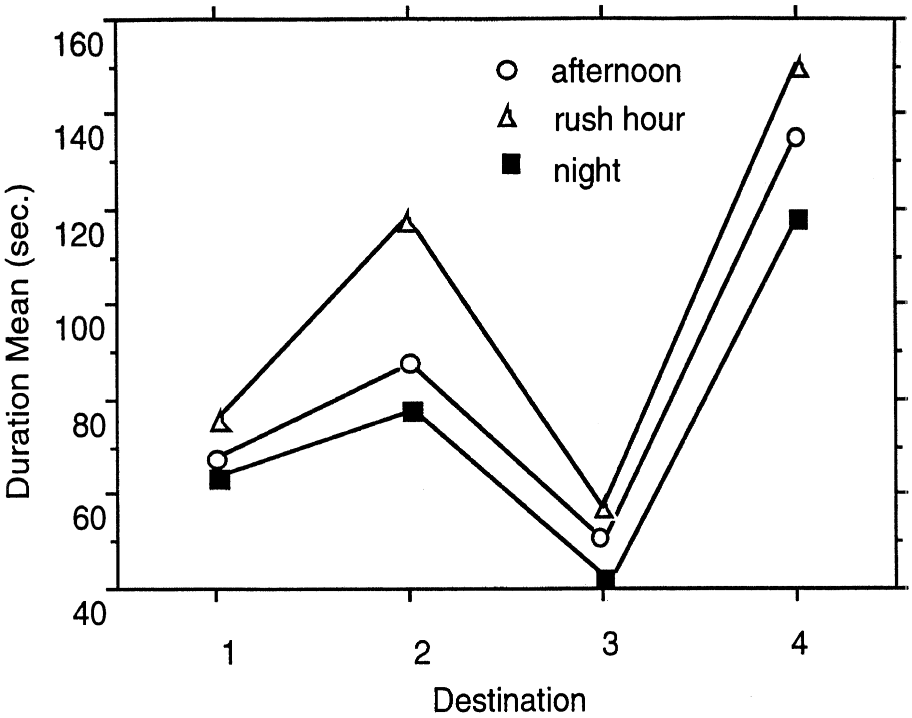


Figure 13. Mean duration by destination and session time.

Overall mean speed

Overall mean speed is the measure of a driver's speed while driving a section of a destination, a destination, or the entire test route. This measure is of interest to traffic engineers for whom high speeds represent operational efficiency. The overall mean speed (measured in mi/hr) includes the speed while the vehicle is in motion, and while it is stopped. Even though the section lengths were fixed and stopped data was included in this set, that does not necessarily mean that the results (in terms of what was significant) should be identical to the duration data. While the means will be similar, the variance may not be.

In contrast to the duration data, age differences were significant (p=0.0001). Overall mean speed decreased with age. Young, middle-aged, and older drivers had overall mean speeds of 32.4 mi/hr, 32.3 mi/hr, and 31.0 mi/hr, respectively. However, sex was not found to be significant. A significant difference was found due to subjects when nested within age group and sex (p=0.0001). Figure 14 shows the scatter for mean speed.

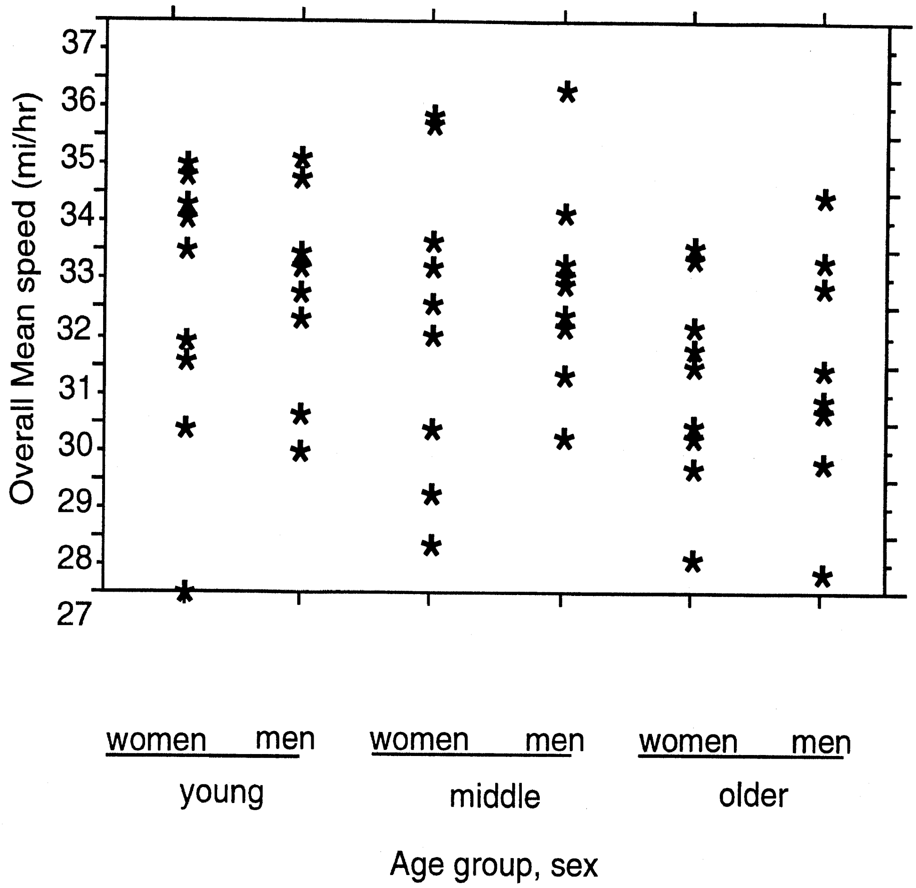


Figure 14. Overall mean speeds by age group and sex.

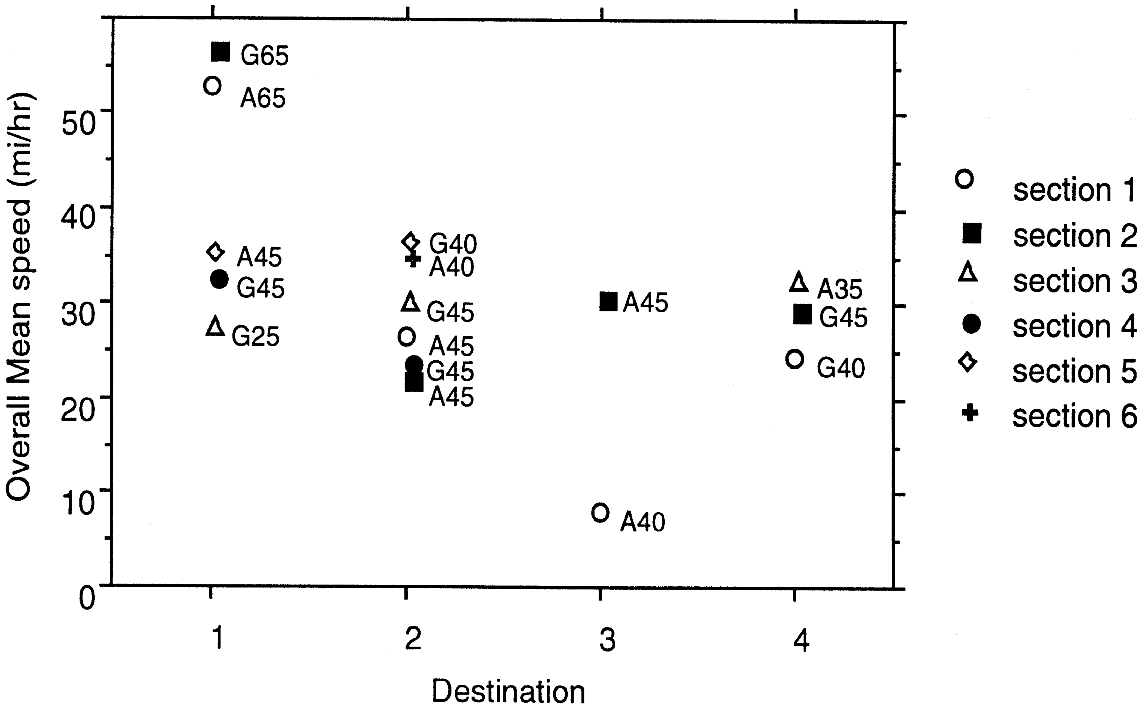


Figure 15. Overall mean speeds for each section.

As with the duration data, there were significant differences due to destinations (p=0.0001) and sections within destinations (p=0.0001). (See Figure 15.) Two sections of destination 1 were highway driving (sections 1 and 2) leading to the high overall mean speed for these sections. Notice the imperfect correlation for destinations 2 and 4 between posted speed and speed driven.

In addition, the trial number during experimentation was found to be significant (p=0.0001). Trial one had an overall mean speed of 31.4 mi/hr, trial two had an overall mean speed of 31.5 mi/hr, and the baseline trial had an overall mean speed of 32.8 mi/hr. This increase in overall mean speed in successive trials reflects familiarity with the test route and the guidance information, with better guidance providing the largest gain (three percent faster driving). Trials one and two, in which the Ali-Scout was used for navigation, did not reflect much in the way of speed gains due to some (but limited) experience with that interface. Also, notice in Figure 15 that the guidance mode (autonomous versus guided) had no apparent influence over the speed driven.

As with the duration data, the session time also had a significant effect on the overall mean speed (p=0.0001). The overall mean speed during the afternoon session was 32.3 mi/hr, during the rush hour session was 30.4 mi/hr, and during the night session was 33 mi/hr, reflecting varying traffic levels throughout the day.

An interaction between time slot and destination was also found to be significant (p=0.0171). Figure 16 shows that the rush hour session consistently had a lower overall mean speed over all destinations. Destination three consists of an especially short route and is a residential area where traffic conditions did not change significantly over different session times.

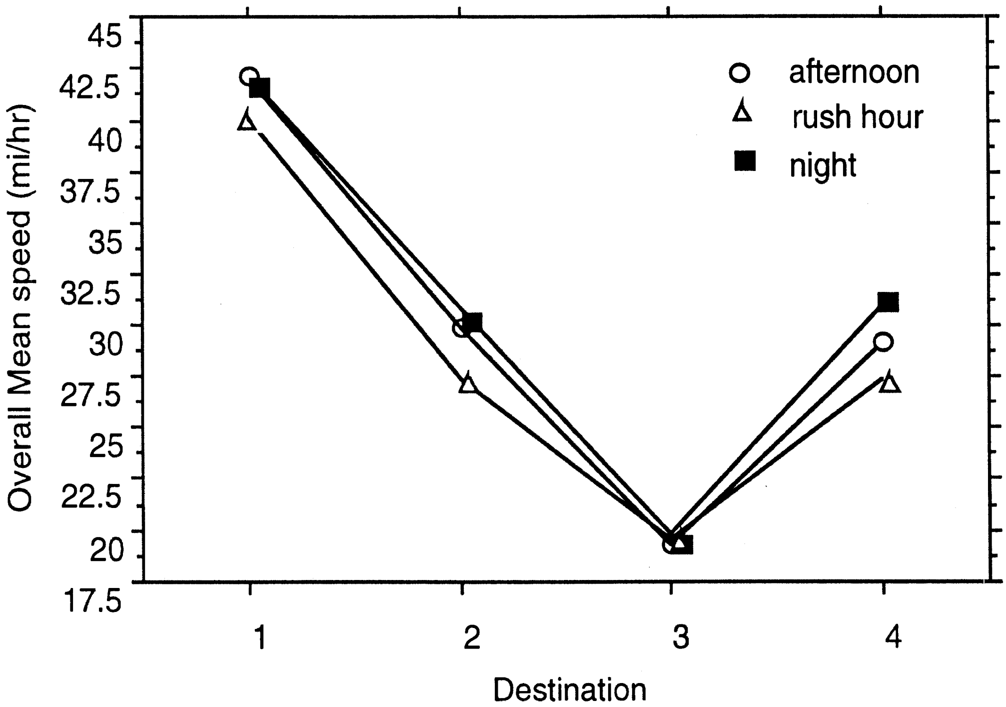


Figure 16. Overall mean speed for destinations by session time.

Mean speed while moving

Mean moving speed is all mean speed data (measured in mi/hr) not including any period when the vehicle was stopped (any speed data below 3.5 mi/hr). A significant difference in mean speed moving was found between age groups (p=0.0001). Young, middle-aged, and older subjects had mean moving speeds of 36.2 mi/hr, 36.0 mi/hr, and 34.6 mi/hr, respectively. Sex, on the other hand was not found to be significant.

A significant difference was found for subjects when nested by age group and sex (p=0.0001). Notice the considerable difference in scatter between subject groups. Figure 17 shows the mean moving speed for each subject. The only discernible pattern from this graph was that older subjects had a lower mean moving speed.

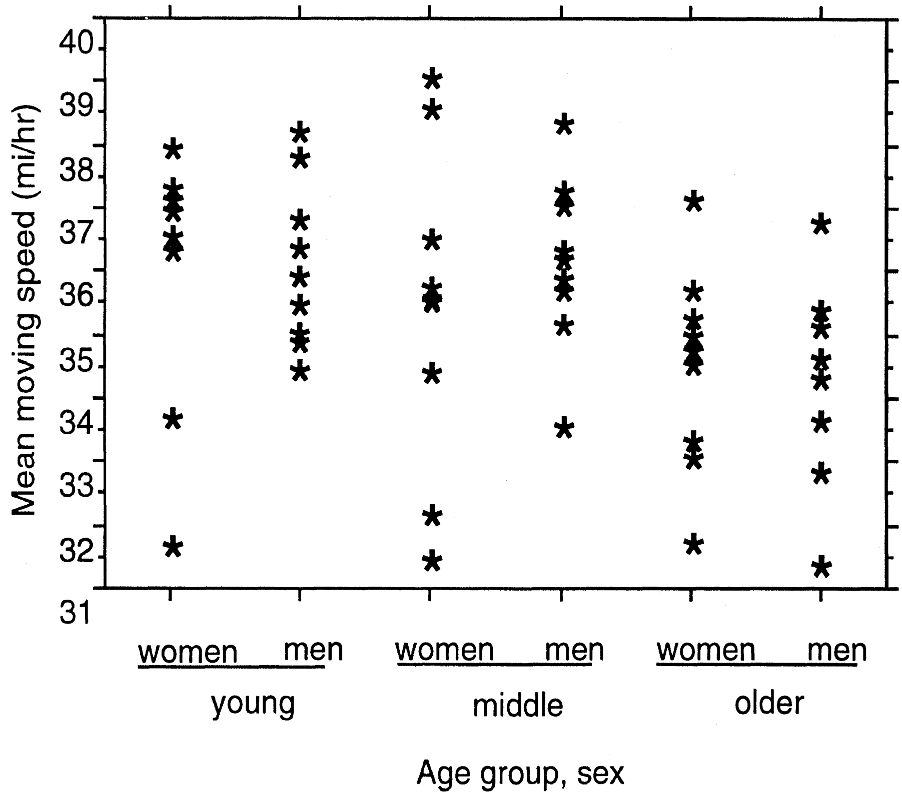


Figure 17. Mean moving speeds for subjects by age group and sex.

Destinations were also found to be significant (p=0.0001). Mean moving speeds for destination 1, 2, 3, and 4, respectively, were 43.7 mi/hr, 33.2 mi/hr, 23.1 mi/hr, and 35.1 mi/hr. The trip to destination one involved expressway driving, hence the high mean moving speed to that destination.

In addition, the trial number was significant (p=0.0001). Trial one had a mean moving speed of 34.8 mi/hr, trial two had a mean moving speed of 35.4 mi/hr, and the baseline trial had a mean moving speed of 36.6 mi/hr. Generally, there was a steady increase in mean moving speed for each subsequent trial. The difference between trial one and two was 0.6 mi/hr, whereas the difference between baseline and trial two was 1.2 mi/hr. Thus, while the effects of practice with the Ali-Scout only led to a marginal increase in moving speed, the change in overall mean speed was essentially 0 (actually 0.1 mi/hr). This highlights the importance of using mean moving speed (as opposed to overall mean speed) to assess the effects of interface differences in small scale experiments involving stop and go driving.

Differences between sections (within destinations) were found to be significant (p=0.0001). Figure 18 shows the mean moving speed for sections of each destination. Two sections of destination 1 were highway driving (sections 1 and 2) which gives the high mean moving speed for these sections. The route to destination three was largely through a residential area which lead a low mean moving speed for both sections. This pattern is very similar to that of Figure 15 of the overall mean speed of sections within destinations. Also notice that in this case, people tended to drive faster when in guided mode, a distinction that is not clear when overall mean speed (not moving mean speed) is the dependent measure.

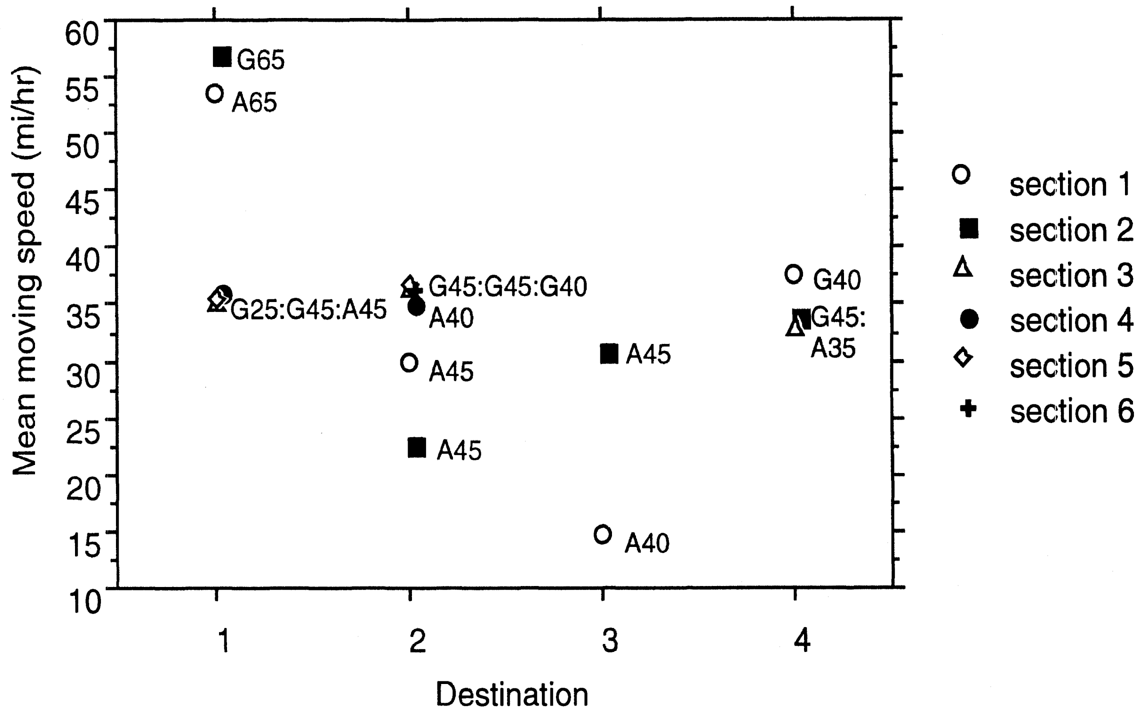


Figure 18. Mean moving speeds for each section.

The session time was found to be significant (p=0.0057). The mean moving speed for the afternoon session was 36.1 mi/hr, rush hour session was 35.0 mi/hr, and night session was 35.7 mi/hr. The mean was lowest during rush hour session due to the high traffic density.

Finally, the interaction between session time and destination was significant (p=0.0465). Figure 19 shows the mean moving speed for each destination by session time. As mentioned above, the mean for destination three is similar for all three session times.

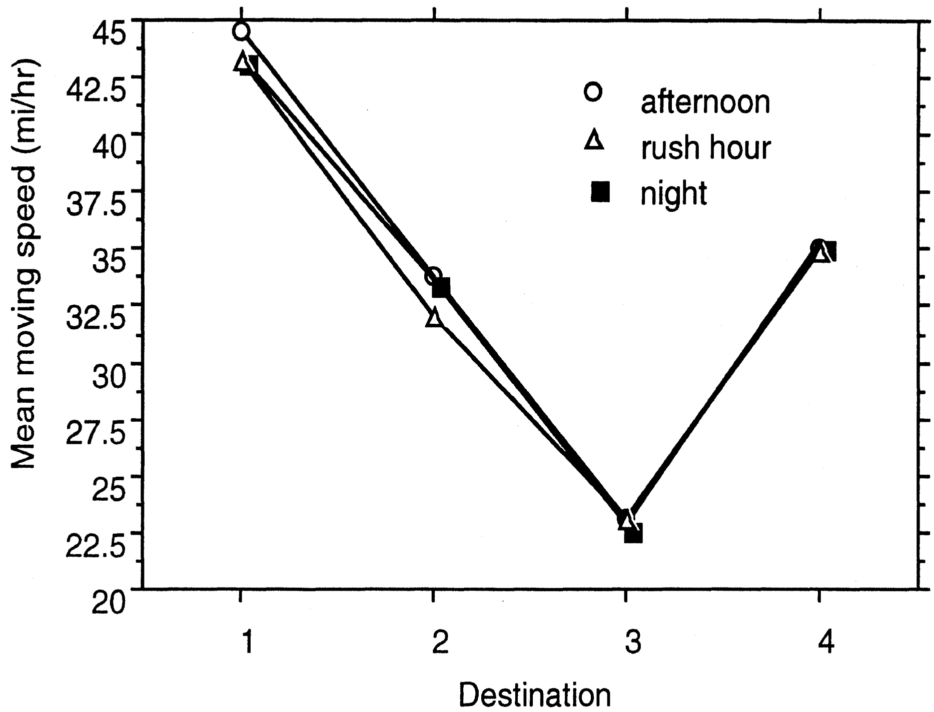


Figure 19. Mean moving speed for each destination by session time.

Not only are duration, overall mean speed, and mean speed while moving highly correlated, but the factors having significant effects on them are the same. Duration is the least sensitive measure because there is only one data point for each run, though the results should be computationally similar to mean speed. However, duration and mean speed are of intrinsic interest to drivers since they determine arrival time. A drawback to overall mean speed is that it is affected by factors other than the interface (traffic and traffic signal status) which cause the driver to stop. Such extraneous variations can muddy distinctions between interface designs (such as between guided and autonomous mode performance). Mean speed while moving is not as susceptible to these variations. However, the data suggest there were only minor differences between these measures in terms of their sensitivity to the differences of interest.

Speed standard deviation (while moving)

Speed standard deviation (measured in mi/hr) is the standard deviation of the moving speed, not the overall speed. Again, the moving speed is all of the data for 3.5 mi/hr and above. Age had significant effect on the speed standard deviation (p=0.0001). The mean speed standard deviation for young, middle-aged, and older drivers is 8.7 mi/hr, 8.6 mi/hr, and 8.2 mi/hr, respectively. Older drivers exhibited the steadiest moving speed. Sex was not found to be significant.

The effect of subjects nested within age group and sex was found to be significant (p=0.0001). Figure 20 shows the mean of the speed standard deviation for each subject by sex and age group. It is unclear why the data for older male drivers are so homogenous.

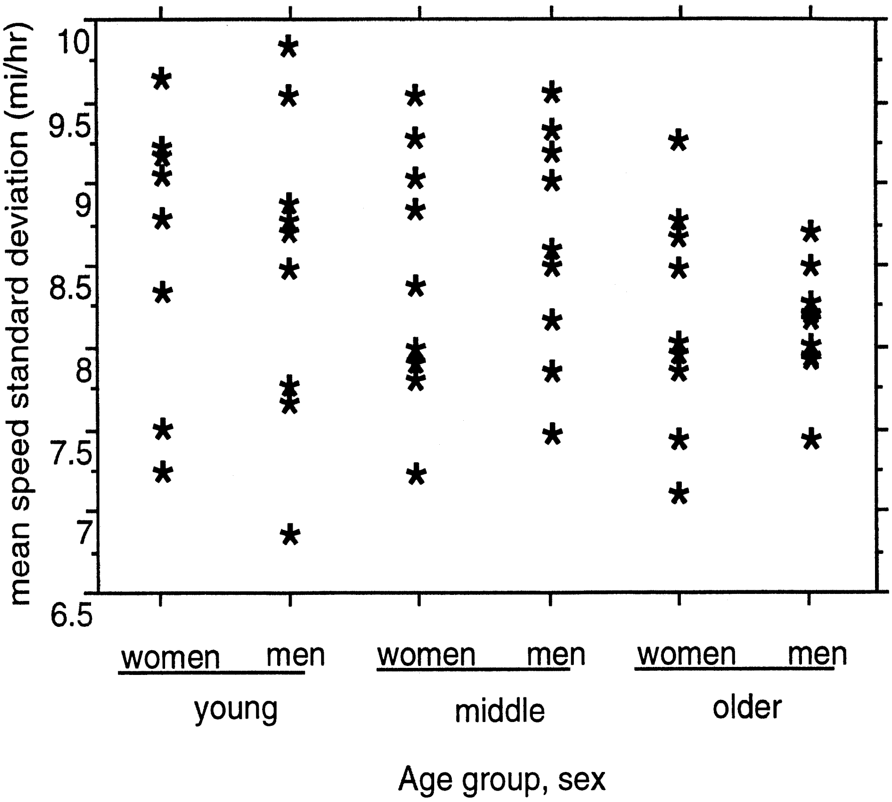


Figure 20. Speed standard deviation (mean) for each subject.

Destination was found to be significant by speed standard deviation (p=0.0001). The mean speed standard deviations for destinations 1, 2, 3, and 4 were 7.6 mi/hr, 9.4 mi/hr, 7.3 mi/hr, and 9 mi/hr, respectively. In addition, the sections of each destination were significant (p=0.0001). Figure 21 shows the mean speed standard deviation for each section by destination. The mean standard deviations were highest for sections 3 and 4 of destination 2 because they were effected by traffic density the most. Section three of destination one is the exit ramp off of the expressway; therefore, the driver must slow the vehicle's speed from 65 mi/hr on the expressway to under 30 mi/hr on the winding ramp.

The trial number was also significant (p=0.0002). The mean speed standard deviation for trial one was 8.3 mi/hr, the mean speed standard deviation for trial two was 8.7 mi/hr, and the mean speed standard deviation for the baseline trial was 8.6 mi/hr. Speed variance is affected by two factors, overall speed (variance increases with the mean), and erratic behavior (variance increases with erratic behavior). In this case, it appears the effect of mean speed predominated (leading to greater variance). The differences found, while significant, are so small that they are of minimal practical significance. Interestingly, these differences appear within guidance modes. Notice that when main roads having the same posted speed are compared, that speed variance is greater in guided mode.

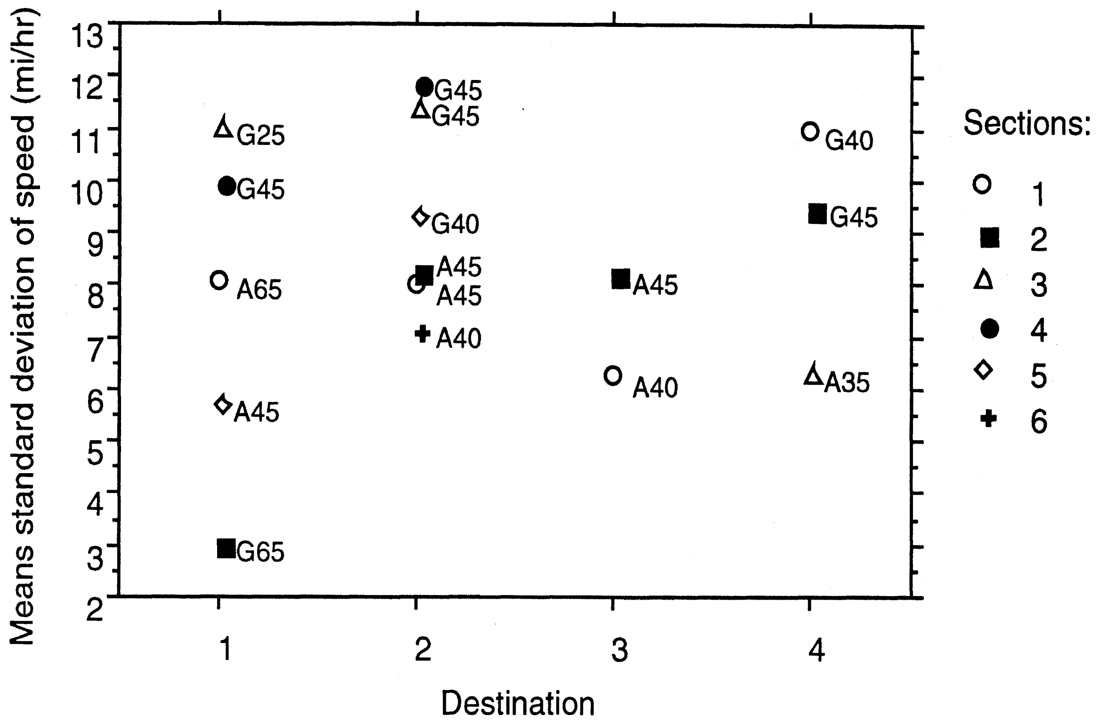


Figure 21. Mean standard deviation of speed by destination.

The time at which test sessions were run was found to be significant (p=0.0001). The mean speed standard deviation for the afternoon session was 8.5 mi/hr, the mean speed standard deviation for the rush hour session was 8.9 mi/hr, and the mean speed standard deviation for the night session was 8.2 mi/hr. The traffic density at rush hour, and during the afternoon is a contributing factor to their increased mean standard deviation of speed.

The interaction between destination and trial number was found to be significant (p=0.0231). As shown in Figure 22, during destination 1, 2, and 4 the mean speed standard deviation followed a general pattern of peaking during the second trial. However, destination 3 did not follow this pattern. There is no explanation for the interaction shown in Figure 22.

In addition, the interaction between session time and destination was found to be significant (p=0.0182). Figure 23 shows that the rush hour session had the highest mean speed standard deviation for destinations 1, 2, and 4, but had the lowest for destination 3. The afternoon and night session mean speed standard deviation followed the same pattern consistently over all four destinations. No explanation can be found for the interaction at destination three.

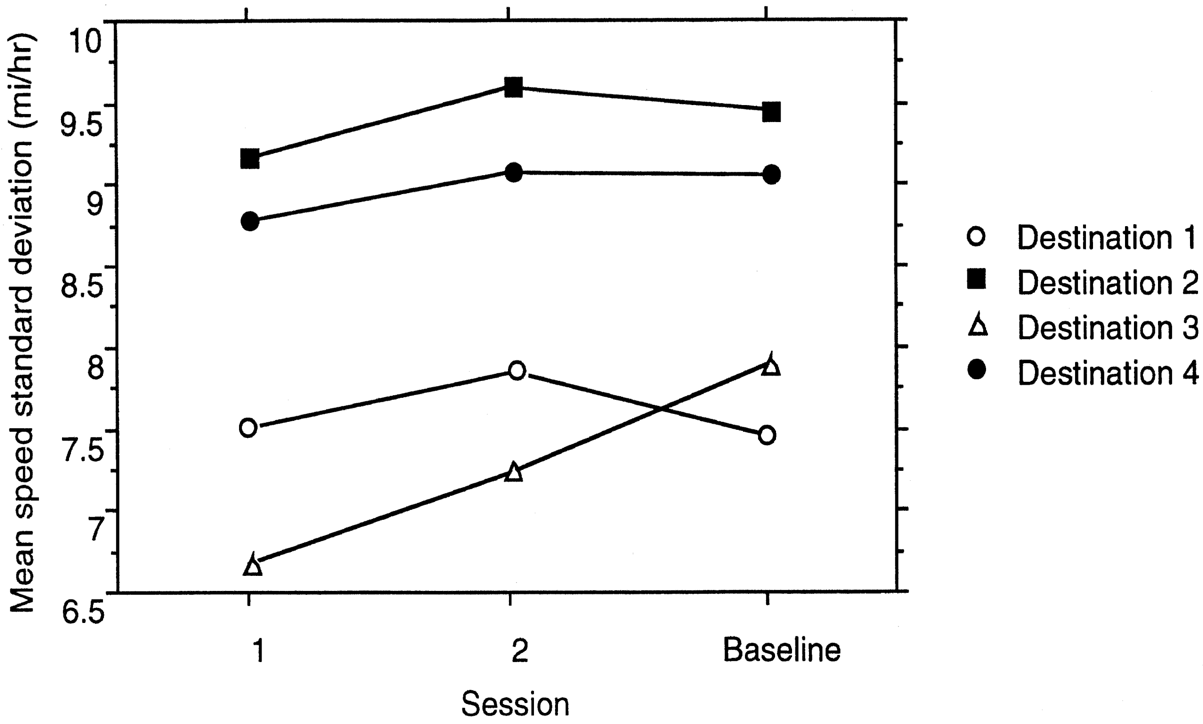


Figure 22. Mean speed standard deviation by destination and trial number.

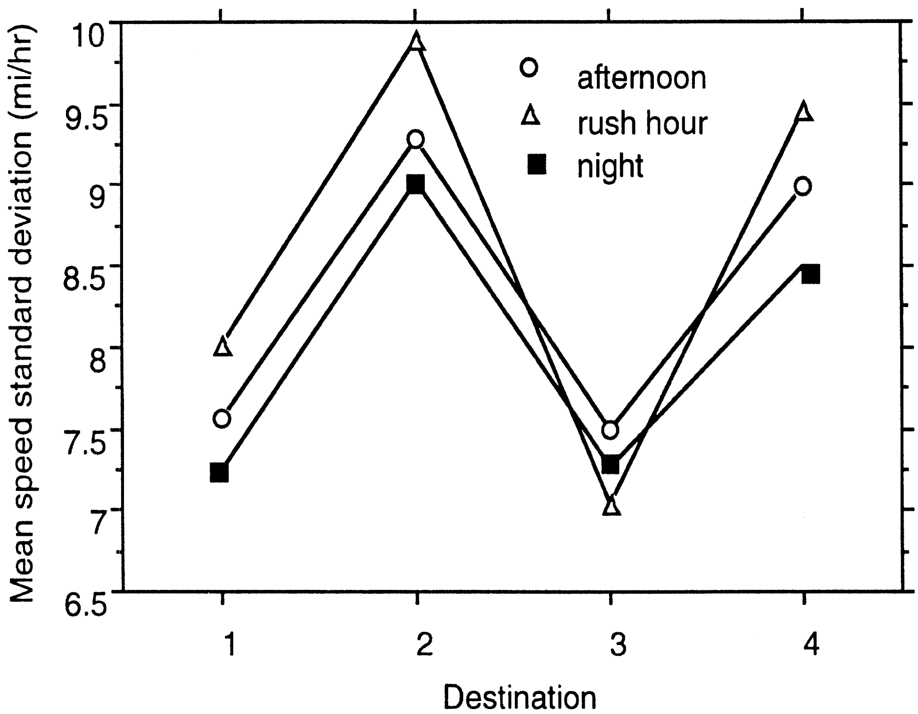


Figure 23. Mean speed standard deviation for all destinations by session time.

Mean throttle position

Mean throttle position is a measure of the average percentage of throttle applied throughout the driving period, whether that be section of destination, a destination, or the entire test route. Mean throttle has a range of 0 percent (when the driver's foot is not touching the pedal) to 100 percent (when the drivers foot has depressed the pedal fully to the floor). Age group was found to be significant (p=0.0001). The mean throttle for young, middle-aged, and older drivers was 9.5 percent, 9.1 percent, and 8.5 percent, respectively. This is consistent with the pattern of age affecting mean overall speed and mean moving speed. Sex, on the other hand was not significant.

In addition, subjects nested within age group and sex were found to be significant (p=0.0001). Figure 24 shows the mean throttle for each subject by sex and age group.

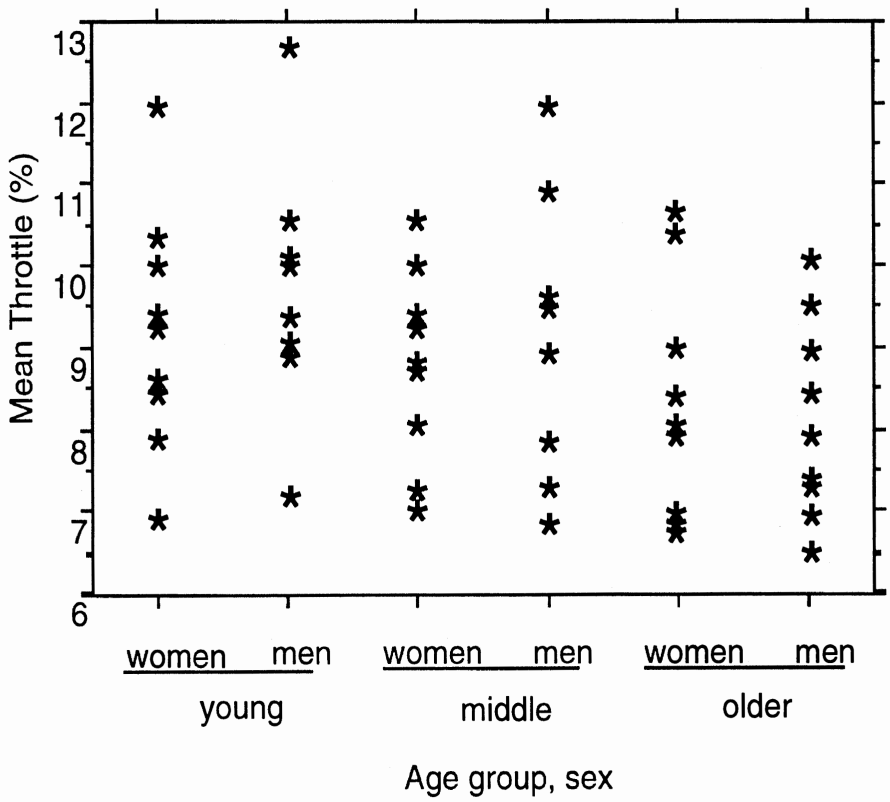


Figure 24. Mean throttle position for subjects by sex and age group.

An interaction between sex and age group was also found to be significant (p=0.0016). Figure 25 shows the mean throttle position for age group by sex. The young and middle-aged males have higher mean throttle positions than their female counterparts, whereas the older males have lower mean throttle positions than the older females.

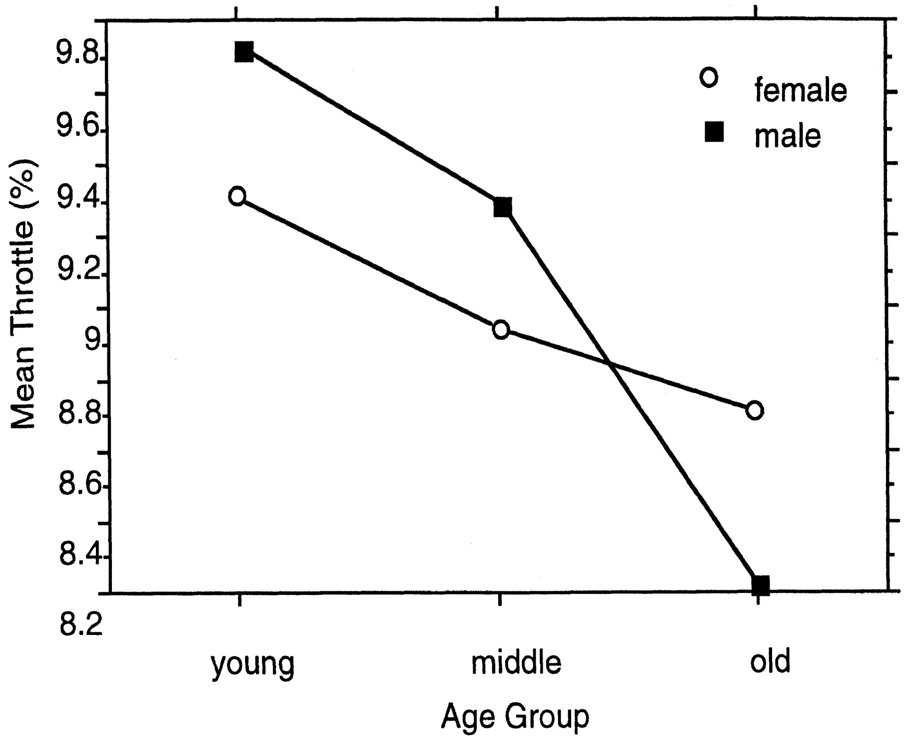


Figure 25. Mean throttle position for age groups by sex.

Destination (p=0.0001) and section within destination (p=0.0001) were both found to be significant. The mean throttle position for destinations 1, 2, 3, and 4 were 9.8 percent, 9.8 percent, 7.1 percent, and 7.6 percent, respectively. Figure 26 gives the mean throttle for sections within destinations. Section two of destination two is comprised of a short section that follows a turn and precedes a long, straight stretch of open road. Therefore, subjects had a tendency to "step on the gas" over this short distance. Section one of destination one consists of a merge onto the expressway.

In addition, the trial number was found to be significant (p=0.0009). The mean throttle position for trial one was 8.8 percent, the mean throttle for trial two was 9.1 percent, and the mean throttle for the baseline trial was 9.2 percent. This is consistent with the pattern found in mean speed; there is an increase in mean throttle over consecutive trials. However, there is no pattern apparent with regard to autonomous versus guided mode.

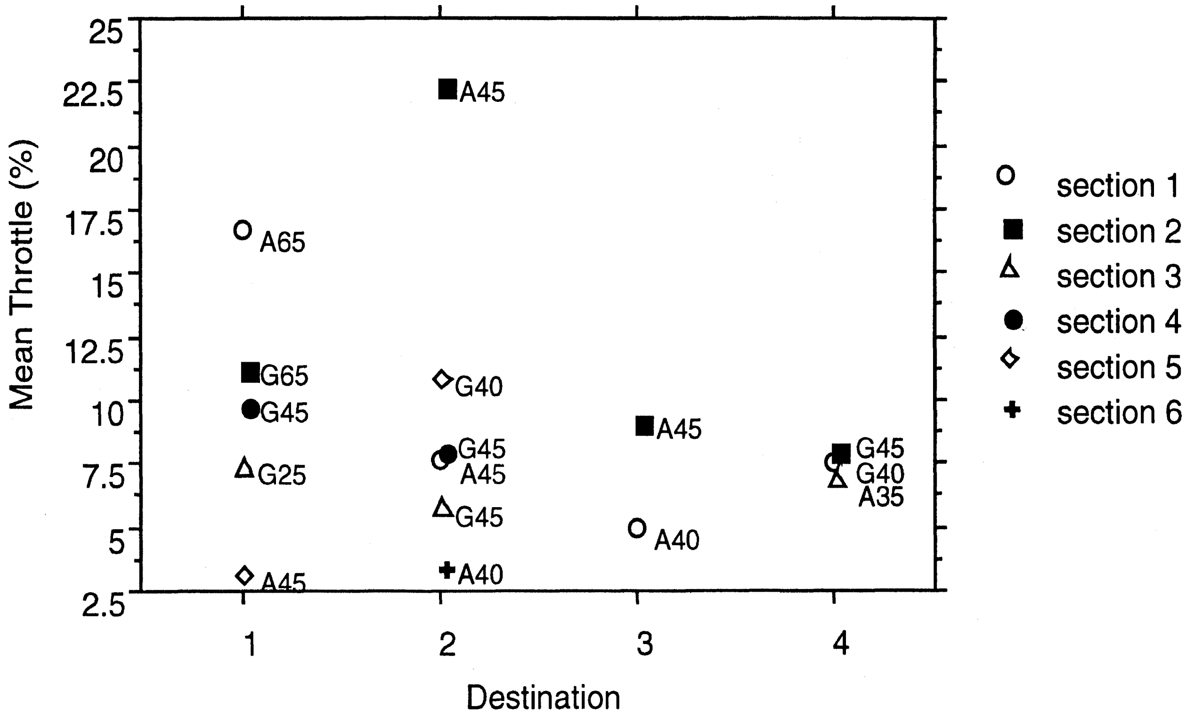


Figure 26. Mean throttle for all sections.

The session time (afternoon, rush hour, and night) was found to be significant (p=0.0005). The mean throttle position for afternoon session, rush hour session, and night session were 9.0 percent, 9.4 percent, and 8.8 percent, respectively.

An interaction between destination and trial number was found to be significant (p=0.0001). Figure 27 shows the mean throttle position by trial number and destination. A consistent increase in mean throttle position over successive trial numbers (1, 2, and baseline) is found for destinations 2, 3, and 4. However, destination 1 does not follow this pattern. There is no explanation for this outcome.

A comparison between mean speed moving and mean throttle is important as they are input and output measures of essentially the same factor, speed control. A priori, throttle angle was thought to be a much more sensitive measure of longitudinal control because speed is damped by the vehicle's inertia. A comparison of respective ANOVA tables reveals that mean throttle is only slightly more sensitive with only one more significant effect (7 for mean speed moving versus 8 for mean throttle). The one extra significant result was an interaction. Thus, if forced to choose between the two measures for the purpose of identifying significant differences, mean throttle is slightly preferable.

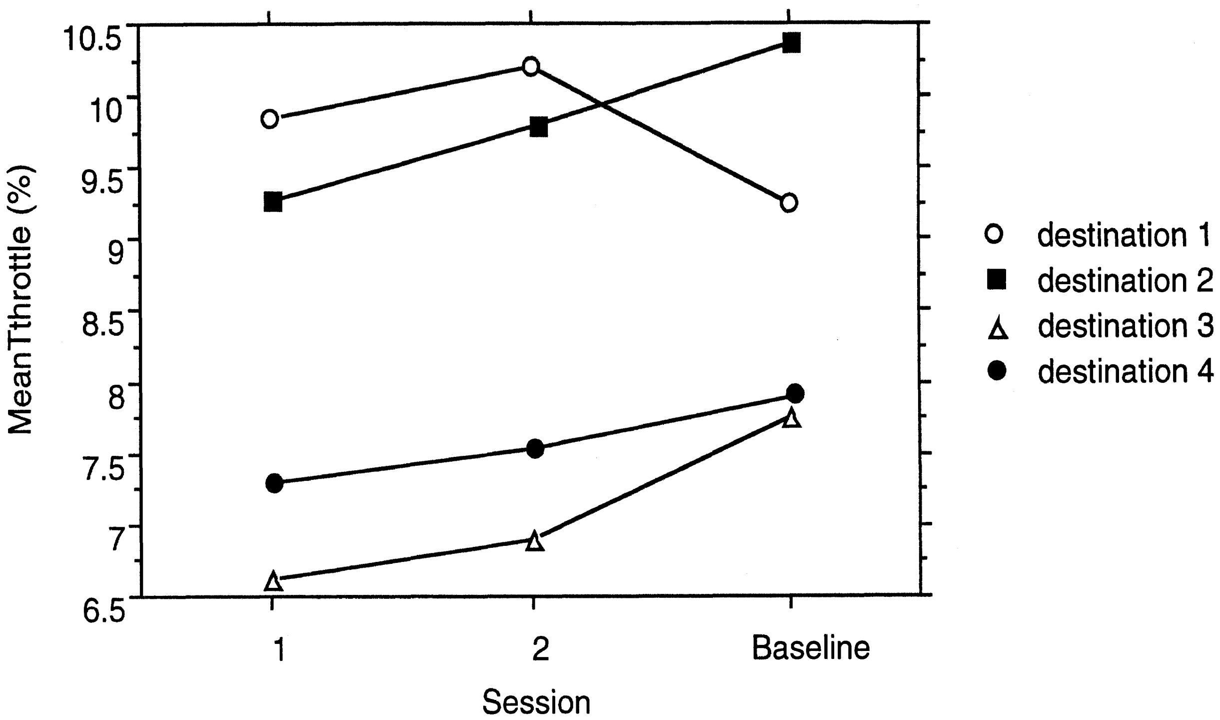


Figure 27. Interaction between trial number and destination for mean throttle position.

Standard deviation of throttle position

The standard deviation of throttle position is the measure of the variance of throttle position, how much the driver changes the position of the gas pedal, here measured in percentages. The effect of subjects nested within age group and sex was found to be significant (p=0.0001), although neither age group, nor sex was. Figure 28 shows the mean standard deviation of the throttle position for subjects by sex and age group.

The sex by age group interaction was significant (p=0.0001), though it is not apparent why. Figure 29 shows the mean standard deviation of throttle position by sex and age group.

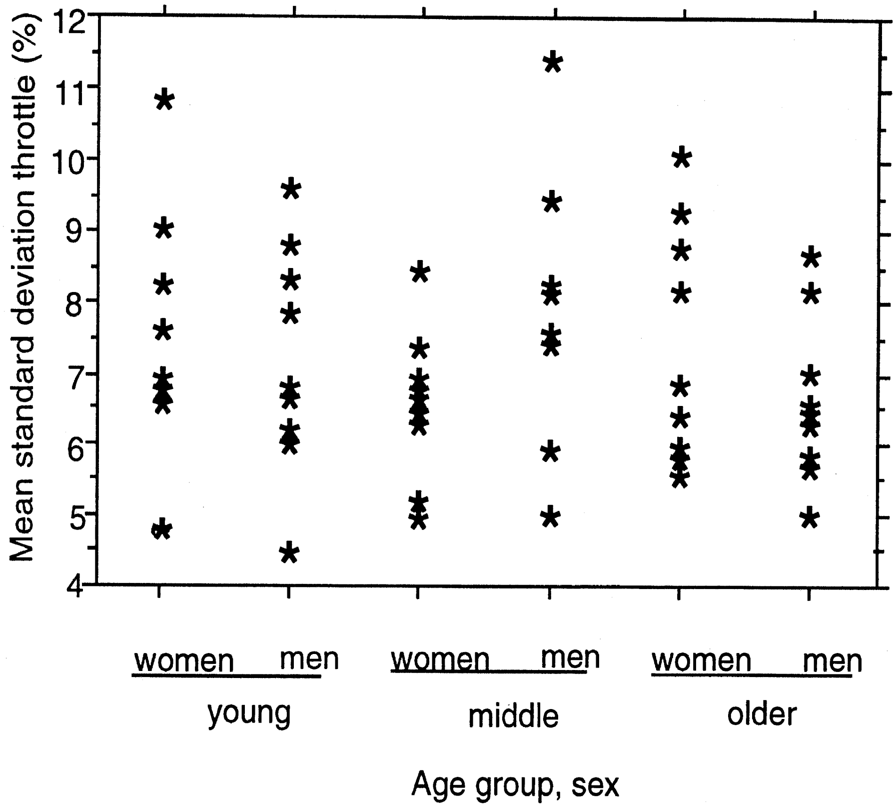


Figure 28. Mean standard deviation of throttle position for all subjects.

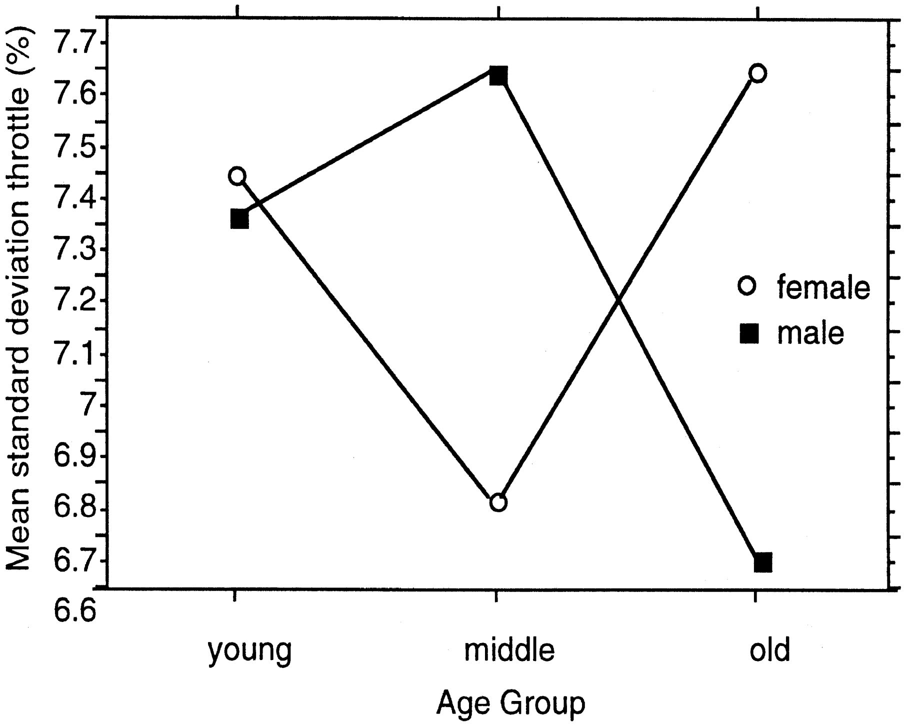


Figure 29. Standard deviation of throttle position by age group and sex.

Destination (p=0.0001) and section within destination (p=0.0001) were both found to be significant. The mean standard deviation for throttle position for destinations 1, 2, 3, and 4 were 6.9 percent, 7.1 percent, 8.2 percent, and 7.3 percent, respectively. Figure 30 shows the mean standard deviations of throttle position for sections within each destination. At section one of destination two, subjects were approaching a point in the route which was commonly perceived to be confusing (autonomous arrow pointing right, but no audio cue provided). This confusion was reflected in the high mean standard deviation of throttle. During destination three, section two subjects were reading street names, thus the large variance in throttle position.

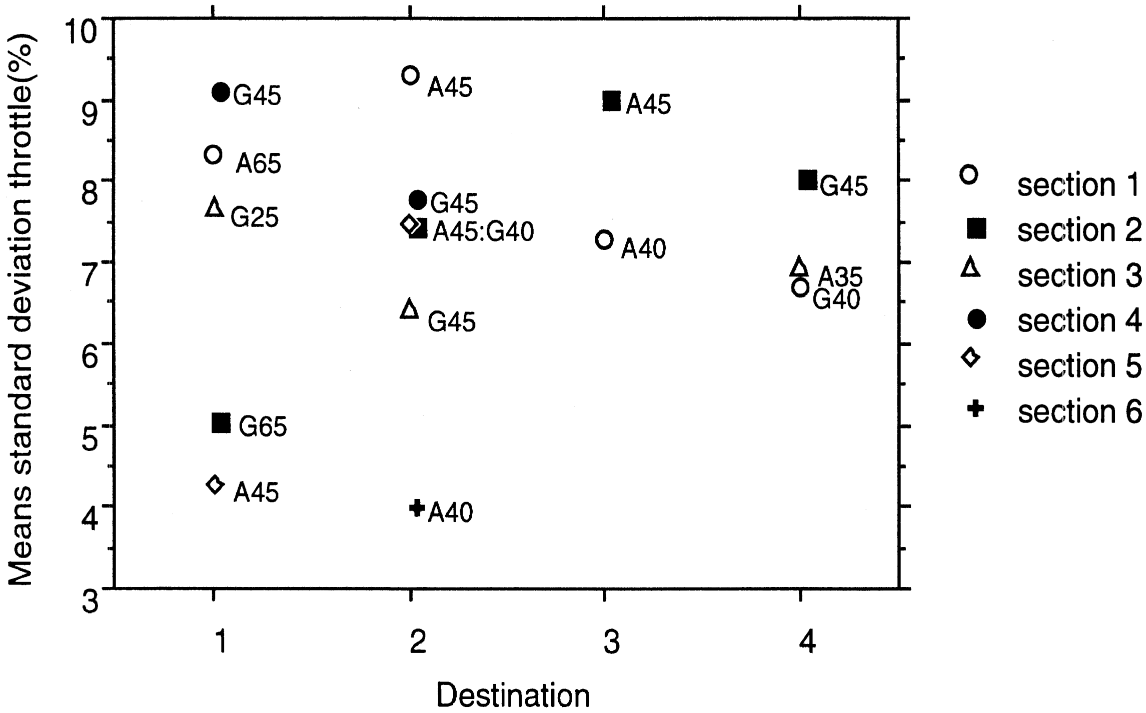


Figure 30. Mean standard deviation of throttle position for each section.

In addition, trial number was found to be significant (p=0.0001). The mean standard deviation of throttle position for trial 1 was 6.8 percent, trial two was 7.3 percent, and the baseline trial was 7.6 percent. A counter-intuitive result was that there was more variance in throttle position as the driver became more familiar with the route, possibly reflecting more aggressive driving. There are no clear distinctions between autonomous and guided mode.

The session time gave a p-value of 0.0001, therefore also proving to be significant with respect to standard deviation of throttle position. The mean standard deviation of throttle position for afternoon, rush hour and night drivers was 7.2 percent, 7.7 percent, and 6.8 percent, respectively. Traffic density could be considered a contributing factor to the higher variance of throttle during the rush hour session.

The interaction between destination by trial number had a p-value of 0.0001. Figure 31 shows the mean standard deviations of throttle positions for trial number (1, 2, baseline) by destination number. Destination three consistently had a higher variance in throttle position across all three trial numbers. This is largely due to the short distance traveled during destination three. Destination one follows the same pattern as the mean standard deviation of speed for the same interaction. It should be noted that both of these measures are longitudinal measures and are thus related. It should not be surprising that a significant outlier appears in both performance measures.

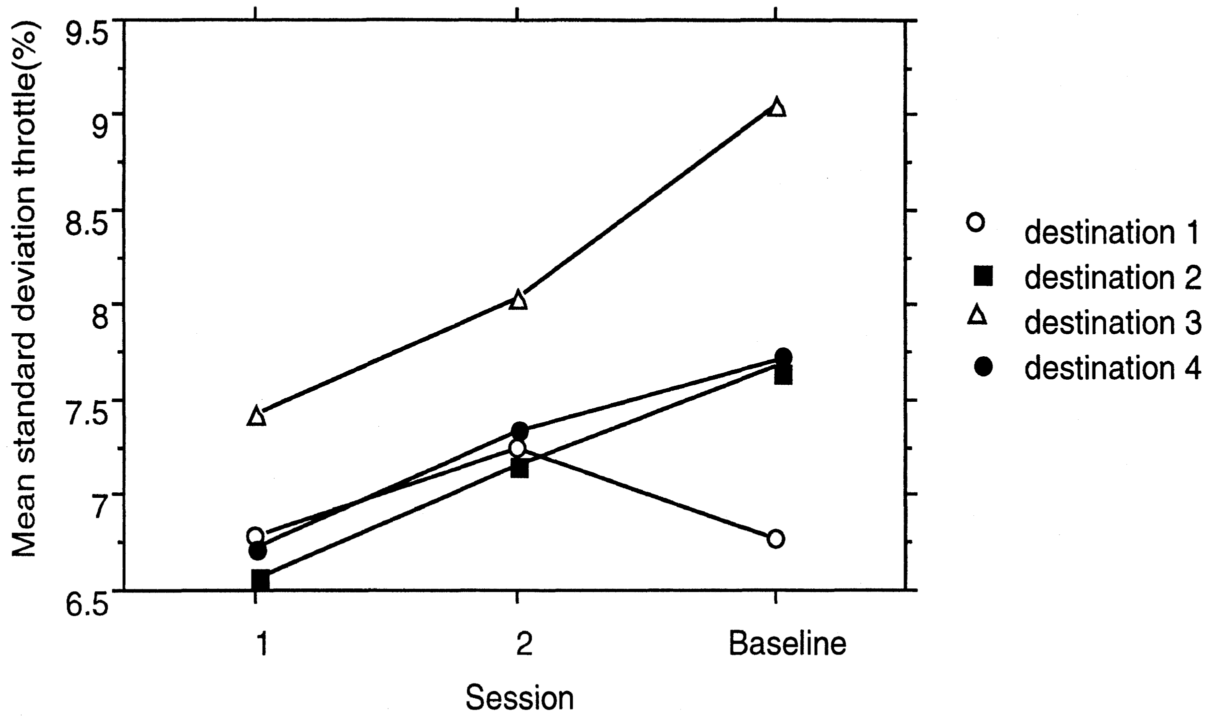


Figure 31. Mean standard deviation of throttle position for each trial by destination.

The comparison between the standard deviation of throttle and the standard deviation of speed is important in determining appropriate measures. This comparison is important because throttle is an input measure while speed is an output measure. In the comparison of the respective ANOVA tables standard deviation of speed produced a higher number of significant effects (8 for speed versus 7 for throttle). However, the p-values for standard deviation of throttle achieved higher levels of significance.

Mean headway

During experimentation several technical problems related to the headway sensor developed. The headway sensor slowly died in the beginning third of subject running. Its death was a slow process with its functional range slowly decreasing to zero across several subjects. Once the problem was identified, the headway sensor was removed, although subject running continued. A replacement headway sensor was installed toward the end of data collection. Thus, several subjects were missing headway data entirely, while others had incomplete data sets. The headway data, while suspect, is presented here for completeness. To verify that data was not lost due to a gradual decline of the headway sensor, the mean headway for each subject was plotted as a function of the date that subjects were tested. (See Figure 32.)

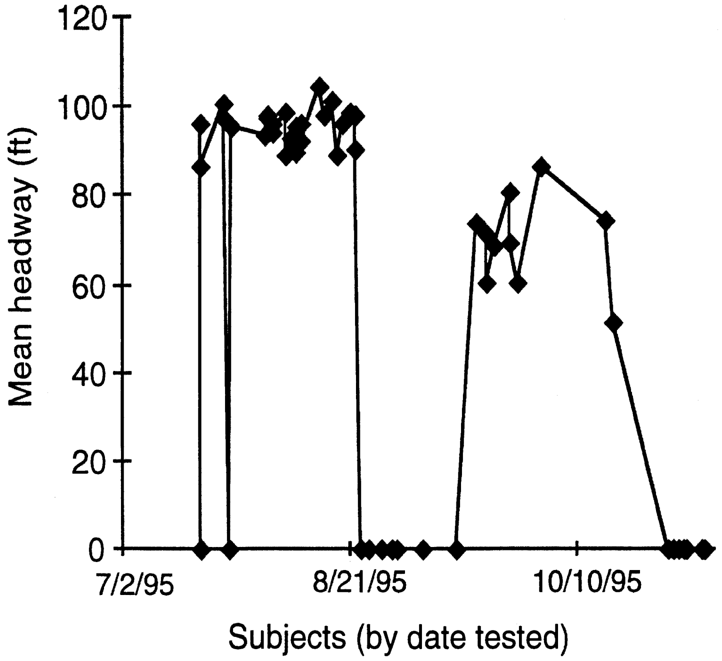


Figure 32. Mean session headway for subjects across study period.

Mean headway is the average distance between the research vehicle and the first vehicle in front of it (measured in feet). Age groups were found to be significant with respect to mean headway (p=0.0001). The mean headway for young, middle-aged, and older drivers were 96.5 ft, 81.8 ft, and 80.5 ft, respectively. This is in contrast to the stereotype that older individuals drive more cautiously and leave larger gaps between themselves and other vehicles. Sex, however, was not found to be significant. The age difference may reflect some confounding effect between order and age. Younger subjects predominated in the beginning of the experiment.

In addition, the effect of subjects nested within age group and sex was found to be significant (p=0.0001). Figure 33 shows the mean headway for each subject by sex and age group. Young subjects consistently maintained a high mean headway, while there was considerable variation in the middle-aged group (possibly due to the larger amount of headway data obtained).

The interaction, sex by age group, had a p-value of 0.0017. Figure 34 shows the mean headway by sex and age group. Young men and women were very similar with regards to their mean headway while the disparity between sex increased with age. Women showed a trend towards decreased headway as age increased.

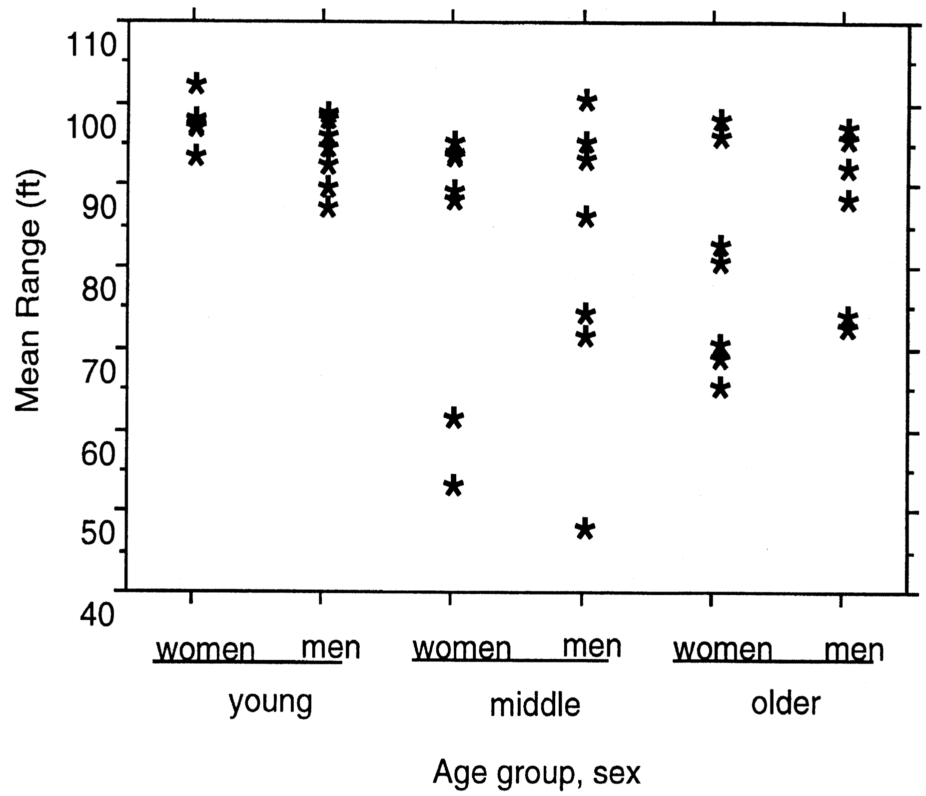


Figure 33. Mean headway for subjects by age group and sex.

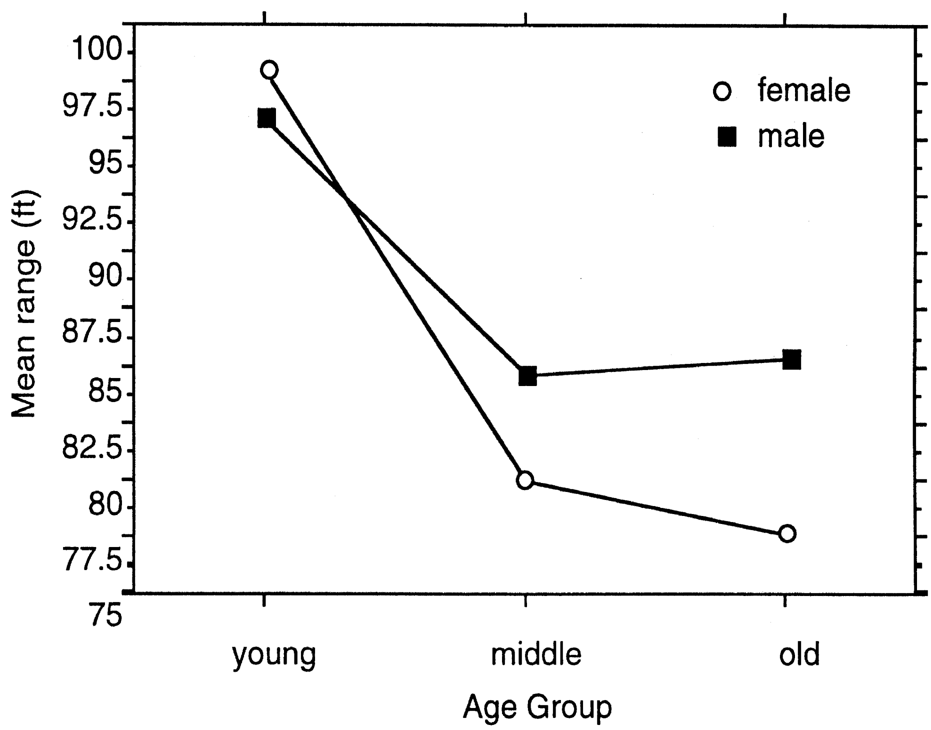


Figure 34. Mean headway by age group and sex.

Destination (p=0.0017) and section within destination (p=0.0001) were both found to be significant. The mean headway for destinations 1, 2, 3, and 4 were 86.3 ft, 87.5 ft, 82.6 ft, and 87.4 ft, respectively. Figure 35 shows the mean headway for sections within each destination. Section three of destination two exhibited the lowest mean range, due to the aforementioned bottleneck. Section one of destination three also had a very low mean range. It was such a short stretch and included a stop light.

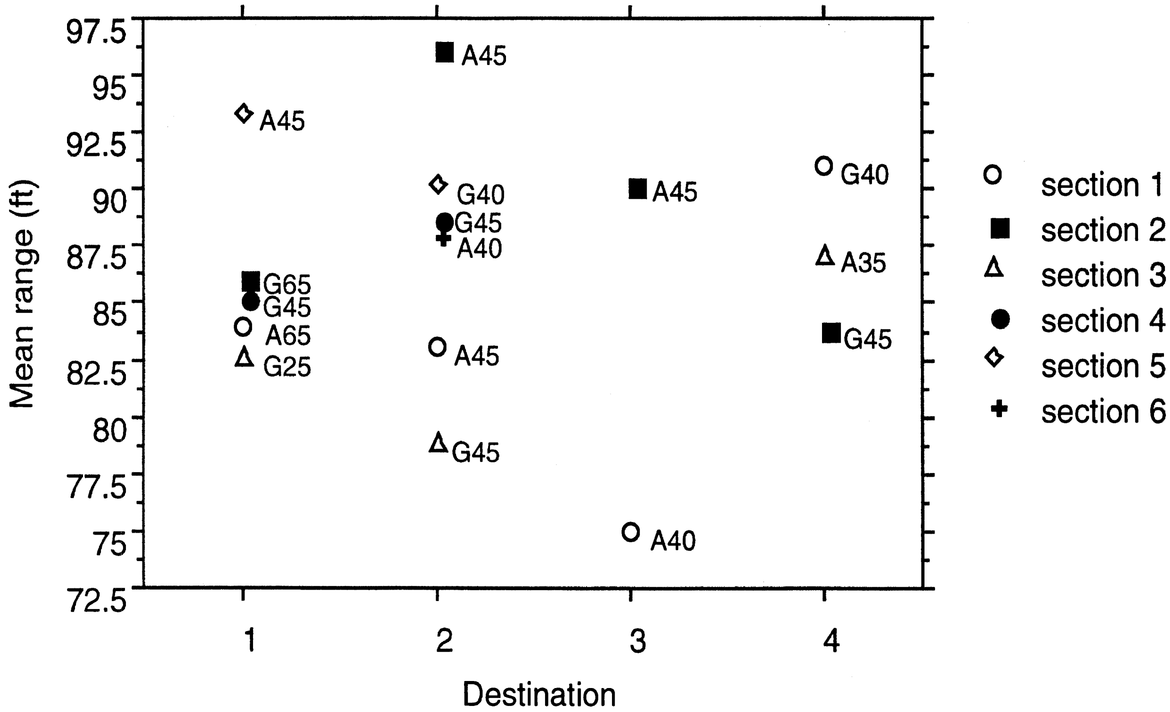


Figure 35. Mean headway for sections within each destination.

The effect of session time was significant (p=0.0002). The mean headway for afternoon, rush hour and night drivers was 87.2 ft, 82.7 ft, and 89.8 ft, respectively. Traffic density could be considered a contributing factor to the lower mean of headway during the rush hour session.

Although trial number was not found to be significant, differences in mean headways were small. The mean headway for trials one, two (both Ali-Scout) and baseline (experimenter guidance) were 88.6 ft, 86.5 ft, and 83.8 ft, respectively. Subjects decreased their mean headway with successive trials, possibly indicating that subjects felt more comfortable when familiar with the route, therefore decreasing their headway. Notice that in comparing modes (for equivalent speeds) there was a slight trend for subjects to allow for greater headways while in autonomous mode. This may be due to the need to allow for greater maneuvering room when provided with less specific navigation information.

Standard deviation of headway

Standard deviation of headway is the variability in distance between the research vehicle and the first vehicle in front of it (measured in feet). Age groups were found to be significant with respect to standard deviation of headway (p=0.0001). The mean standard deviation of headway for young, middle-aged, and old subjects was 37.8 ft, 34.7 ft, and 35.2 ft, respectively. The standard deviation of headway was not significantly affected by subject sex.

In addition, subjects nested by age group and sex were significant with respect to standard deviation of headway (p=0.0001). Figure 36 shows the subject mean standard deviation of headway. Generally, young drivers have greater overall variability in their headway, than middle-aged and older subjects (but less variability between them).

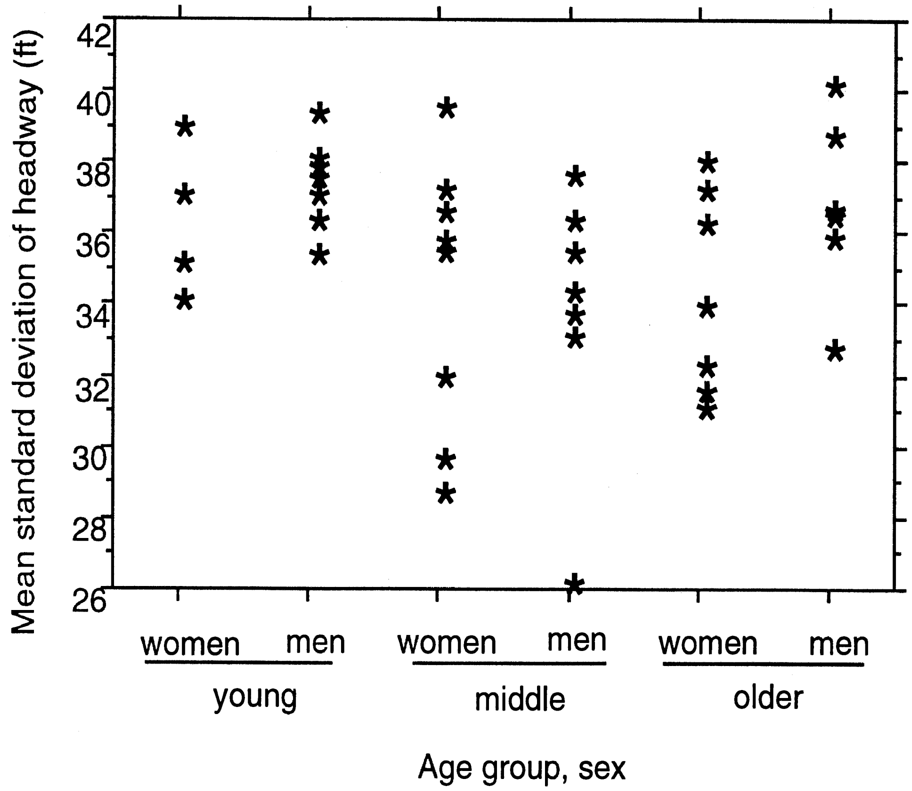


Figure 36. Mean standard deviations for subjects by age group and sex.

Destination had a p-value of 0.0001, and section within each destination had a p-value of 0.0001; therefore, both of these variables were significant. The mean standard deviations of headway for destination 1, 2, 3, and 4 were 34.4 ft, 35.9 ft, 36.2 ft, and 38.1 ft, respectively. Figure 37 gives the mean standard deviations of headway for the sections within each destination. Section three of destination two had the highest variance of headway due to the bottleneck.

Finally, the session time was found to be significant (p=0.0174). The mean standard deviation of headway for the afternoon session was 35.9 ft, the mean standard for the rush hour session was 34.3 ft, and the mean standard deviation for the night session was 37.6 ft.

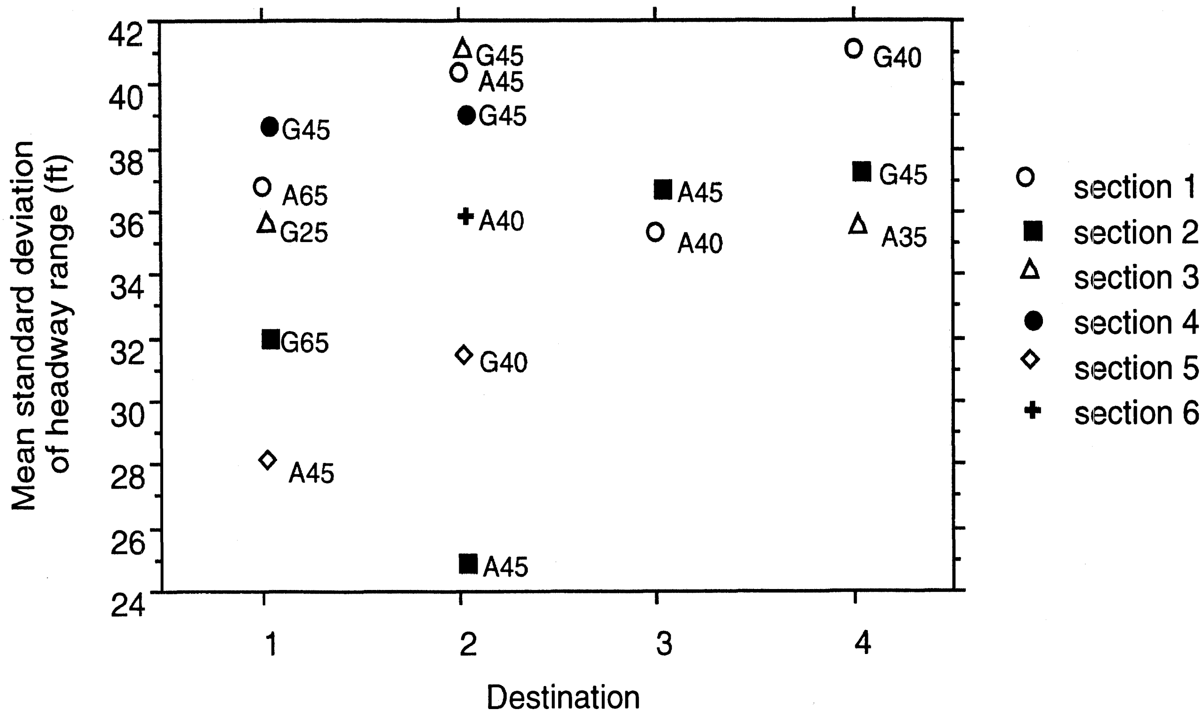


Figure 37. Mean standard deviations of headway for each section.

Trial number was not found to be significant, but means for each trial number are included. The mean standard deviation of headway for trials one, two, and baseline were 36.5 ft, 35.8 ft, and 35.2 ft, respectively. This indicates that greatest variance in headway was experienced during the subjects' first trial with the Ali-Scout system, and the least variance was found during experimenter navigation. The successive decrease in the mean standard deviation of headway over trials may also be due to subject familiarity with the test route. The data also suggest that headway variability was smaller in autonomous mode, reflecting more cautious driving behavior.

Lateral Measures

Lateral measures include lane position, and steering with means and standard deviations for each. As with the longitudinal measures, ANOVAs were based on a total of 864 data cells, of which 41 were missing.

Mean lateral position

Mean lateral position is a measure of the test vehicle's position in the lane of the road. A measurement of zero feet is defined when the car is centered in the middle of the lane (equal distance from the left and right lane markings). Negative values (measured in feet) are returned when the test vehicle is positioned to the left of center, and positive values (in feet) are given when the test vehicle is positioned to the right of center. The first significant variable is age group ($p=0.0014$). Mean lateral position for young, middle-aged, and older drivers were -0.09 ft, -0.19 ft, and -0.1 ft, respectively. All three age groups had a tendency to drive to the left of center within specified lane markings. Sex, on the other hand, was not found to be significant.

Subjects nested by age group and sex were also found to be significant (p=0.0001). Figure 38 shows subject mean lateral positions by age group and sex.

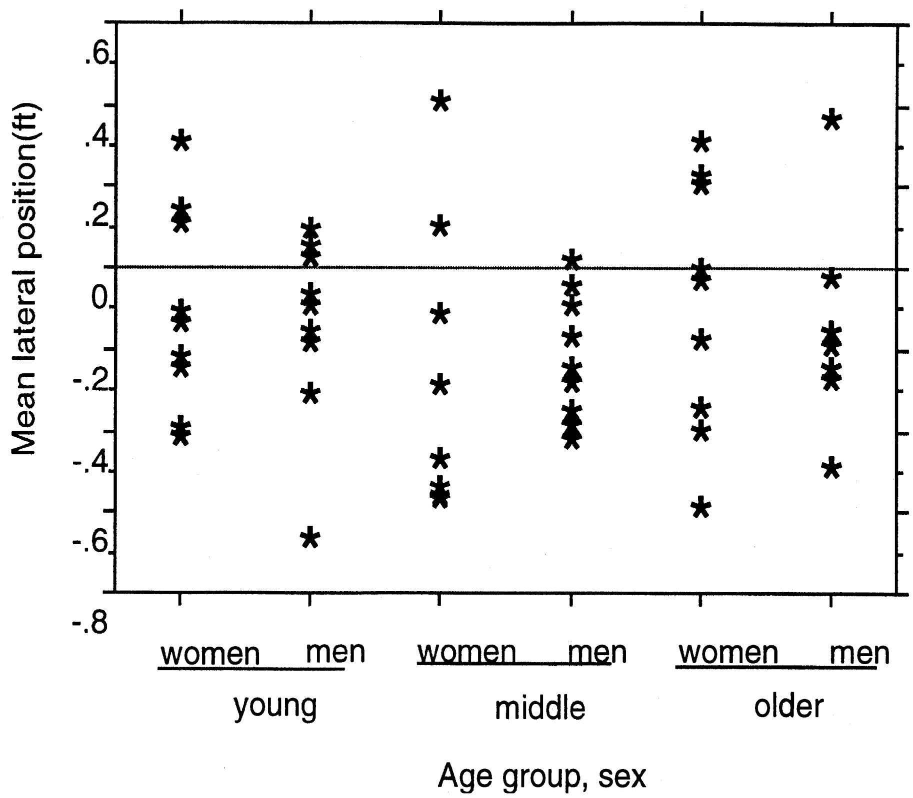


Figure 38. Mean subject lateral positions by age group and sex.

Both destination (p=0.0001) and section within destination (p=0.0001) were significant with respect to mean lateral position. Means for destination 1, 2, 3, and 4 were 0.033 ft, -0.16 ft, -0.46 ft, and -0.1 ft, respectively. Figure 39 shows mean lateral positions for sections within destination.

Another significant variable was trial number (p=0.0254). The mean lateral position for trial one was -0.095 ft, the mean for trial two was -0.1 ft, and the mean for the baseline trial was -0.18 ft. No reasonable explanation for subjects moving slightly to the left with practice (and farther from the lane center) can be found. There may also be a tendency to drive farther to the left in guided mode, although it is unclear why this might occur.

In addition, session time proved to be significant (p=0.0001). The afternoon session had a mean lateral position of -0.13 ft, the rush hour session had a mean of -0.2 ft, and the night session had a mean of -0.05 ft. Thus, greater traffic caused drivers to depart farther from the center of the lane.

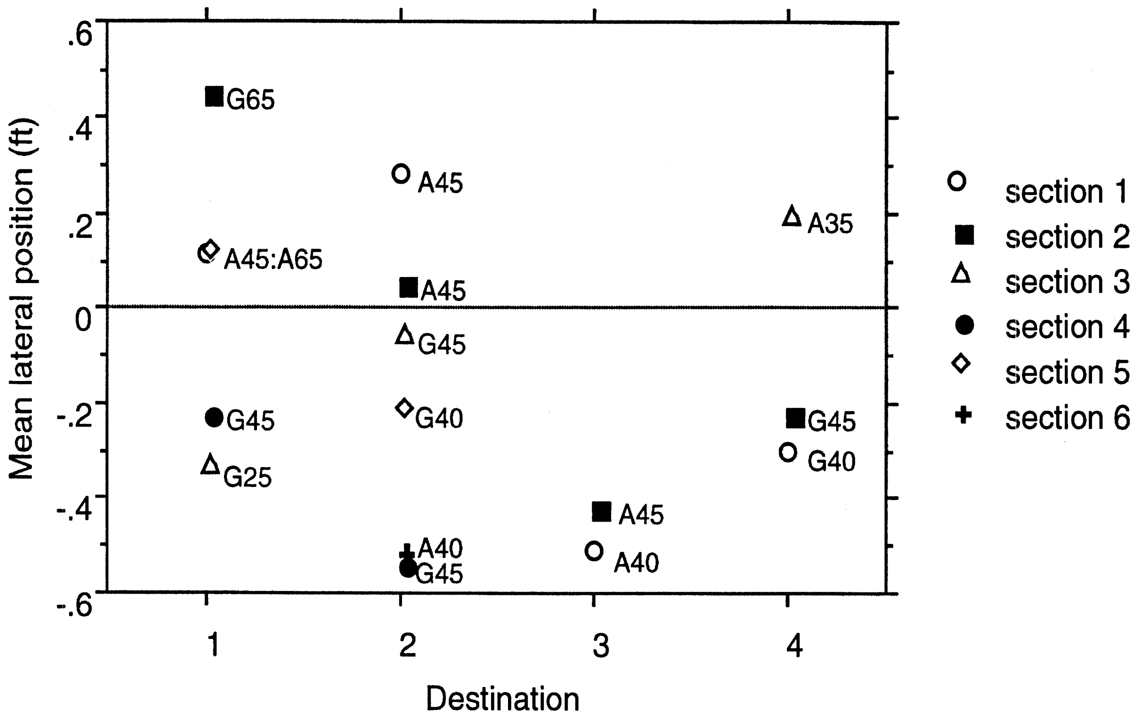


Figure 39. Mean lateral positions for each section.

An interaction between session time and destination was also found to be significant (p=0.0001). Figure 40 shows the mean lateral position for destinations by session time.

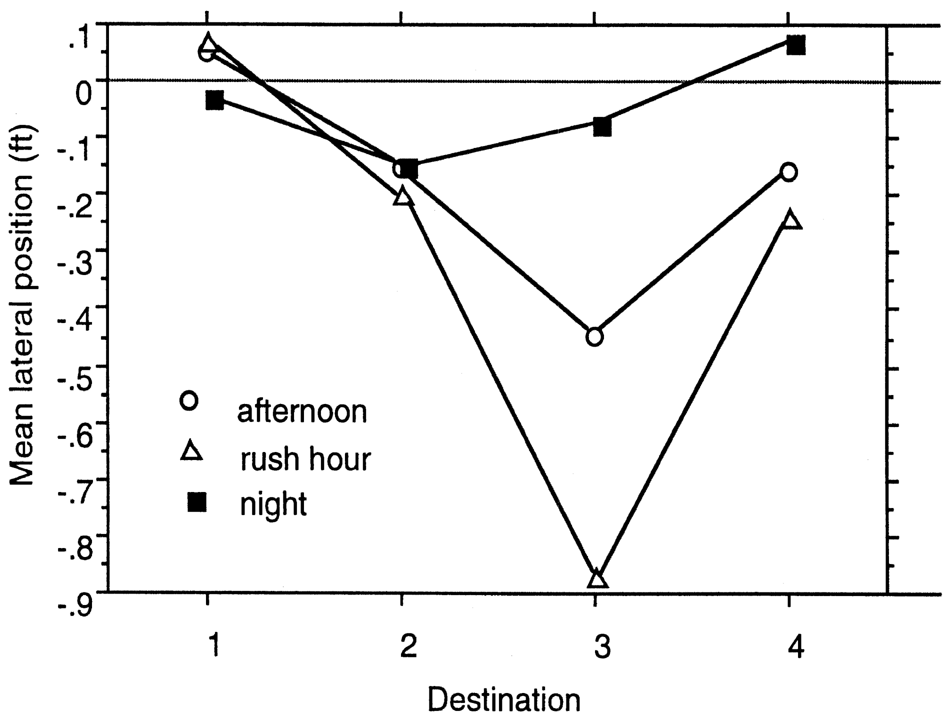


Figure 40. Mean lateral position for destinations by session time.

Standard deviation of lateral position

Standard deviation of lateral position (measured in feet) is the variance of the test vehicle's position within the lane of the road. Greater lane variability reflects poorer driving and may lead to crashes. The first significant variable with respect to standard deviation of lateral position is sex (p=0.0004). The mean standard deviation for women was 0.87 ft, and the mean standard deviation for men was 0.91 ft. In contrast to most other performance measures, age group was not found to be significant.

Subjects nested by sex and age group were found to be significant (p=0.0001). Figure 41 shows the subject mean standard deviations of lateral position by sex and age group.

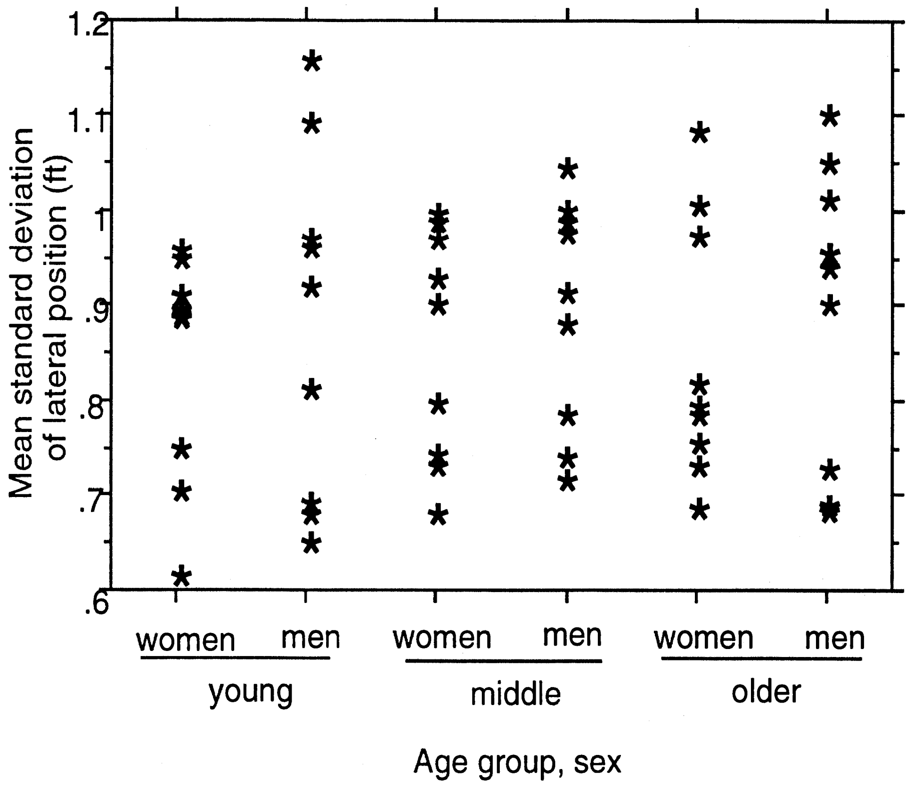


Figure 41. Mean standard deviation of lateral position for subjects by age group and sex.

Both destination (p=0.0001) and section within destination (p=0.0001) were found to be significant. The mean standard deviations of lateral position for destinations 1, 2, 3, and 4 were 0.89 ft, 0.86 ft, 0.83 ft, and 0.97 ft. Figure 42 shows the mean standard deviations for sections within each destination. Section three of destination one has the highest mean standard deviation of lateral position. This probably is because it is a curving expressway exit ramp.

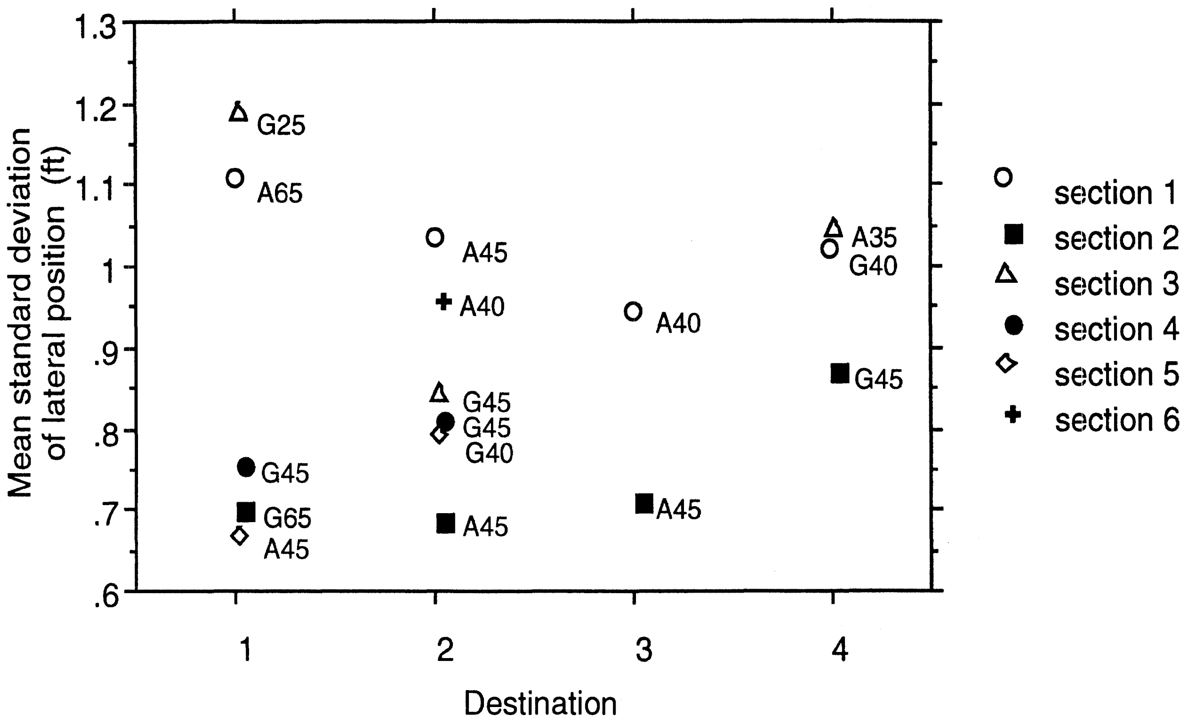


Figure 42. Mean standard deviation of lateral position for each section.

In addition, the session time was found to be significant (p=0.0001). The mean standard deviation of lateral position for afternoon was 0.97 ft, the mean standard deviation for rush hour was 0.97 ft, and the mean standard deviation for night was 0.73 ft. The variance in lane position may be higher for afternoon and rush hour sessions due to the traffic density.

Trial number was not found to be significant. The mean standard deviation of lateral positions for trials one, two, and baseline were 0.89 ft, 0.91 ft, and 0.88 ft, respectively. The standard deviation of lane position was least during the baseline trial when experimenter navigation was provided. The difference in standard deviation of lane position between trial one and trial two can not be explained. Thus, this evidence suggests lane-keeping (a safety measure) does not vary significantly with the quality of guidance provided. The guidance data reflect a similar pattern. Guidance mode seemed to have no effect on lane variance.

One interaction between session time and destination number was found to be significant (p=0.0001). Figure 43 shows the mean standard deviations for destinations by session time. The night session follows a pattern that is unlike both the afternoon session and the rush hour session. The major difference between the night session and the other two sessions is the presence of sunlight. One explanation is that there are different cues which govern lane position during night and day. What these cues may be was not explored. Another unexplored possibility is that the lane trackers were not able to lock on to both lane markings when the test vehicle was well off center at night (due to poor illumination), hence biasing the sampling.

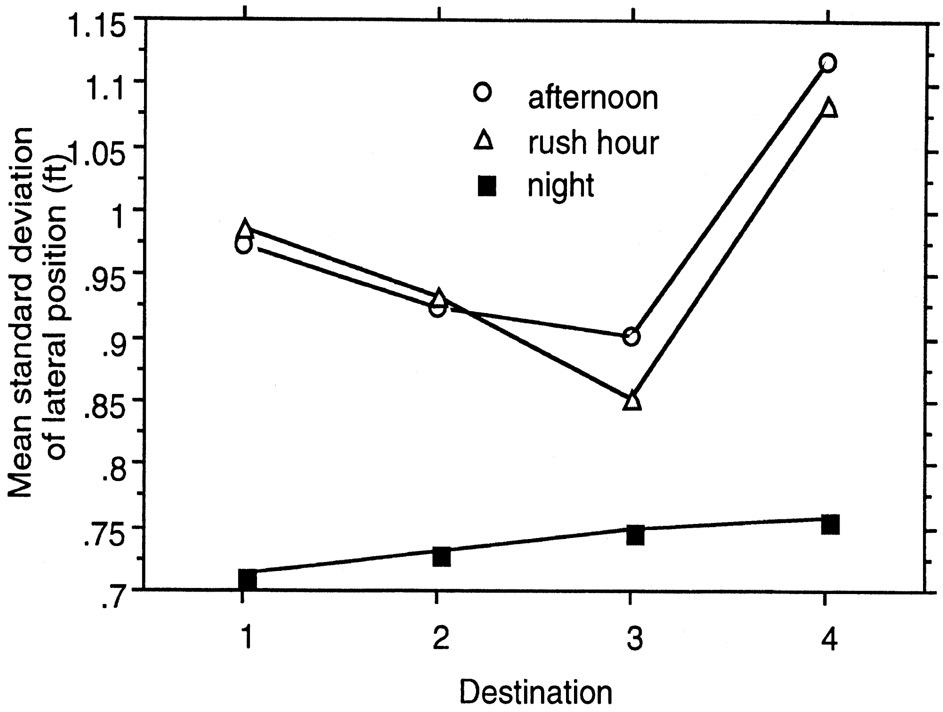


Figure 43. Mean standard deviations of lateral position for destination by session time.

Standard deviation of steering wheel angle

The standard deviation of the steering wheel angle (measured in degrees) is the variance in the position of the steering wheel (turning the wheel clockwise or counterclockwise). Due to imperfect mounting of the sensor, when the steering wheel is completely centered a measurement of -18.8° is recorded. Furthermore, this measurement is changed in positive increments when turned clockwise, and changed by negative increments when turned counterclockwise.

Subjects nested by sex and age group were found to be significant (p=0.0494), however neither age group, nor sex were. Figure 44 shows the mean standard deviation of steering wheel angle for subjects by sex and age group.

Both destination (p=0.0001) and section within destination (p=0.0001) were found to be significant. The mean standard deviations for destinations 1, 2, 3, and 4 were 14.4 degrees, 33.2 degrees, 52.8 degrees, and 18.7 degrees, respectively. Figure 45 shows mean standard deviations for sections within destinations. The high variance of steering wheel position found in section two of destination two may be because this is a very short section and subjects are coming out of a turn.

Figure 44. Mean standard deviation of steering wheel angle for subjects by sex and age group.

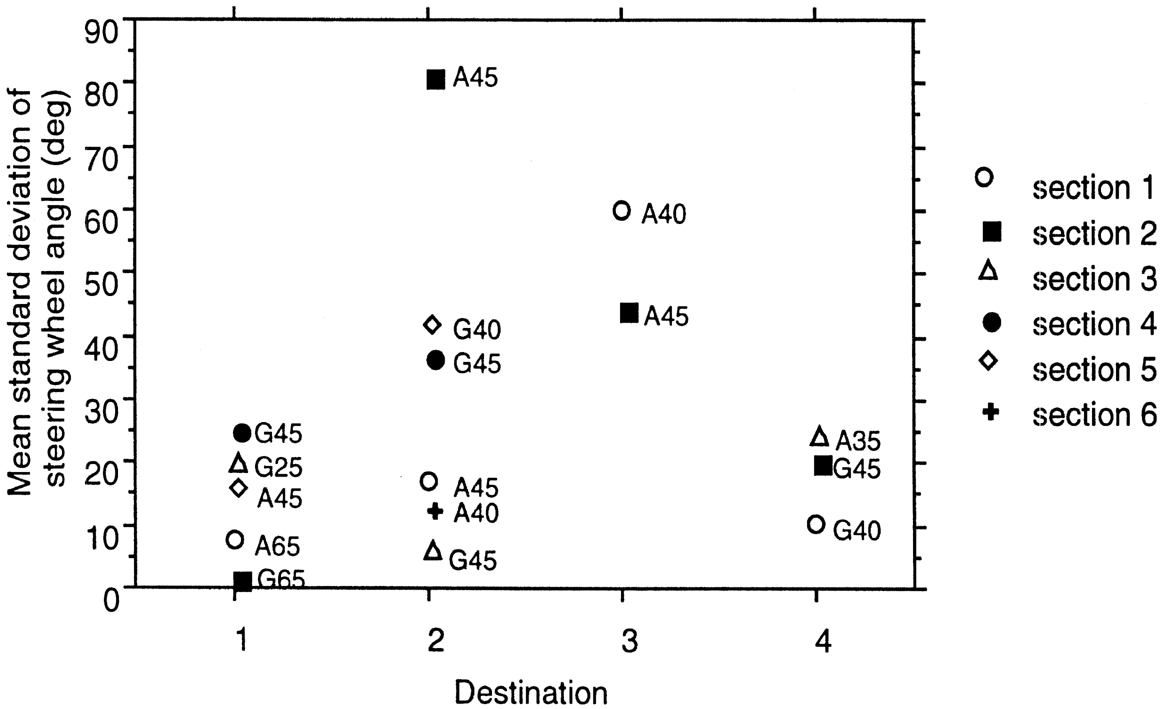


Figure 45. Mean standard deviation of steering wheel angle for each section.

Although trial number was not found to be significant, means are included. The mean standard deviations for trials one, two, and baseline were 28 degrees, 27 degrees, and 27 degrees, respectively. As expected, a slight decrease should occur with route familiarity and enhanced guidance.

An interaction between destination and trial number was also found to be significant (p=0.0121). Figure 46 shows the mean standard deviations of steering wheel angle for destinations by trial number. The number of turns relative to the distance traveled during destination 3 was greater than the other destinations, hence the higher standard deviation of steering wheel angle.

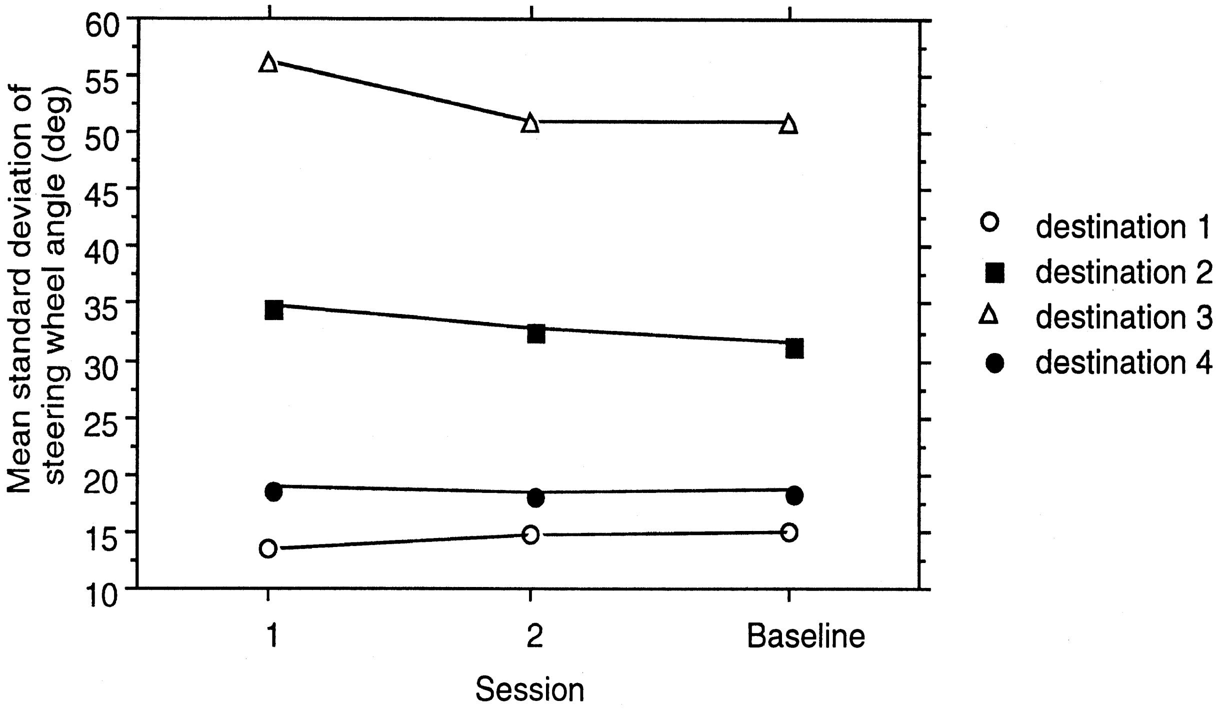


Figure 46. Mean standard deviation of steering wheel angle for each trial by destination.

In the comparison between standard deviation of steering wheel angle (an input measure) and standard deviation of lateral position (an output measure), lateral position may be a better measure for horizontal vehicle control. Six factors have significant impacts on the standard deviation of lateral position as opposed to five for the standard deviation of steering wheel angle. Furthermore, the significant effects affecting lateral position achieved a higher degree of significance.

Summary of ANOVAs

To facilitate understanding of the results, summary tables listing p-values follow, significant or otherwise, for all driving behavior (longitudinal control and lateral control measures). (See Tables 38, 39, and 40.) Statistically significant values are shown in bold. Notice that no single variable stands out as the ideal measure of longitudinal or lateral control (in terms of being more likely to be significant), especially in regards to differences in interface design and experience with the interface (here trial number).

From a practical perspective, there were concerns regarding the reliability of the headway data. The problems encountered may reflect the specific difficulties with the particular sensor utilized, not general problems with sensitivity of those measures. Over the time period of this project, improvements in technology should have eliminated the concerns over sensor reliability.

Table 18. Compiled p-values for sample sizes.

Factor	Dependent Variable	
	Mean Number of Straight Points	Mean Number of Stopped Points
Age Group	**0.0009**	0.7975
Gender	0.9083	0.9473
Subject (Gender, Age Group)	**0.0001**	0.0749
Destination	**0.0001**	**0.0001**
Trial Number	**0.0004**	0.0607
Section (Destination)	**0.0001**	**0.0001**
Session Time	**0.0001**	**0.0001**
Destination * Session Time	0.7429	0.3435
Destination * Trial Number	0.2041	**0.0281**
Gender * Age Group	**0.0001**	**0.0001**

Table 19. Compiled p-values for longitudinal control.

Factor	Dependent Variable							
	Duration	Mean Moving Speed	Standard Deviation of Speed	Overall Mean Speed	Mean Throttle Position	Standard Deviation of Throttle Position	Mean Headway	Standard Deviation of Headway
Age Group	0.3708	**0.0001**	**0.0001**	**0.0001**	**0.0001**	0.1256	**0.0001**	**0.0001**
Gender	0.9061	0.3768	0.6901	0.1590	0.4832	0.6297	0.3766	0.5743
Subject (Gender, Age Group)	**0.0022**	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0001**
Destination	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0017**	**0.0001**
Trial Number	**0.0043**	**0.0001**	**0.0002**	**0.0001**	**0.0009**	**0.0001**	0.1152	0.1525
Section (Destination)	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0001**
Session Time	**0.0001**	**0.0057**	**0.0001**	**0.0001**	**0.0005**	**0.0001**	**0.0002**	**0.0174**
Destination * Session Time	**0.0001**	0.2106	**0.0231**	0.4506	**0.0001**	**0.0001**	0.7726	0.4474
Destination * Trial Number	0.3586	0.1747	0.2113	0.9460	**0.0016**	**0.0001**	**0.0017**	0.1749
Gender * Age Group	0.0762	**0.0465**	**0.0182**	**0.0171**	0.9228	0.3840	0.2177	0.1055

Table 20. Compiled p-values for lateral control.

Factor	Dependent Variable		
	Mean Lateral Position	Standard Deviation of Lateral Position	Standard Deviation of Steering Wheel Angle
Age Group	**0.0014**	0.4854	0.1789
Gender	0.1086	**0.0004**	0.4512
Subject (Gender, Age Group)	**0.0001**	**0.0001**	**0.0494**
Destination	**0.0001**	**0.0001**	**0.0001**
Trial Number	**0.0254**	0.0902	**0.0291**
Section (Destination)	**0.0001**	**0.0001**	**0.0001**
Session Time	**0.0001**	**0.0001**	0.3819
Destination * Session Time	0.3655	0.2119	**0.0121**
Destination * Trial Number	0.4395	0.8810	0.6362
Gender * Age Group	**0.0001**	**0.0001**	0.2160

SUPPLEMENTAL EXPERIMENT - TEST PLAN

A supplemental experiment was conducted for two reasons. First, eye-fixation video recordings from night sessions, involving Ali-Scout use, in the initial experiment were too dark to analyze. Therefore, for this supplemental experiment low-light level cameras were installed in the test vehicle so additional eye fixation data could be obtained at night. Since this data was collected exclusively for eye fixation analysis, the performance data from the supplemental testing was not analyzed.

Second, while there was baseline data in the initial experiment (experimenter guidance), other types of baseline information were needed to provide a sense of the safety and usability of the Ali-Scout interface. To avoid a major programmatic change, an expanded pilot test was conducted using another navigation unit, the PathMaster developed by Rockwell International, on the same test route. The performance data and eye fixation data obtained from subjects driving with the PathMaster was compared with matched subjects from the initial Ali-Scout experiment, not the supplement Ali-Scout subjects (tested at a different time of the day).

Test Participants

Ali-Scout supplement

A total of 12 licensed drivers participated in the Ali-Scout supplemental experiment. Six subjects were selected from two age groups: young (22-25 years), and older (65-73 years). Preliminary analysis of the performance data in the first experiment indicated that the middle-aged subjects did not perform significantly different from the young drivers. Therefore, due to time constraints, the middle-aged subjects were not scheduled for the supplemental experiment.

The mean age in the two groups tested was 23 and 69 years, respectively. Corrected visual acuity ranged from 20/20 to 20/40. Each age group contained an equal number of men and women. Experimentation took place only at night (9-11 PM). Subjects were either friends of the experimenters, or respondants to a newspaper advertisement.

Participants reported that they drove between 1,000 and 23,000 miles per year (mean = 12,500). Subjects rated their familiarity with driving in the city of Troy as 2.6 (mean) on a scale from 1 to 5 (1 = not at all familiar, and 5 = very familiar). On the same scale, subjects rated their familiarity with the FAST-TRAC project in Oakland County as 1.4, and pretest familiarity with the Ali-Scout navigation system as 1.3, indicating little to no familiarity. These numbers do not give a mean of 1.0, because watching the videotape concerning the FAST-TRAC project and completing the experiment gave them some familiarity, leading some subjects to rate their familiarity as 2. Both before and after experimentation subjects were asked if they knew the location of any of the destinations on the test route prior to testing. Three subjects had prior knowledge of the Honeybaked Ham location (destination one).

PathMaster supplement

The original experiment plan called for having six subjects use the PathMaster. As a result of the unforeseen equipment problems and schedule constraints, only 4 subjects (2 men and 2 women) were tested. Unfortunately, the PathMaster made large errors in displaying its current locations for one of the subjects (due to calibration problems), so her data was not included in the driving performance analysis (leaving two men and one woman in that sample) but was included in the ratings analysis. The four licensed drivers in the PathMaster portion of the supplemental experiment from whom usable data was obtained were all young (20-25 years, mean=23). Corrected visual acuity of the three drivers ranged from 20/20 to 20/25. Experimentation took place during rush hour (5-7 PM). Subjects were friends of the experimenters.

Participants reported that they drove between 12,000 and 22,000 miles per year (mean = 16,250). Subjects rated their familiarity with driving in the city of Troy as 3.0 (mean) on a scale from 1 to 5 (1 = not at all familiar, and 5 = very familiar). On the same scale, subjects reported a mean pretest familiarity with the PathMaster navigation system as 1.5, indicating little to no familiarity. Both before and after experimentation subjects were asked if they knew the location of any of the destinations on the test route prior to testing. No subjects were familiar with any of the destinations.

Instrumented car

Based on experience from the initial experiment, several modifications were made to the instrumented car. For the most part data-collection and sound equipment remained the same; however, changes were made to the video system and headway sensor. To improve the quality of the data collected at night, two low-light level cameras (one aimed at the driver and mounted on the dash above the center console, a second aimed at the road and mounted in place of the passenger sun visor) were added to the video recording system. While the new cameras were larger (about the size of a brick) than the lipstick cameras used in experiment one, the new cameras were not easily seen at night when testing took place. All camera outputs were combined, along with computer output, by a newly installed eight by four video switcher and fed to a quad splitter, monitor, and VCR. Figure 1 in the Equipment section for the previous experiment shows a typical quad-screen image.

A new infrared headway sensor developed by Mitsubishi, model (type: E9Z505-02, including laser radar head unit [X4T25571T1] and laser radar control unit [E2Z561-04]) was mounted to the front grill resting on the front bumper of the vehicle. (This replaced the Leica ODIN II. The laser diode in the ODIN II had failed several times midway through the initial experiment and replacement parts were not available as the unit was no longer in production.) The new sensor is identical to that used in Japan for the adaptive cruise control unit on the current model Mitsubishi Diamante. Software written by the project team processes returns from the scanning laser (via a serial link) operating at about 8 Hz, slightly slower than the Leica sensor. Based on the number of beams interrupted and their relative locations, the software identifies lead vehicles, vehicles in other lanes, signs, and false returns.

Figure 47 shows most of the engineering data equipment and the power supplies, as well as the newly installed eight by four switcher, headway signal conditioner, and PathMaster navigation equipment (described in the next section).

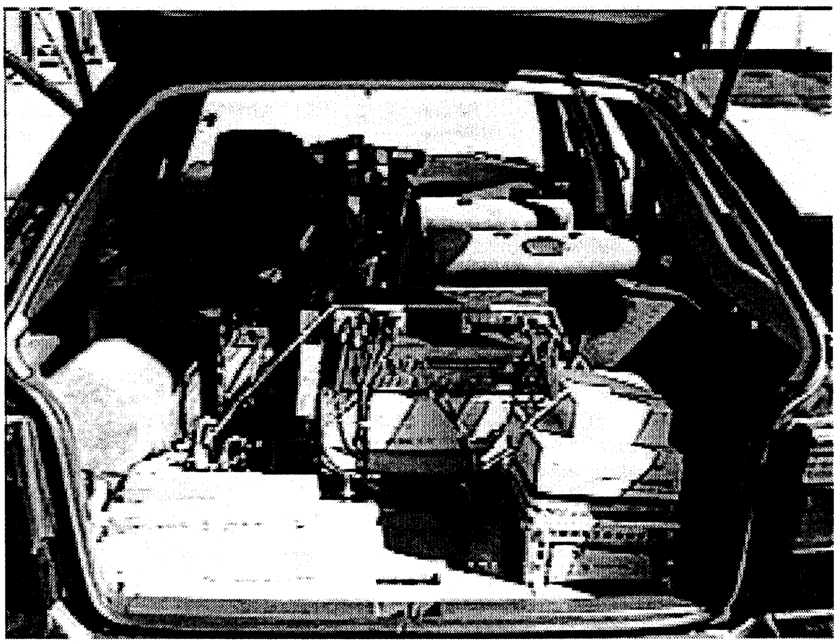


Figure 47. Data collection equipment and power supplies.

All equipment is operated by an experimenter seated in the right rear passenger seat. An LCD panel mounted on top of the equipment rack was added to monitor the data collection program. The LCD panel is attached to the rack by hinges and may be folded down to lay flush with the rack when not in use. The controller for the eight by four video switcher was mounted to the front of the rack to allow the experimenter to choose the proper image for each quadrant. Figure 48 shows the arrangement of most of the equipment operated by the experimenter. Appendix B shows a plan view of the test vehicle and the model numbers of all equipment in the vehicle.

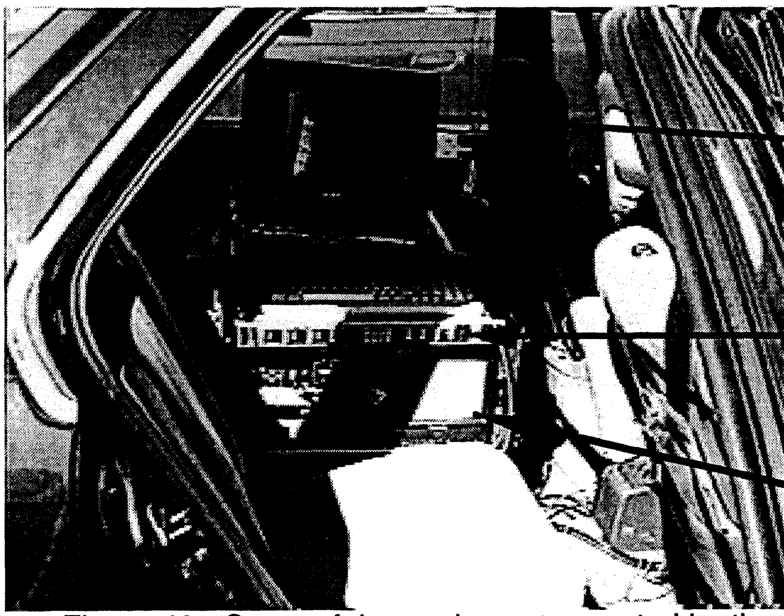


Figure 48. Some of the equipment operated by the experimenter.

PathMaster

The Rockwell PathMaster navigation system provided turn-by-turn guidance to specified destinations using voice and visual instructions. The PathMaster system relied upon Global Positioning System (GPS) and dead reckoning to continually match the vehicle's position to the stored map data. Figure 49 shows both the Ali-Scout navigation system, as well as the PathMaster as they were installed in the test vehicle during supplemental testing.

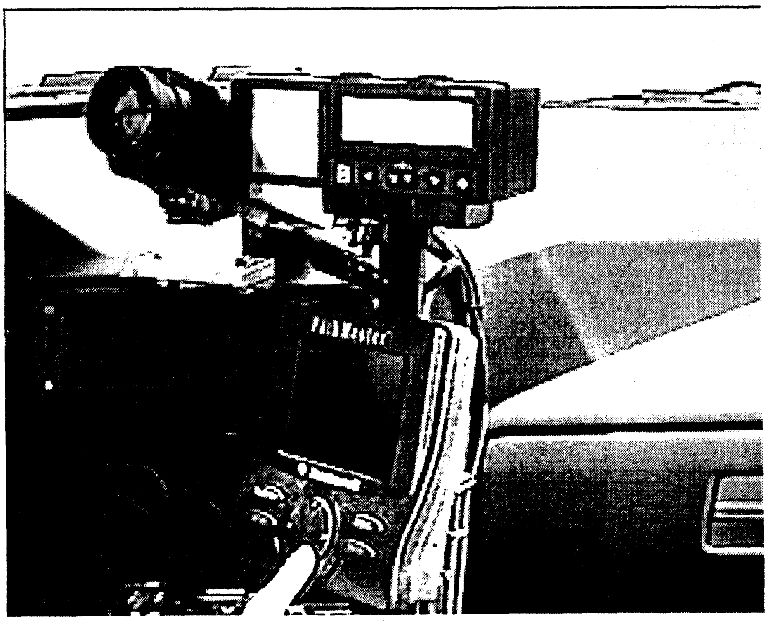


Figure 49. Ali-Scout navigation unit (top) and PathMaster navigation unit (bottom) as installed in the test vehicle.

Note: A low-light level camera is mounted to the left of the Ali-Scout Display Unit.

In addition to the PathMaster control and display unit, a GPS satellite antenna and a self-contained map storage and data processing unit were also installed. A typical PathMaster screen is depicted in Figure 50.

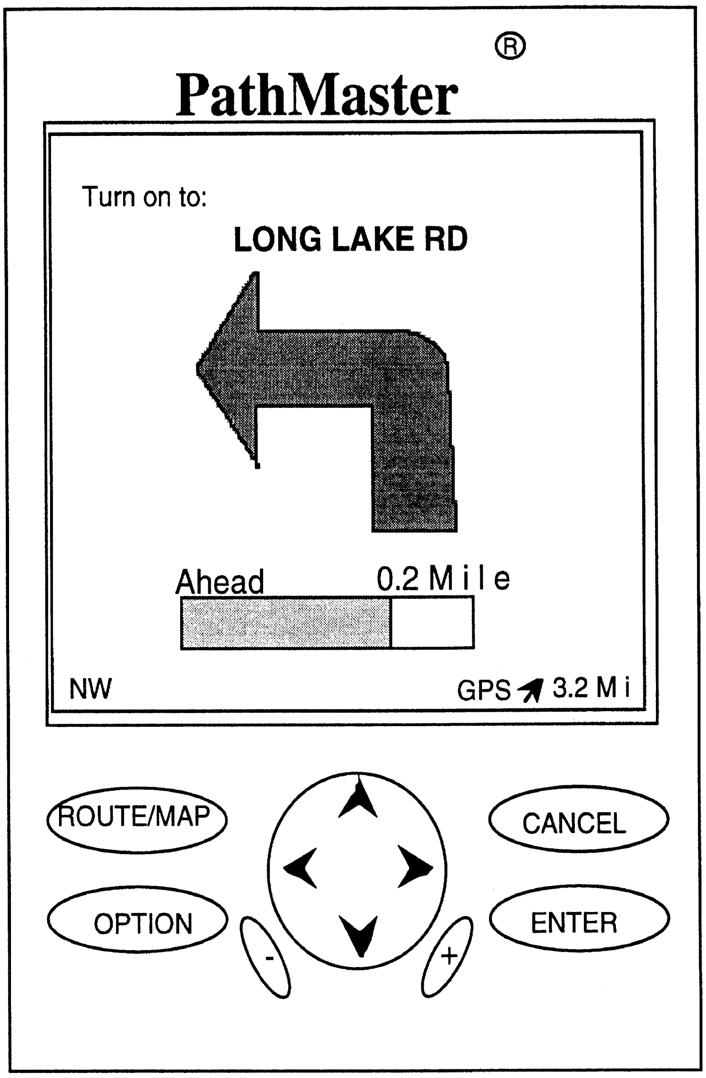


Figure 50. PathMaster unit in guidance mode.

The PathMaster provides specific route guidance to reach the destination specified, relying upon auditory messages and visual cues on the display screen. Visual cues include the distance in miles to the destination (lower right corner of display), bar graph to next turn and distance in miles to the next turn (below large arrow in center of display), direction traveling (lower left corner of display), turn icon (arrow in center of display), and the road that the driver should turn onto (top, center of display) (see Figure 50).

Destinations and Test Route Overview

A map of the full test route is given in the description of the original experiment and can be found in Figure 6. The supplemental test route was identical to the original route except for a change to destination one necessitated by revisions Siemens made to the software between the two experiments. (A description of this new destination is given in Appendix F.) Specifically, the Ali-Scout would switch into autonomous mode before reaching the intersection at Crooks and Long Lake Rd. The system would then switch back into guided mode after passing the beacon at that intersection, directing the driver past their destination (SOC Credit Union). Therefore, the Ali-Scout provided accurate directions during the first experiment, but inaccurate directions to SOC Credit Union at the time of supplement experiment.

To correct this problem, the first destination was changed to Honeybaked Ham which is located on the same side of the street as SOC Credit Union, but is 925 feet closer to the intersection between Crooks and Long Lake Rd. (433 feet from the intersection). The Honeybaked Ham building and SOC Credit Union building appeared to be equally noticeable. The main difference between the two, is that Honeybaked Ham is only 80 feet from the street, whereas SOC Credit Union is 298 feet from the street. Appendix E gives the destination criteria for Honeybaked Ham as compared to that of SOC Credit Union.

Test Activities and Their Sequence

Ali-Scout

Since there were no offices available to the experimenters at the time of supplemental testing, all preparation prior to testing was completed in the parking lot of the Liberty Center office building. The experimenter met the subjects in front of the Liberty Center and escorted them to the test vehicle. Subjects were asked to watch a brief 10-minute video concerning the FAST-TRAC project and the operation of the Ali-Scout unit while sitting in the back seat of the test vehicle where a small CRT was located. (See Figure 48.) Participants were then directed to the driver's seat and told that the experiment involved one two-hour on-the-road session. Subjects were informed that they would be paid a total of $40 for their time. (A copy of the Ali-Scout supplement instructions can be found in Appendix T.) Subjects completed a biographical form and a consent form. (The biographical and consent forms can be found in Appendices I and U, respectively.)

While the subject adjusted the vehicle mirrors, etc., the experimenter, seated in the right back seat of the vehicle, initialized the test equipment, and then reinforced key points concerning the Ali-Scout's use. (See Appendix G.) After initializing the video equipment, the experimenter verbally guided the subject to the beginning of the test route. The experimenter then began saving data and told the subject to "use the Ali-Scout" to get to Honeybaked Ham.

The specifics of the test route used to reach Honeybaked Ham (including the instructions provided by the Ali-Scout, and the mode segments) are given Appendix V.

At Honeybaked Ham the subject parked the car, so the experimenter could save the data, enter new test parameters into the data collection computers, and enter the next destination into the Ali-Scout (Harlan Plaza). Once the subject was guided onto the correct path and heading north on Crooks Rd. he/she was asked to use the Ali-Scout to get to Harlan Plaza.

There was one other minor change in the performance of the Ali-Scout during the test route leading to destination two. The Ali-Scout would not direct the driver to turn right onto Rochester Rd.; instead it advised driving straight on Long Lake Rd. and then turning right on John R Rd. to get to Harlan Plaza. Because it was important to keep the supplement experiment as similar as possible to the original test, experimenters asked the subjects to turn right onto Rochester Rd. even though the Ali-Scout did not recommend this route. Because there is a beacon located at the intersection between Rochester Rd. and Long Lake Rd. the Ali-Scout would quickly recover to guided mode after the turn was made and direct the subject correctly from that point on. The specifics of the test route used to reach Harlan Plaza (including the instructions provided by the Ali-Scout, and the mode segments) are given in Appendix V.

All testing following arrival at destination two was completed exactly as during session one of the original testing. For details see the Test Activities and Their Sequence section for that experiment. One exception existed: when subjects arrived at destination four, they were told that the final or baseline trial, would begin from that point.

The baseline run involved driving the then familiar test route a second time, without the aid of the Ali-Scout navigation system. (The experimenter turned it off.) To ensure that subjects would reach each destination, the experimenter provided explicit directions. Subjects were also told that they should feel free to ask questions concerning the route, or where to turn, whenever they liked. (See Appendix N for a complete listing of the directions to each destination.) At each destination, data was saved by the experimenter. The experimenter drove the test vehicle from the fourth destination back to TOC/Liberty Center where the subject was paid $40 cash.

Upon returning to the parking lot of the Liberty Center, the subject completed a survey concerning their familiarity with the project, the destinations, etc., as well as survey concerning the usability and usefulness of the Ali-Scout unit. (These forms were identical to those used in the original Ali-Scout experiment and can be found in Appendix K and L, respectively.) Subjects were then paid $40 cash after paperwork was completed. (See Appendix M for the payment form.)

PathMaster

As with the Ali-Scout supplemental experiment, subjects were read instructions concerning the experiment and were asked to fill out two forms. (A copy of the PathMaster instructions can be found in Appendix W. The biographical form was the same as that for the Ali-Scout subjects, and the PathMaster consent form can be found in Appendix X.)

While the subject adjusted him/herself in the vehicle, the experimenter stressed key points concerning the PathMaster's use. (See Appendix W.) Similar procedures to those for the Ali-Scout supplement experiment were followed. The specifics of the test route used to reach Honeybaked Ham (including the instructions provided by the PathMaster) are given in Appendix V.

Upon arriving at each of the four destinations the subject parked the vehicle. The experimenter then saved the data that was collected during the route and entered new test parameters into the computer and changed the destination in the PathMaster.

The experimenter then provided the subject with directions to begin each of the following three test routes. Once the subject was headed in the right direction, the experimenter asked the subject to use the PathMaster to get to the specified destination. Appendix V gives PathMaster behavior for destinations 2, 3, and 4, respectively. Unlike the Ali-Scout portion, the experimenter gave the subject some directions out of the parking lot at Harlan Plaza. The subject was told to make a left out of the parking lot, because the PathMaster did not begin to direct the driver until he/she was on the road.

The PathMaster baseline run followed the exact procedures described in the Ali-Scout supplement baseline trial. Appendix N contains a complete listing of the directions given to subjects for each destination during PathMaster baseline testing.

Upon arriving at the Liberty Center parking lot, the subject completed a survey concerning their familiarity with the navigation system, as well as a survey concerning the usability and usefulness of the PathMaster. (Copies of the Route Knowledge and Usability Surveys appear in Appendix Y and Z, respectively.) Subjects were then paid $40 cash after paperwork was completed.

SUPPLEMENTAL EXPERIMENT -- RESULTS

Crashes, Near Misses, and Critical Incidents

No crashes, near misses, or critical incidents occurred while using the PathMaster navigation unit. This may be due to the small sample size involved in the supplemental experiment.

Turn Errors

No turn errors were encountered during the PathMaster portion of the supplemental experiment. In part this is due to the small sample size, but credit must also be given to the clearly defined auditory and visual cues provided by the PathMaster navigation system. Subjects did not show confusion over any of the commands given by the system.

One subject did make a comment concerning the PathMaster's auditory cue when approaching the destination. He asked, "Why can't it say destination ahead on the left or right?, instead of just destination ahead?" The subject reiterated this comment on the survey provided at the end of experiment.

Analysis of Post-Experiment Questionnaires

Similar to the first experiment concerning the Ali-Scout interface, questionnaires were distributed at the end of the PathMaster supplemental experiment concerning the safety, system usefulness, and feature usefulness. Identical questions were asked for safety and overall usefulness in both samples, except for a few Ali-Scout questions that did not pertain to the PathMaster (e.g., those dealing with autonomous mode).

Data was obtained for all four PathMaster participants (2 men, 2 women) and their equivalent Ali-Scout counterparts (3 men, 3 women), matched on age and time of day. PathMaster subjects were run at one time only, 5-6 PM (rush hour). Although the entire original Ali-Scout sample could have been used, the ANOVA of the original data set identified age has a significant effect in at least one case. Not having age-matched samples would have confounded age differences between samples with interface differences. For simplicity, only young subjects run at rush hour from the original sample were used for comparison. In any comparison, the limiting factor was the small PathMaster sample size.

Each group of questions (safety, system usefulness, and feature usefulness) were considered separately in the ANOVAs concerning differences between the PathMaster navigation system and the Ali-Scout navigation system. Main effects were sex, subjects, question, time of day, and interface (Ali-Scout, PathMaster). (See Appendix AA.)

In terms of safety, there was a significant difference due to question concerning safety ($p = 0.0001$), subject nested in test and sex ($p=0.0266$), and navigation interface ($p=0.0348$), but not sex. In brief, subjects rated the PathMaster as safer for themselves than the Ali-Scout and safer for inexperienced drivers (but not very much). (See Table

21.) Readers are reminded that as in the original experiment the scoring of the third safety question has been revised (to include the word not) to be consistent with the other two safety questions. (The original question was "The Ali-Scout/PathMaster was distracting".) Further, to put these ratings in perspective, comparable ratings for the full Ali-Scout data set were 4.0, 2.8, and 3.9.

Table 21. Mean ratings of safety.

System Evaluation Strongly disagree 1 ----> 5 Strongly agree	Mean PathMaster Rating	Mean Ali-Scout Rating
1. It is safe for me to use this system while driving.	4.5	4.0
2. It is safe for an inexperienced driver to use this system while driving.	3.3	2.4
3. The Ali-Scout/PathMaster was (not) distracting.	4.3	4.1

Means for each subject based on all three safety questions are shown in Figure 51. Notice that, of the four PathMaster subjects, only one did not rate it highly.

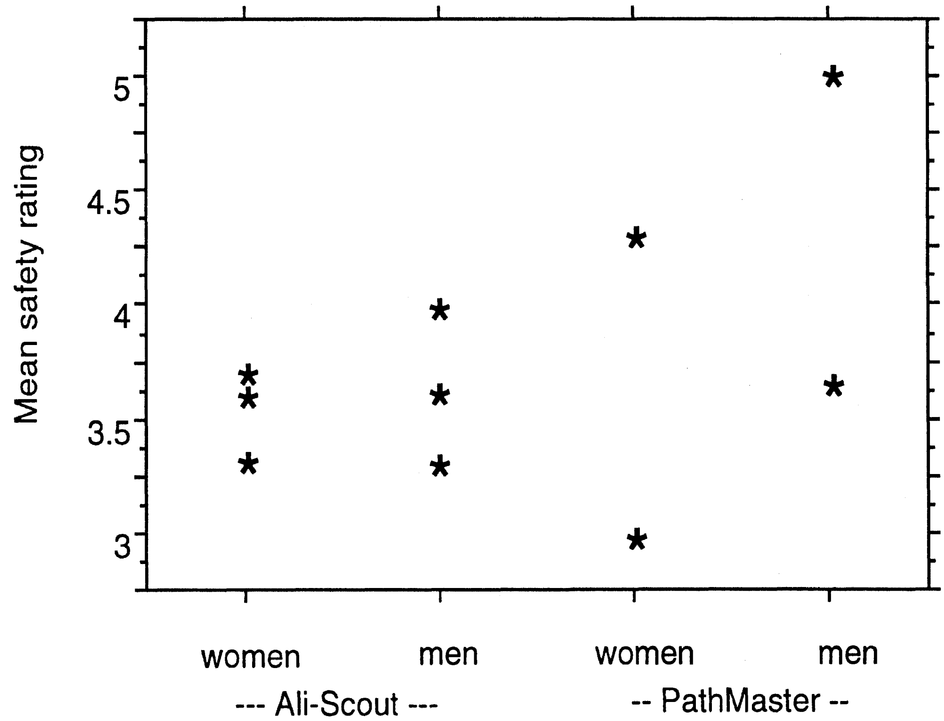


Figure 51. Subject mean safety ratings.

Several questions were asked concerning the general usefulness of the navigation system. (See Table 22.) There were significant differences due to sex (p=0.0014, 4.2 for women, 3.6 for men), and question regarding usefulness (p=0.0001). Higher ratings were typically provided by women. (See Figure 52.) In addition, differences between subjects were significant (p=0.0001). However, differences due to test (Ali-Scout vs. PathMaster) were not significant. (Comparable ratings from the entire Ali-Scout sample from Experiment one were 3.2, 3.7, 4.3, 4.3, 4.1, 4.6, and 2.6, respectively.) From the overall mean ratings it can be seen that generally users strongly agreed that the navigation systems would be helpful in locating an unknown destination.

Table 22. Mean ratings of system usefulness.

System Evaluation Strongly disagree 1 ----> 5 Strongly agree	Mean PathMaster Rating	Mean Ali-Scout Rating
1. I would likely use this system for my daily travel.	3.3	3.6
2. I would use this system if I were in a hurry.	4.0	4.0
3. The route guidance information provided is useful.	4.5	4.3
4. I would rather use a route guidance system similar to this one than use a standard paper road map to find my way.	4.3	4.1
5. I would rather use a route guidance system similar to this one than use written instructions to find my way.	4.5	4.0
6. The system would be helpful in locating a destination that I have never visited before.	4.8	4.7
7. The system would be helpful in driving to familiar locations.	1.5	2.4

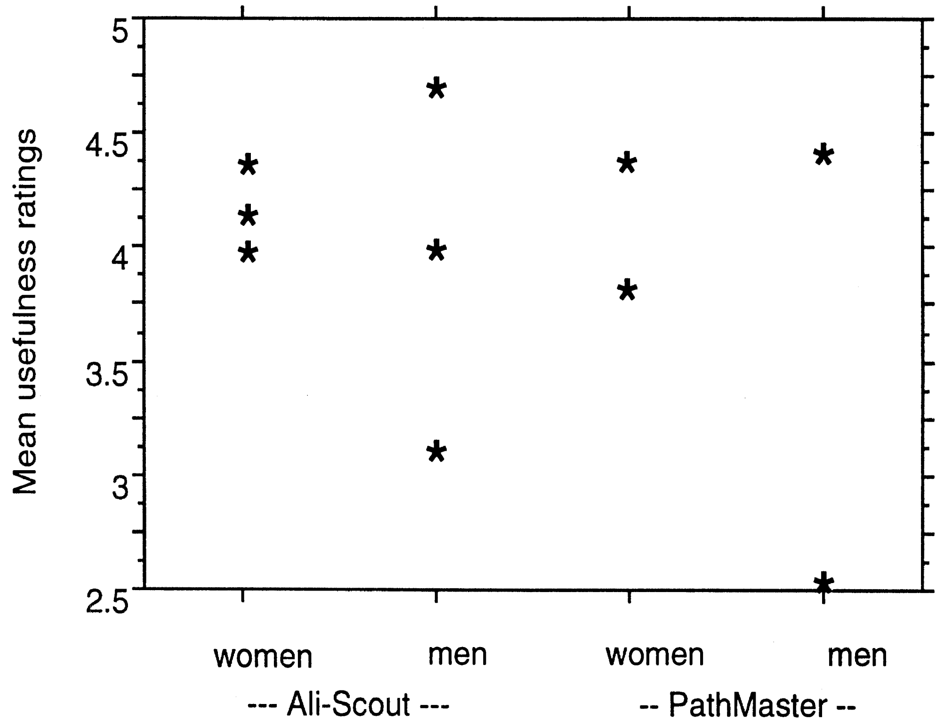


Figure 52. Subject mean system usefulness ratings.

Ratings of the usability of the navigation system features appear in Table 23. The first two questions pertaining to features were actually somewhat different for the two interfaces (Ali-Scout versus PathMaster) but have been included for the sake of completeness. In the ANOVA of these data the effects of sex (p=0.0001, 4.6 for women, 3.9 for men), subject nested within Interface and sex (p=0.0244), and feature usability question (p=0.0067) were all statistically significant. The reason for the sex difference is uncertain, both here and for system usefulness. Differences between interfaces (Ali-Scout versus PathMaster) were not significant. Overall, subjects found the miles to reach destination (Ali-Scout subjects), or miles to reach next maneuver (PathMaster subjects) most useful. The feature rated least useful was the countdown bars to a turn, but that may be because there were few closely spaced streets on the route, where countdown bars are particularly useful. Thus, the ratings of the individual display elements tend to show less in the way of differences than were reflected in the overall ratings.

Table 23. Mean ratings of usability of navigation features.

System Evaluation Strongly disagree 1 ----> 5 Strongly agree	Mean Path-master Rating	Mean Ali-Scout Rating
1. The miles to reach destination (Ali-Scout)/ next maneuver (PathMaster) readout was useful.	4.8	4.9
2. The auditory messages given were useful.	4.3	4.4
3. The auditory messages are given in ample time before a turn is to be made.	4.5	3.6
4. The countdown bars to a turn were useful.	3.8	3.6
5. The turn graphics were useful.	4.3	4.1

Means for each subject based on all five feature usability questions are shown by subject in Figure 53. The two men who rated the PathMaster had identical mean scores.

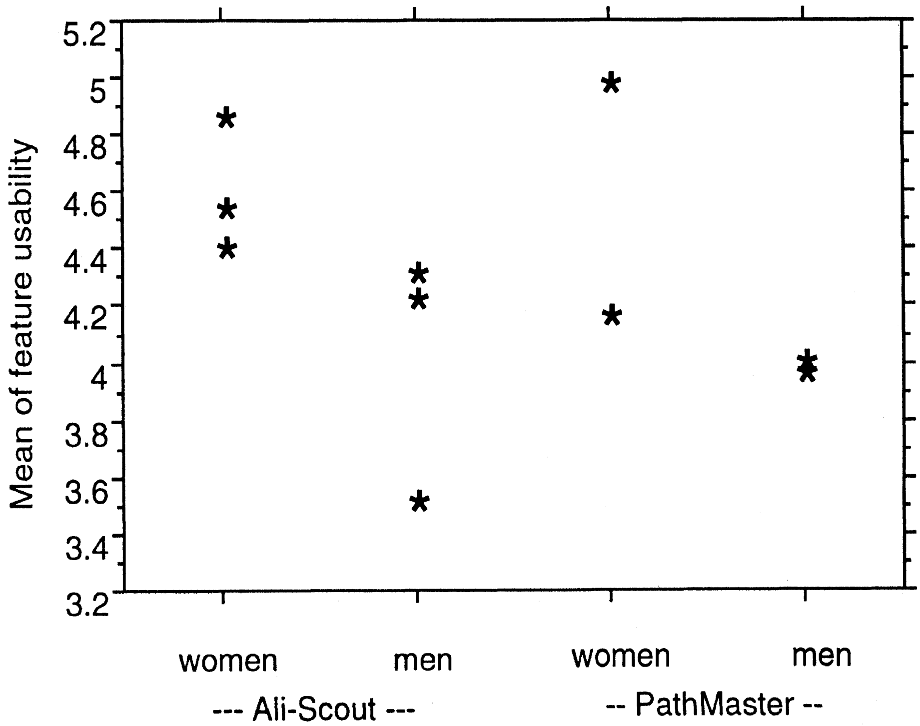


Figure 53. Subject mean feature usability ratings.

Participants indicated they would be willing to pay $567.00 with a range from $35 to $1,000 for an Ali-Scout system. For a PathMaster interface users were willing to pay $300.00 with a range from $0 to $500.

Additional space was given on the questionnaire for subjects to make any general comments concerning the experiment and/or the navigation system. Although the Ali-Scout supplement subjects were not included in the subjective results analysis, they did provide some useful comments concerning the Ali-Scout navigation system. All Ali-Scout supplement subjects were run at night (9-10 PM) to gain further eye fixation data, while all PathMaster subjects were run during rush hour (5-6 PM). The comments provided by subjects on their survey are given in Table 24.

Table 24. Subject comments concerning their exposure to the navigation systems.

System Used	Age	Sex	Comment
Ali-Scout	22	F	Need more time before turns and more details as you approach your destination.
Ali-Scout	65	M	Must forewarn you sooner when to turn right or left. Should be a larger screen and easier to read (colors).
Ali-Scout	25	M	Ali-Scout would be painfully useful in getting around a new or unfamiliar city (rental cars or recent arrivees). Not as useful in a familiar city. Perhaps you can offer navigation service like cable? Keep it on a subscription basis for as long as it's useful
Ali-Scout	73	M	Coloring (green background) with read arrows for turns and black arrow for forward. Mile odometer needs larger type.
Ali-Scout	71	F	Would be better located more to the center of the drivers view.
PathMaster	25	M	Difficult to read display. Direction when approaching destination (i.e. on left or right side of street) were poor. Verbal instructions were more useful in giving landmarks.

Driving Data Reduction

All of the vehicle and driver performance measures were collected using the same basic hardware except that the Leica headway sensor was replaced by a Mitsubishi sensor with different performance characteristics. To examine those differences, side-by-side static and dynamic tests of reliability and accuracy were planned as had been conducted for other sensors (Katz, Green, and Fleming, 1995). A variety of scheduling and equipment problems interfered with conducting these comparisons. Review of the headway data revealed that the Mitsubishi sensor reported a viable target ten times more often then the Leica headway sensor (used previously), raising significant questions of the comparability of the data from the two sensors.

For the most part the data reduction process was the same for supplement data as for the original data though a field was added to the output file to indicate the navigation system used. Also, the change in the first destination caused a change in the final section for destination one. For this reason, the final two sections of destination one were removed from the comparison.

Readers are reminded that the PathMaster subjects were not compared to Ali-Scout subjects in the supplement experiment, but to Ali-Scout subjects from the original experiment who were matched by age (all young) and time of day (all rush hour) at which testing took place. Hence, those factors were not included in the analysis. As before, there were two trials, the first with a navigation system and the second with experimenter directions.

As before, all of the dependent measures (straight driving points, stop points, duration, overall mean speed, mean moving speed, standard deviation of moving speed, mean throttle, standard deviation of throttle, mean headway, standard deviation of headway, mean lateral position, standard deviation of lateral position, and standard deviation of steering wheel angle) were examined using ANOVAs. The independent variables included navigation system (Ali-Scout versus PathMaster), sex, destination, trial number, section nested by destination, subject nested by gender and system, system by destination, system by trial number, and system by section nested by destination. The data set consisted of 252 points (9 subjects *14 sections/subject * 2 runs (1 test, 1 baseline)). Except for the headway data (missing for about half of the trials), data from only 7 runs (5 from 1 subject, 2 from another) were missing. Thus, in comparison to the previous experiment, this data set is quite small. Appendix AB gives the complete ANOVA tables for all dependent measures.

To ensure an adequate amount of data was collected, an analysis of the straight driving points and stopped driving points was performed. (See Appendix AD.)

Speed-Related/Longitudinal-Control Measures

Duration

Duration is the time (in seconds) subjects required to drive a section of a road, to a destination, or the entire test route. To compute the destination or trial duration multiply the section mean by the number of sections within a destination or trial.

Both sex and subject nested by sex and system were not found to be significant. (See Figure 54.)

In terms of route-related factors, both destination (p=0.0001) and section within destination (p=0.0001) were found to be significant. Figure 55 shows the mean duration for system by section nested within destination. Section three of destination two is the bottleneck during rush hour traffic which leads to the large mean duration during this section.

Of particular interest in the experiment were navigation interface differences, here found to be significant (p=0.0393). The means for both the Ali-Scout and PathMaster subjects were 112 seconds/section (1568 seconds total) and 95 seconds/section (1330 seconds total), respectively (ignoring the two sections deleted due to a change in destination one). This is roughly a 10 percent difference.

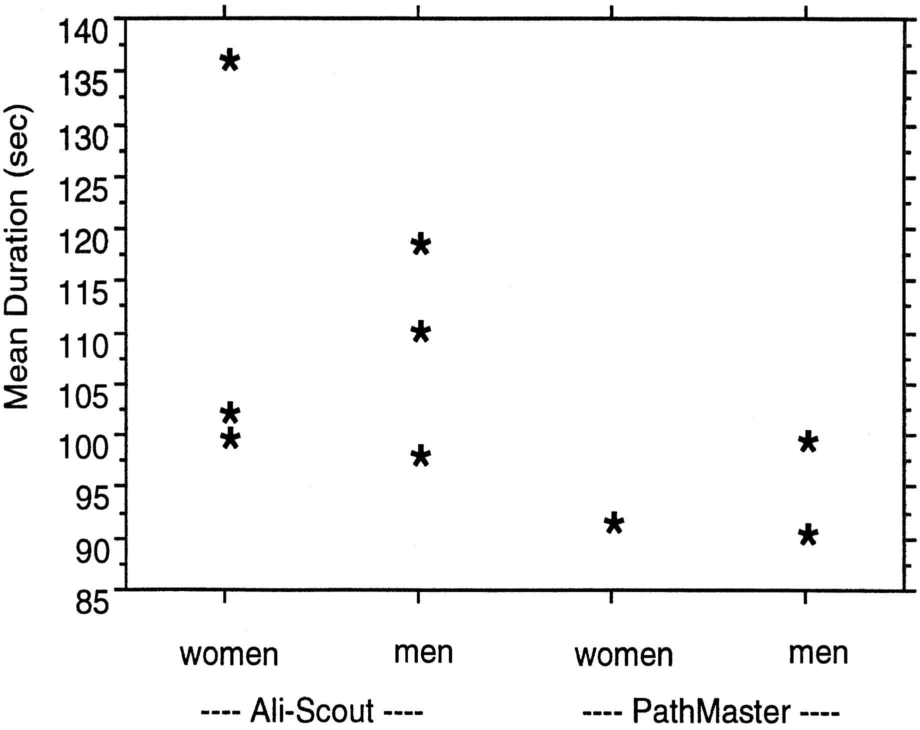


Figure 54. Mean duration by subject.

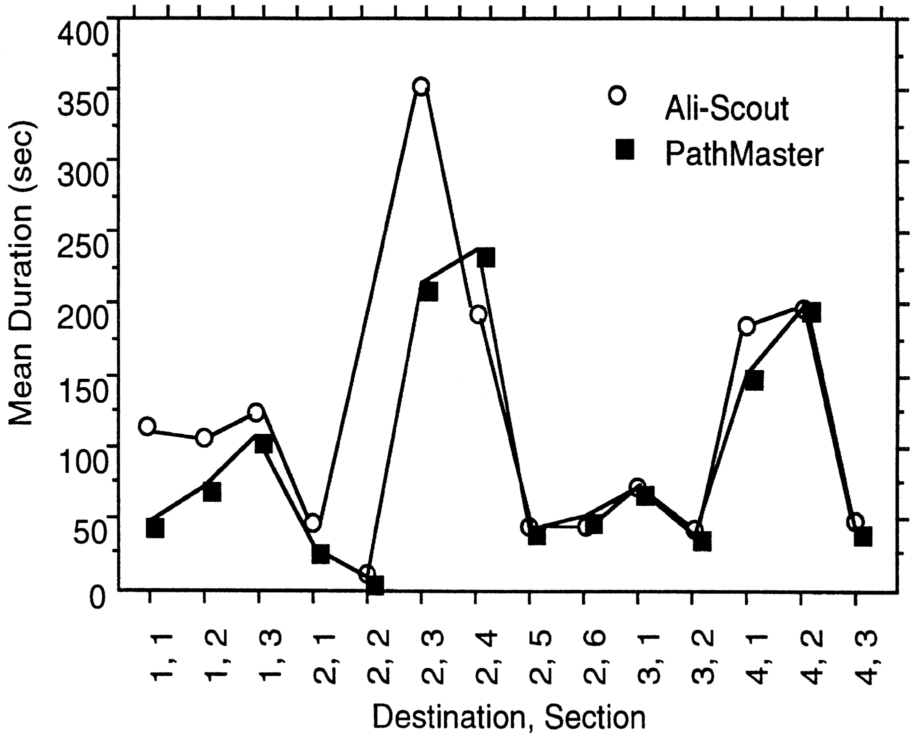


Figure 55. Mean duration by system and section.

In addition, while the effect of trial number was not significant, there was a system by trial number interaction (p=0.0348). Figure 56 shows this interaction. Notice that if the baselines for the two systems are equalized (in theory, they should be the same), differences between the two systems disappear (or even reverse). Readers should keep in mind that the Ali-Scout users were given two trials with the navigation system prior to their baseline trial, therefore, they should be more familiar with the test route.

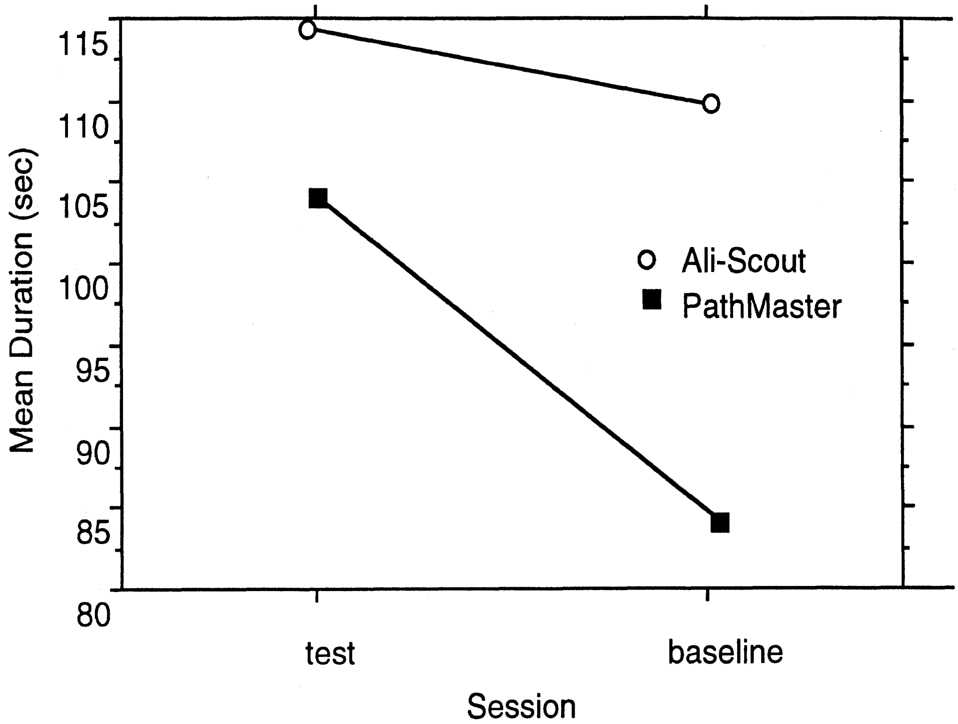


Figure 56. Mean duration by system and trial number.

Overall mean speed

The overall mean speed (measured in mi/hr) includes the speed while the vehicle is in motion, and when it is stopped. Both sex and subject nested by sex and system were not found to be significant, a contrast to the usual result. (See Figure 57.)

Both destination (p=0.0001) and section within destination (p=0.0001) were found to be significant. The mean is highest for destination one because several sections include expressway driving (speed limit 65 mi/hr). Figure 58 shows the mean overall speed for system by section nested by destination. That figure also shows the differences between navigation systems, here found to be significant (p=0.0285). The mean overall speed for both the Ali-Scout and PathMaster subjects were 29.6 mi/hr and 32.3 mi/hr, respectively. Again, readers are reminded this could be a subject sample difference, as subject groups and system differences were confounded.

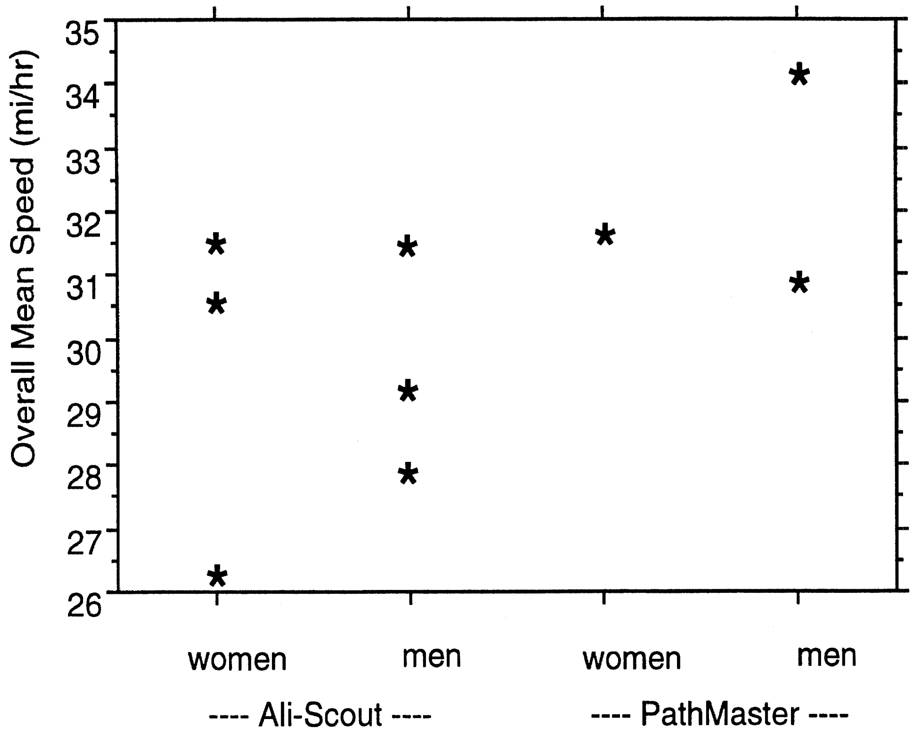


Figure 57. Mean overall speed by subject and system.

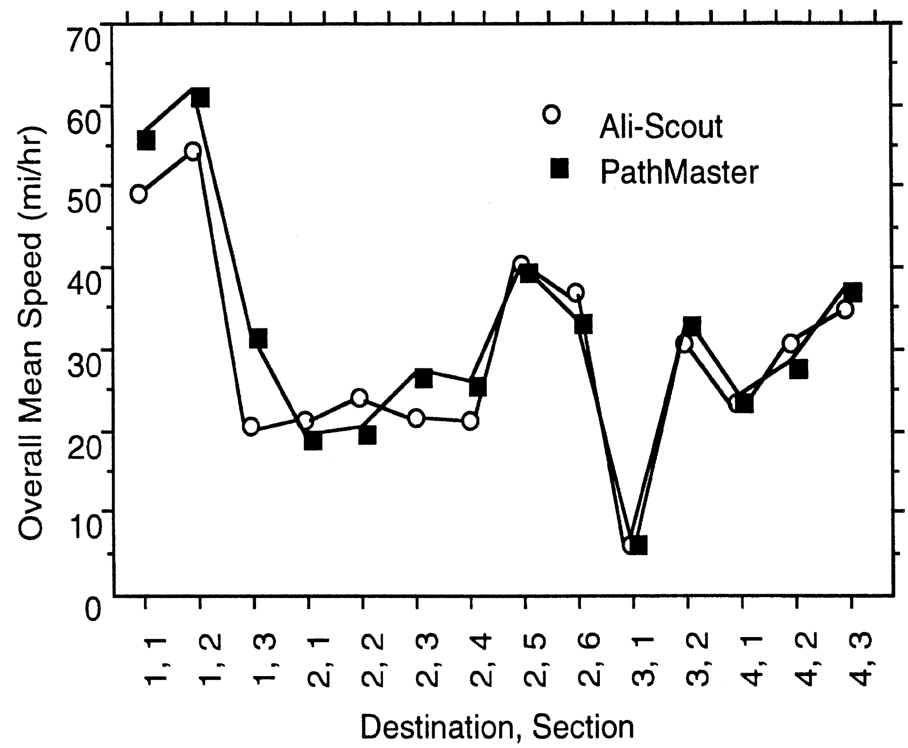


Figure 58. Overall mean speed by section nested within destination.

In addition, trial number was found to be significant (p=0.0128), but not the system by trial interaction (Figure 59). As before, equalizing the baseline trials reverses the difference between interfaces.

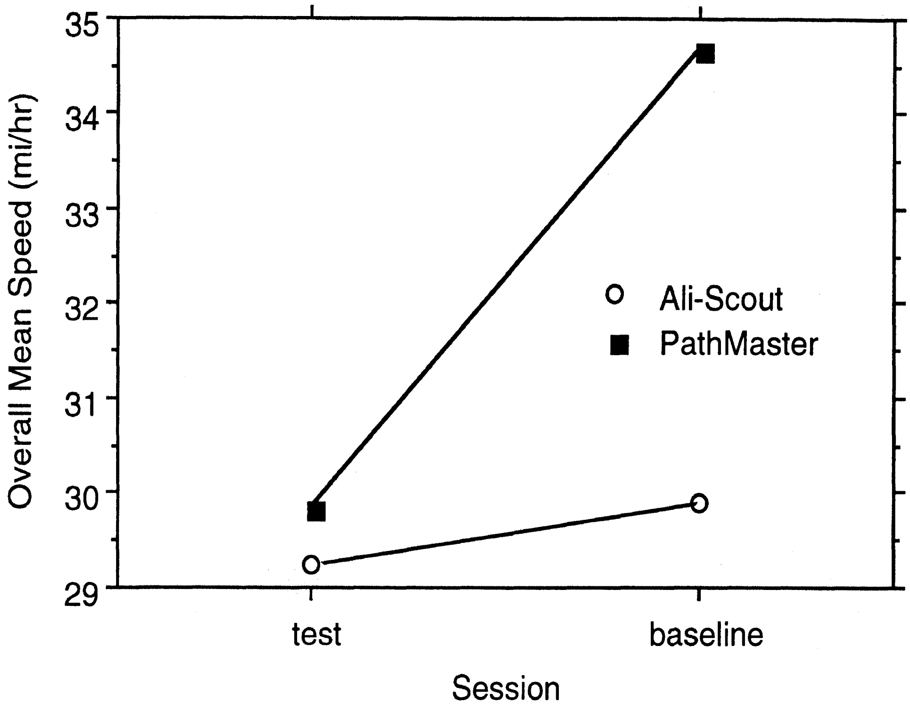


Figure 59. Overall mean speed by system and trial number.

Mean speed while moving

As before, the rationale for exploring mean speed while moving was the overall mean speed included times where the vehicle was stopped due to traffic lights and other factors beyond the control of the navigation system. With respect to mean moving speed sex was not found to be significant, but subjects nested within sex was (p=0.0315). Figure 60 shows both the individual and interface differences.

Both destination (p=0.0001) and section within destination (p=0.0001) were found to be significant. Figure 61 shows the mean moving speed for system by section nested within destination. Both the Ali-Scout and PathMaster follow the same basic pattern across sections. The first two sections of destination one are expressway driving which leads to the high mean moving speed. As suggested by this figure, the differences between interfaces were not significant (p=0.0640), though they were for overall mean speed as described previously. PathMaster subject drove faster (37 versus 35.1 mi/hr).

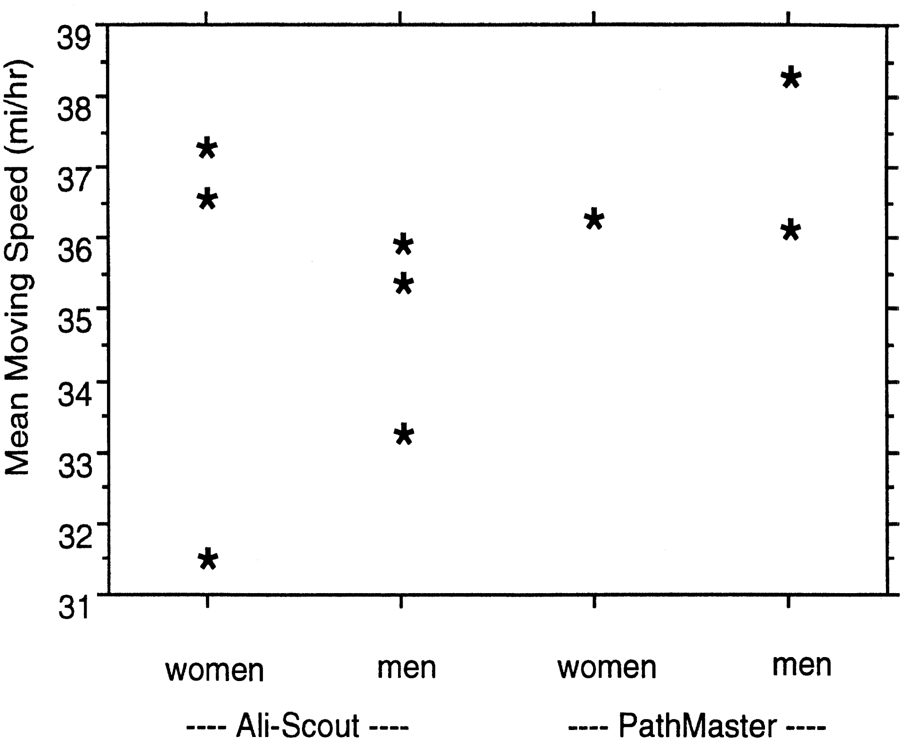


Figure 60. Mean Moving speed by subject and system.

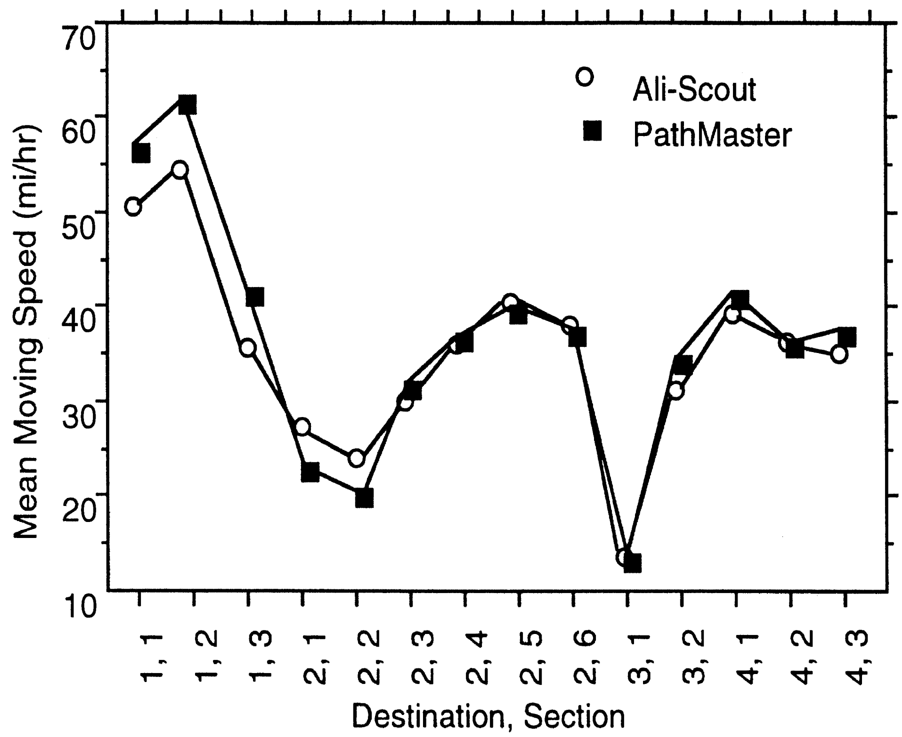


Figure 61. Mean moving speed by system and section.

Consistent with the previous results, trial number was found to be significant (p=0.0035), but there was no system*trial interaction. Figure 62 shows this interaction. Once again, equalizing the baselines reverses the direction of the results.

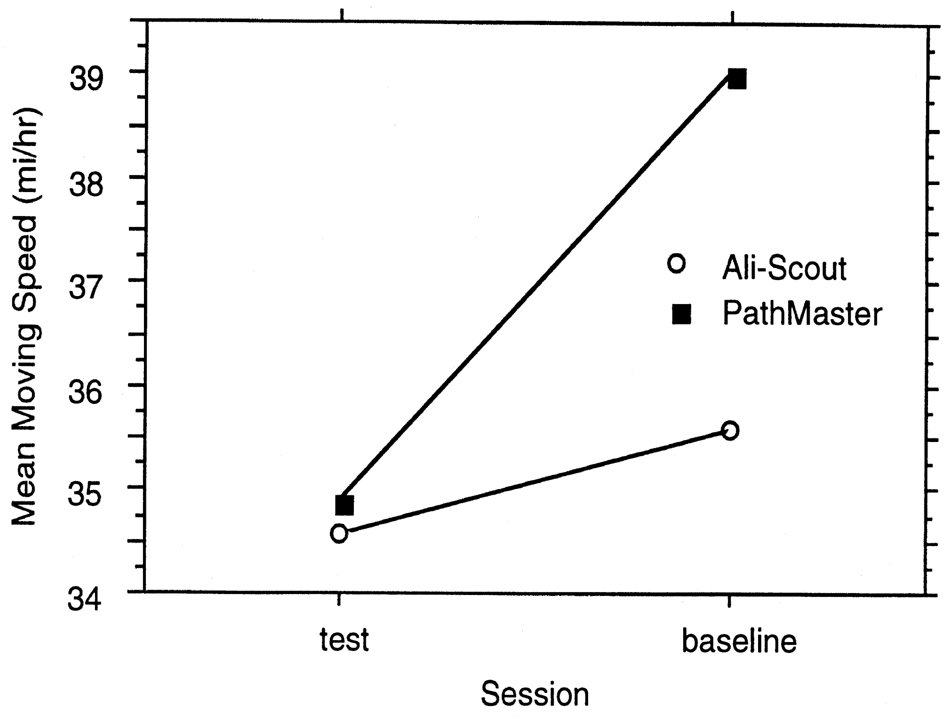


Figure 62. Mean moving speed for system by trial number.

Speed standard deviation (while moving)

In the ANOVA of the moving speed standard deviation, both sex and subject nested by sex were not found to be significant. (See Figure 63.)

Both destination (p=0.0001) and section within destination (p=0.0001) were found to be significant. The large standard deviation for destination two is probably due to the bottleneck found in section three of this destination during rush hour traffic. Figure 64 shows the mean standard deviation of moving speed for system by section nested by destination. In addition, neither trial number nor the interaction of system by trial number were found to be significant. (See Figure 65.) Also not significant were differences due to system, trial, or the system by trial interaction. Generally, the pattern found is that the standard deviation of speed is correlated with the mean speed. However, in this case, the PathMaster has a greater mean speed but a smaller standard deviation of speed. A lower standard deviation is believed to be associated with steadier, safer, and more economical driving.

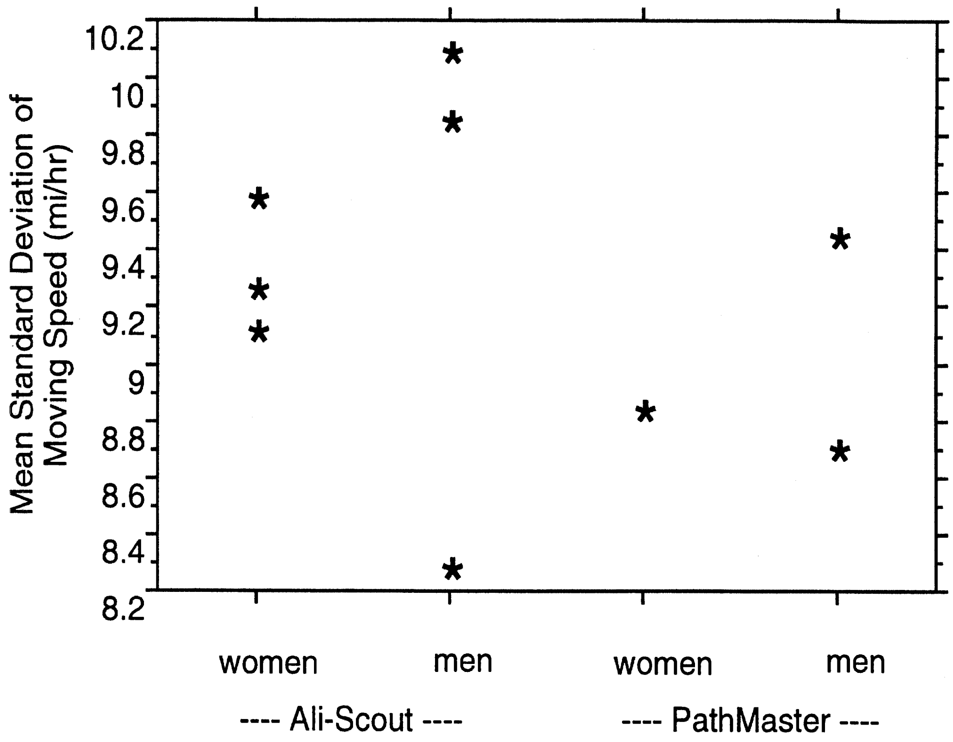


Figure 63. Mean standard deviation of moving speed by subject.

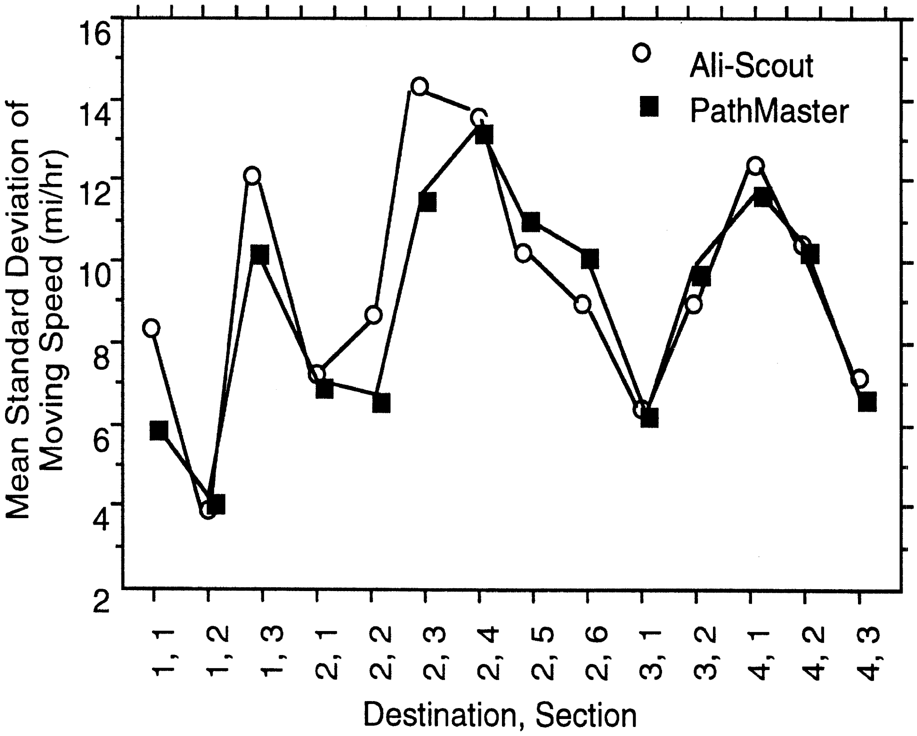


Figure 64. Mean standard deviation of moving speed by section.

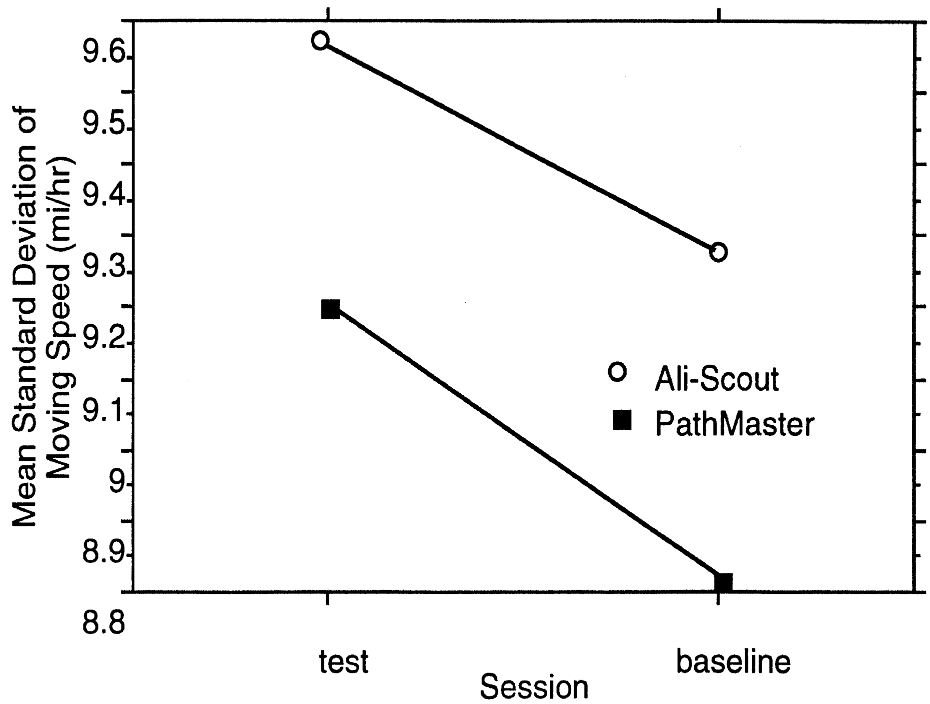


Figure 65. Mean standard deviation of moving speed.

Mean throttle position

With respect to mean throttle position, both sex (p=0.0490) and subject nested within sex and system (p=0.0075) were significant. (See Figure 66.)

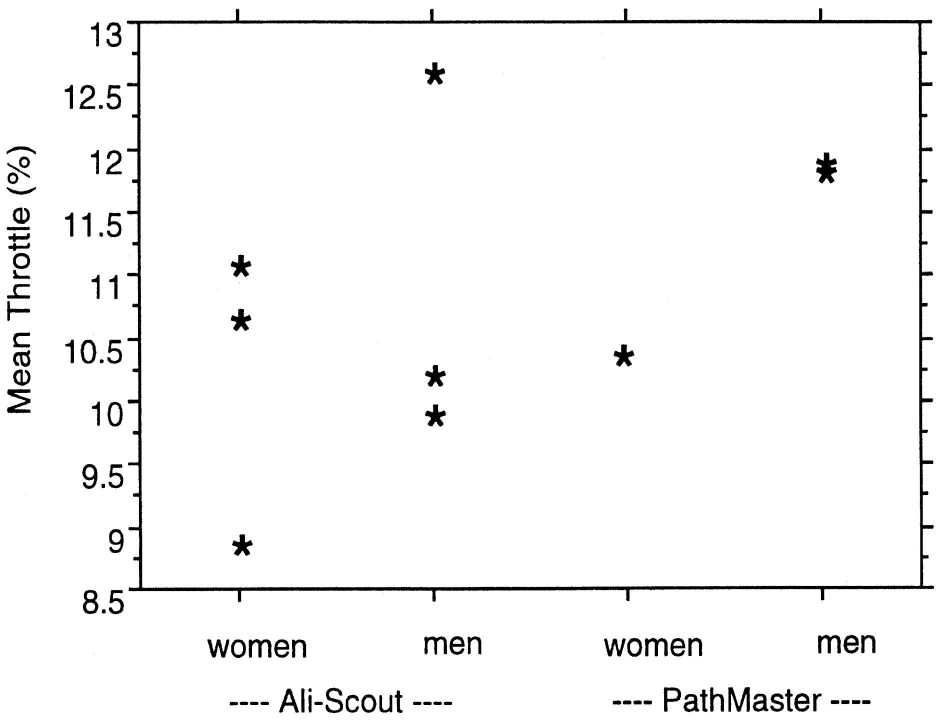


Figure 66. Mean throttle by subject and system.

Both destination (p=0.0001) and section within destination (p=0.0001) were found to be significant. The highest mean (destination one) is found during the destination which includes expressway driving. In addition, Figure 67 shows the mean throttle for system by section nested by destination.

While there were speed differences between systems, the effect of system was not significant for mean throttle position. The mean throttle position was greater for the PathMaster than the Ali-Scout interface (11.4 versus 10.6 percent) in a manner consistent with the speed results. The most likely explanation is that the variability in the throttle data was greater than the speed data (due to traffic), and that variability masked interface differences.

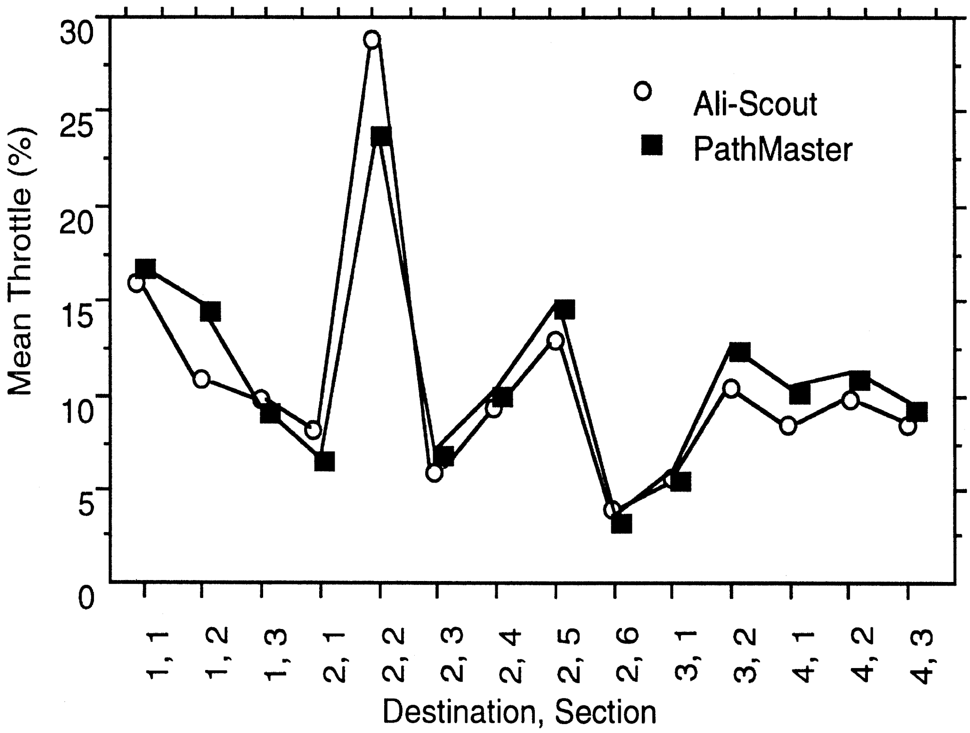


Figure 67. Mean throttle by system and section.

Neither trial number nor the interaction of system by trial number were found to be significant. However, for completeness Figure 68 (the means by system and trial number) is included. Again, notice that if the baselines are equalized, the differences between test trials for the two interface types become minuscule.

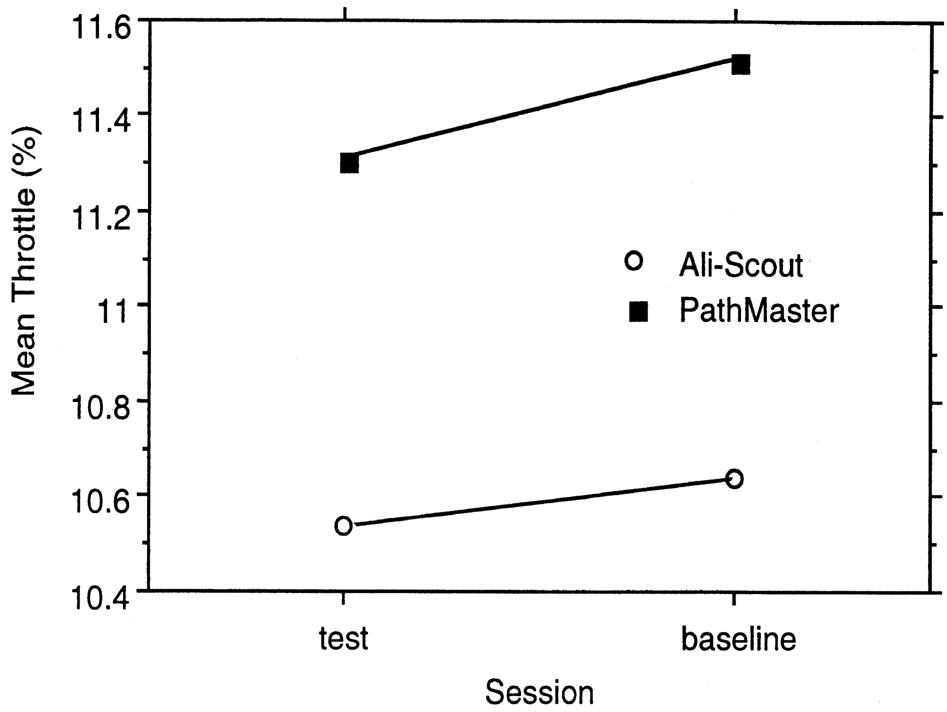


Figure 68. Mean throttle for system by trial.

Standard deviation of throttle position

Consistent with the mean throttle position data, there were significant differences in the standard deviation of throttle position due to sex (p=0.0097) and subject nested within sex and system (p=0.0089). Figure 69 shows those differences.

Also consistent with the mean throttle data, both destination (p=0.0224) and section within destination (p=0.0001) were found to be significant. Figure 70 shows the mean standard deviations for system by section nested within destination. As suggested by the figure, there were significant differences between the two interfaces (p=0.0444). The Ali-Scout users had lower standard deviations (8.1 versus 8.9 percent). The interaction seen during section one of destination one can not be explained. However, in general, the mean and standard deviation are correlated, so higher standard deviations are expected for the Ali-Scout. Alternative explanations are that the PathMaster subjects put more effort into speed maintenance or, depending upon one's perspective, drove more erratically, or responded more quickly to environmental changes such as traffic.

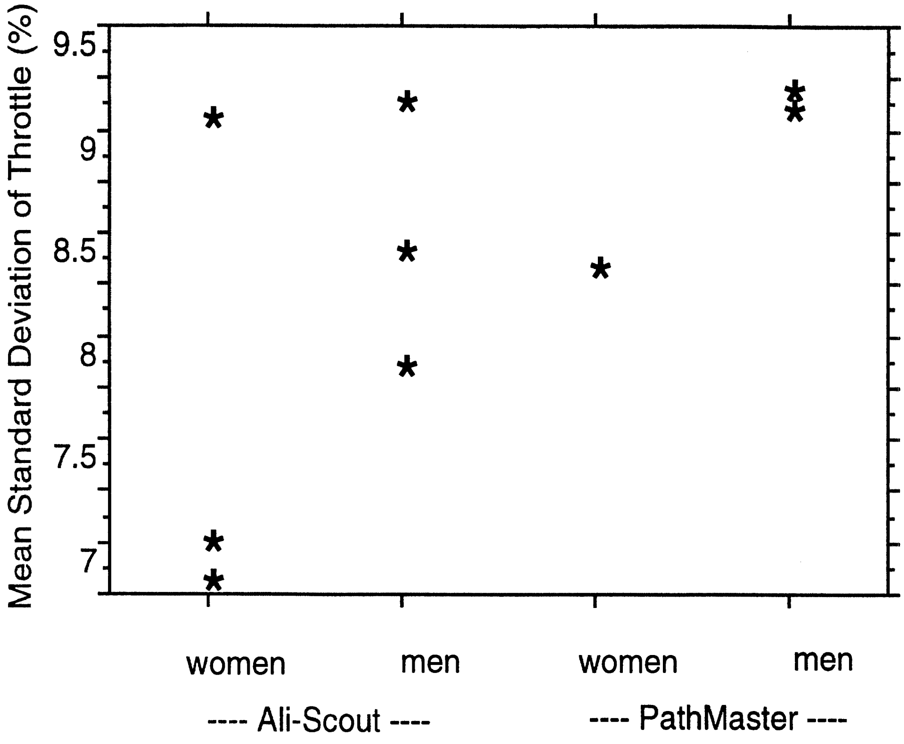


Figure 69. Mean standard deviation of throttle by subject and system.

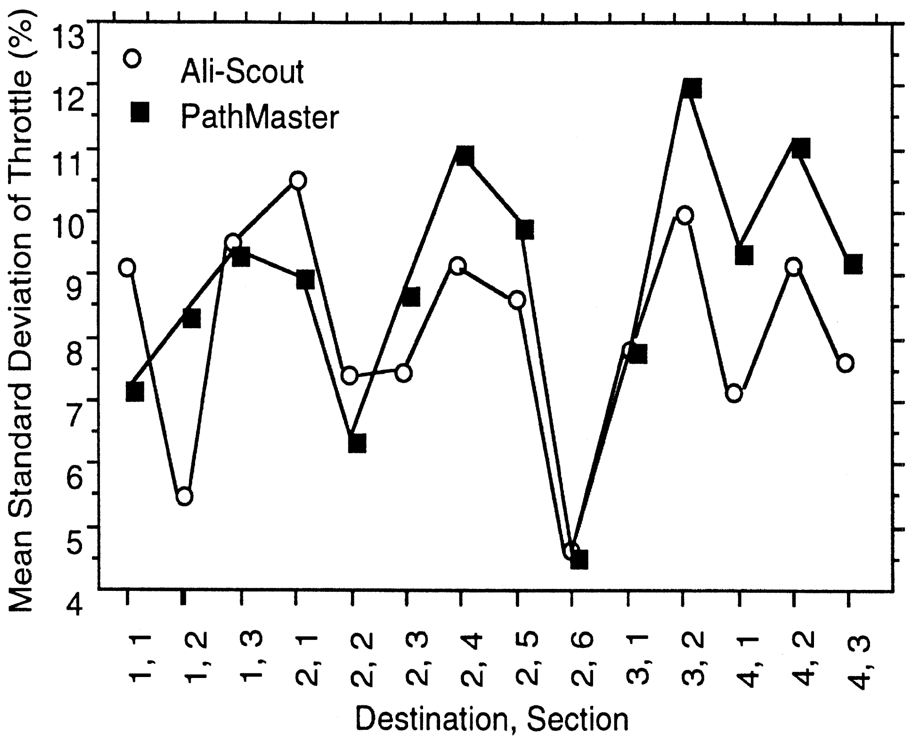


Figure 70. Mean standard deviation of throttle by section.

Neither trial number nor the interaction system by trial number were found to be significant (Figure 71).

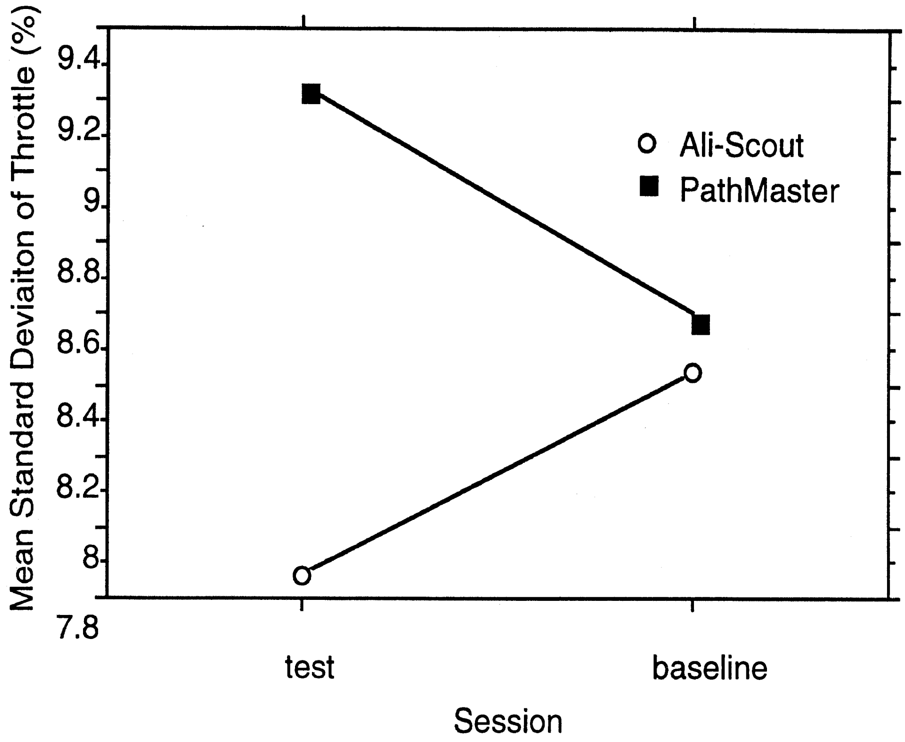


Figure 71. Mean standard deviation by system and trial.

Mean headway

It is important to remind the reader that the headway data from the initial experiment are suspect due to sensor problems and useful data were obtained from only four of the matched Ali-Scout subjects. Headway data is absent for the other two matched Ali-Scout subjects (one male and one female), due to a period of complete headway sensor failure. Changing to a different sensor (using the same technology made by a different manufacturer) solved the reliability problems but led to mismatched data sets.

In the ANOVA of mean headway, sex was not found to be significant, neither was subject nested within sex and system. Figure 72 shows the individual differences. Note that differences between subjects within each group (Ali-Scout, PathMaster) were very small.

Both destination (p=0.0002) and section within destination (p=0.0001) were found to be significant. Figure 73 shows the mean headway for system by section nested by destination. The Ali-Scout data shows almost no variability between sections, a finding that does not make sense.

Differences between navigation interfaces were highly significant (p=0.0001) and large (328 feet for Ali-Scout, 155 feet for PathMaster). This may reflect random variations in traffic or differences in the headway sensors.

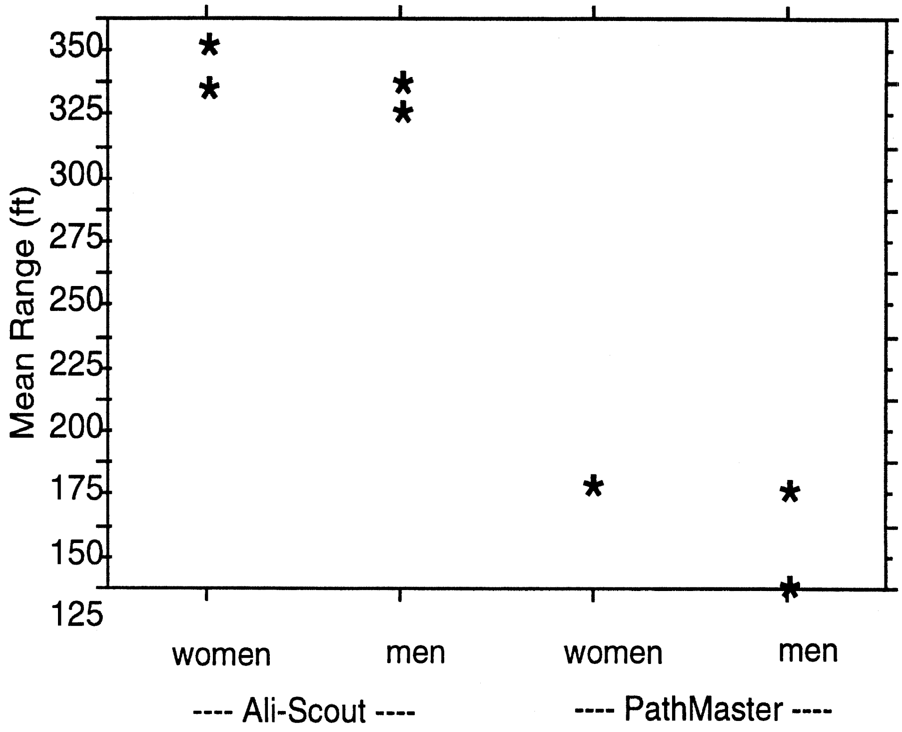


Figure 72. Mean headway by subject.

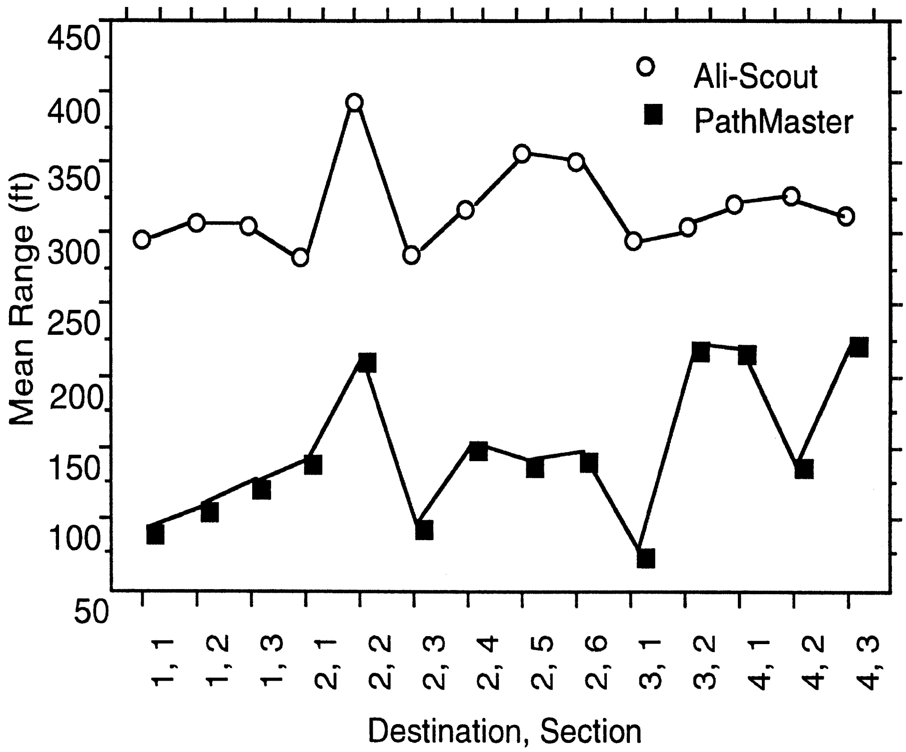


Figure 73. Mean Headway by system and section.

Finally, neither trial number nor the interaction of system with trial were significant. (See Figure 74.) Again, equalizing the baselines removes the differences between test conditions. This difference between systems may be due to the differences between the headway sensors used to collect data. An alternative explanation is that Ali-Scout subjects preferred shorter headways.

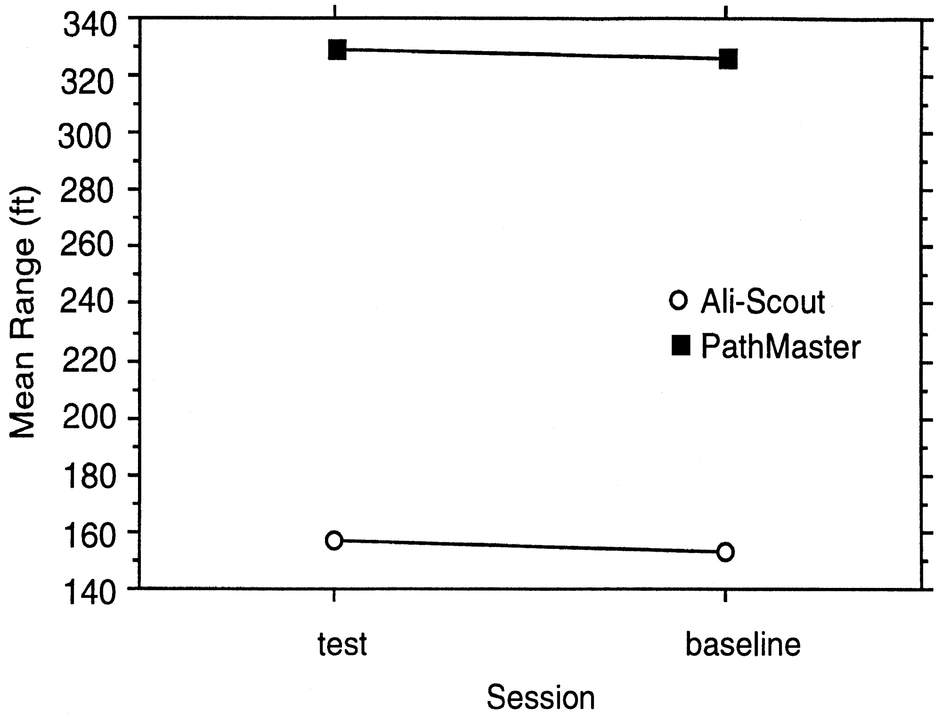


Figure 74. Mean range for system by trial.

Standard deviation of headway

In the ANOVA of standard deviation of headway, neither sex nor subject nested within sex and system were found to be significant. Figure 75 is included to illustrate the distribution of Ali-Scout and PathMaster subjects by sex.

Destination (p=0.0001) as well as section nested within destination (p=0.0001) were found to be significant. In addition, Figure 76 shows the mean standard deviation of headway for system by section nested by destination. There do not seem to be any consistent patterns due to road section as expected. This may be due to differences in headway sensors or subject groups. Notice, for example that section two of destination two showed large headway but little variance for PathMaster subjects, this is in contrast to Ali-Scout subjects.

Navigation system differences were found to be significant (p=0.0001). The means for both the Ali-Scout and PathMaster subjects were 120 ft and 81 ft respectively, large differences in variability. This may be a result of the differences between headway sensors or subject groups.

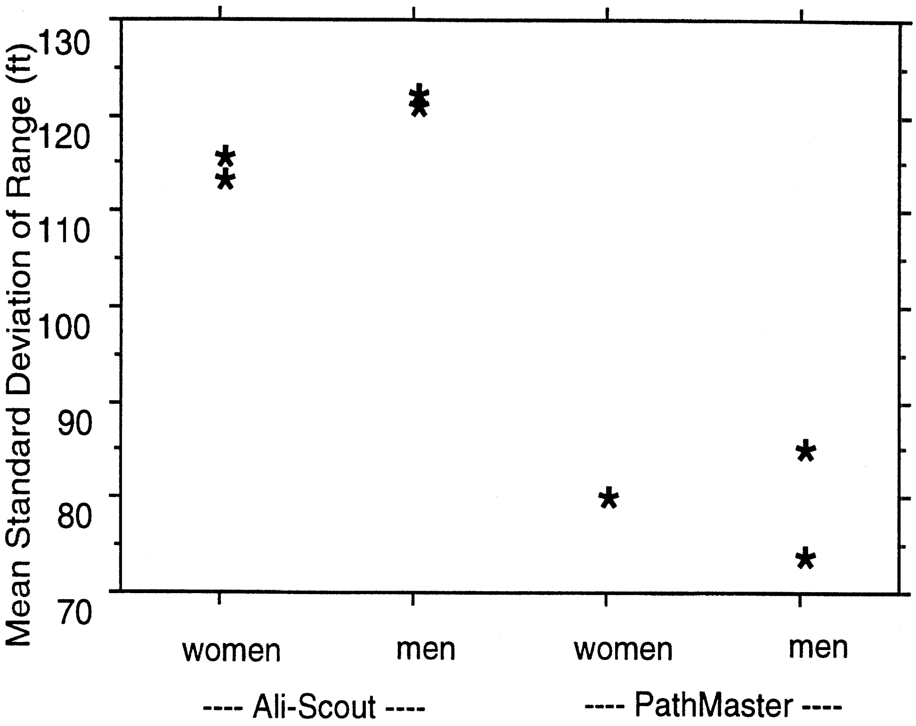


Figure 75. Mean standard deviation of headway by subject.

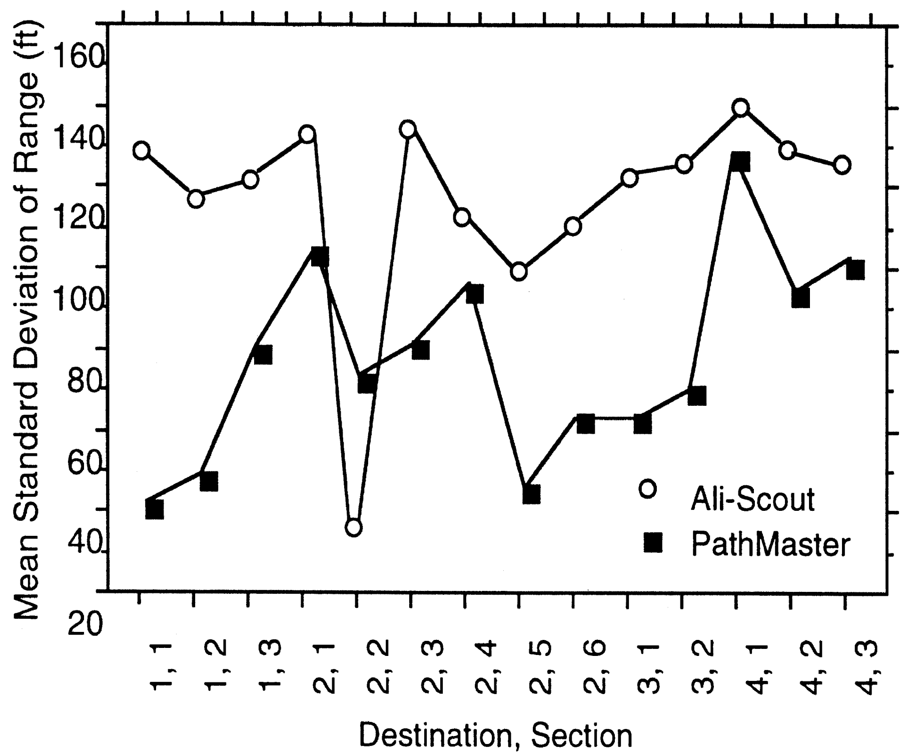


Figure 76. Mean standard deviation of headway by system and section.

The ANOVA also indicated no significant differences due to trial and the trial by system interaction as shown in Figure 77. As before, equalizing the baselines shrinks the differences between interfaces considerably.

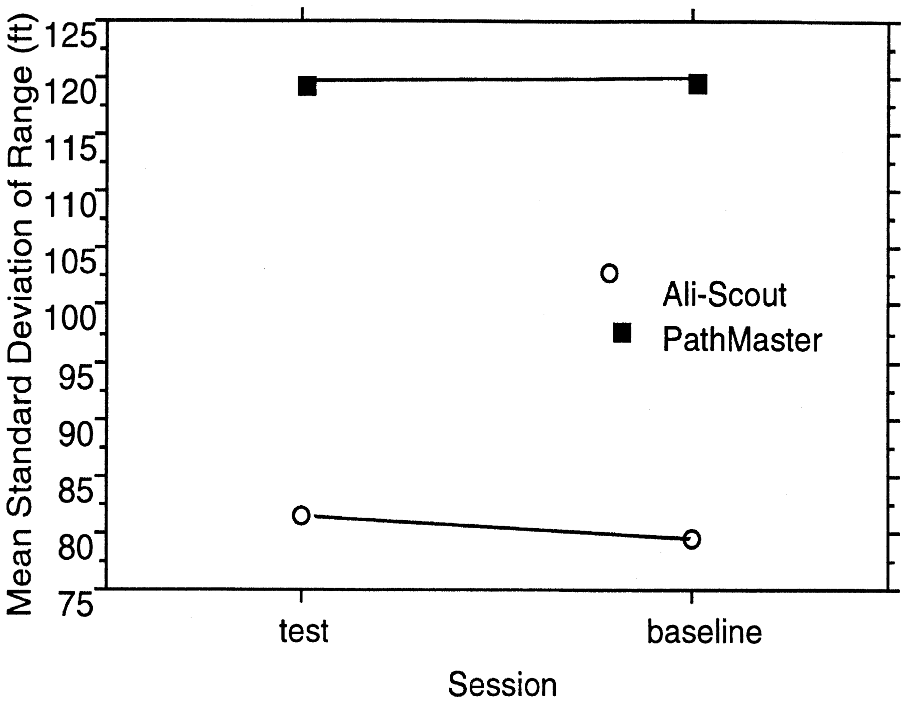


Figure 77. Mean standard deviation of headway by system and trial.

Lateral Measures

Mean lateral position

In the ANOVA of mean lateral position, gender was not found to be significant. Subject nested by sex and system, on the other hand, was found to be significant (p=0.0017). Figure 78 shows the distribution of Ali-Scout and PathMaster subjects by sex.

Consistent with the other measures, destination (p=0.0001) and section nested within destination were significant (p=0.0098). Figure 79 shows the means for system by section nested within destination.

Interestingly, navigation system was also found to be significant (p=0.0001). Ali-Scout subjects position themselves to the left of center (mean=-0.298 feet), and PathMaster subjects to the right (mean=0.244 feet). The authors cannot explain this difference.

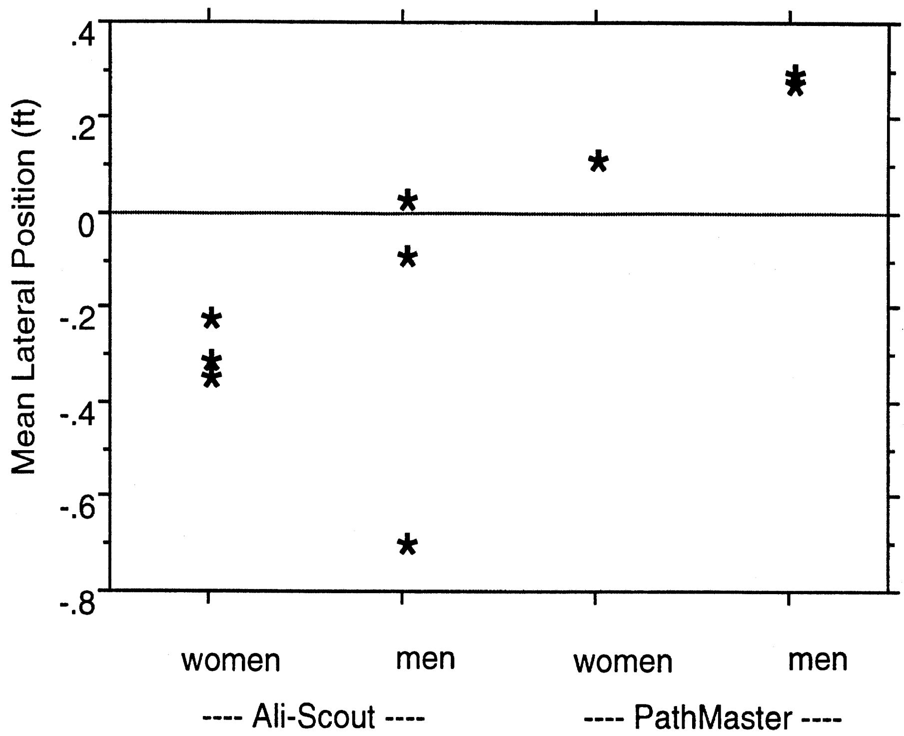


Figure 78. Mean lateral position for subjects by gender and system

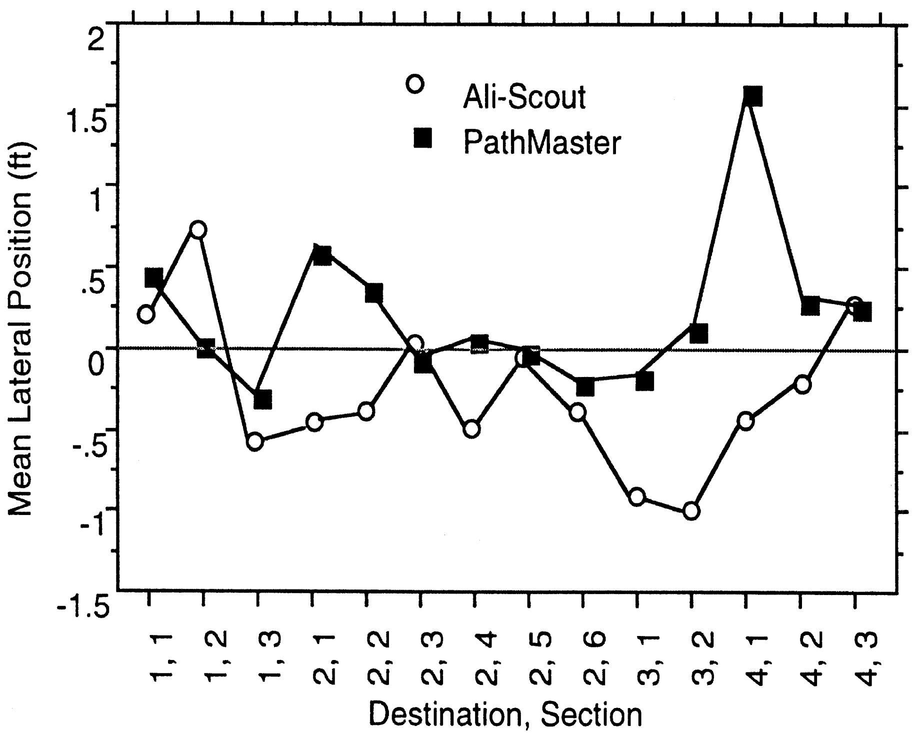


Figure 79. Mean lateral position by system and section.

Shown in Figure 80 are trial differences. The effects of trial and trial by system were not statistically significant. Equalizing the baselines removes most of the between system difference.

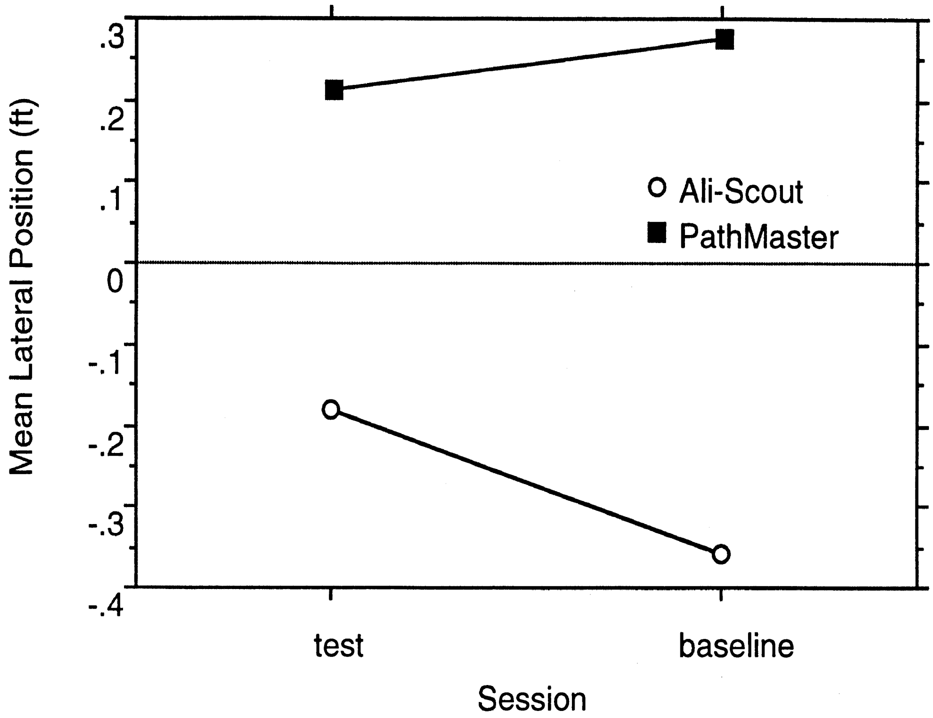


Figure 80. Mean lateral position by system and trial.

Standard deviation of lateral position

With regards to standard deviation of lateral position, both sex and subject nested by sex and system were not found to be significant. (See Figure 81.)

Both destination (p=0.0001) and section within destination (p=0.0035) were found to be significant. Figure 82 shows the mean standard deviations for system by section nested by destination.

Differences in the standard deviation of lateral position due to navigation system (p=0.0001) were statistically significant. The means for both the Ali-Scout and PathMaster subjects were 1.0 ft, and 0.4 ft respectively, a major difference. This may suggest that the Ali-Scout system is demanding more attention and therefore is less safe.

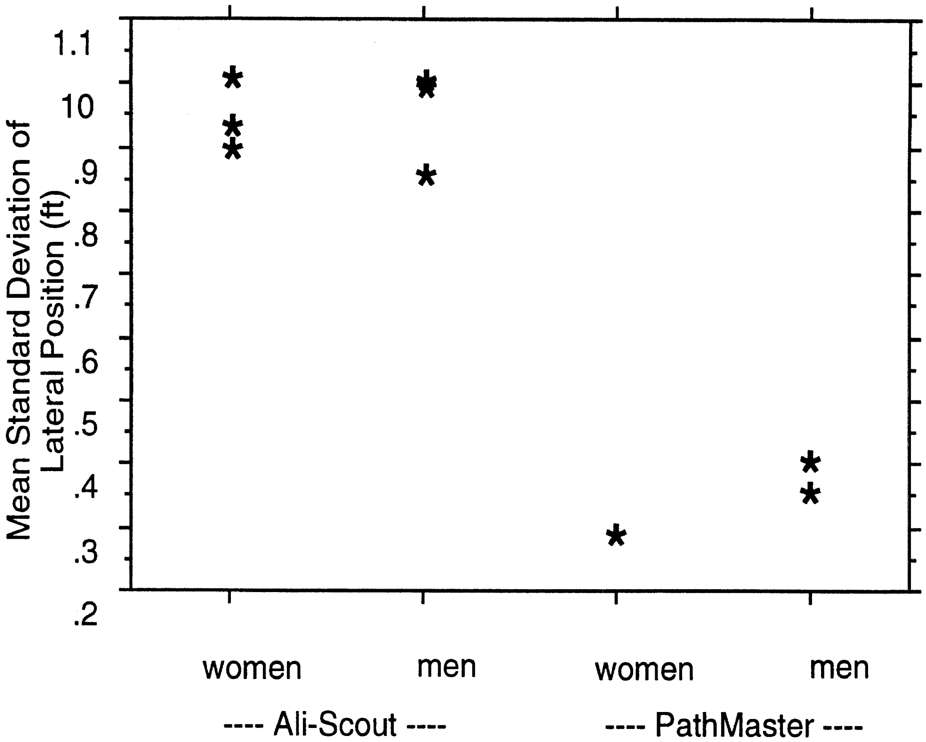


Figure 81. Mean standard deviation of lateral position by subject and system.

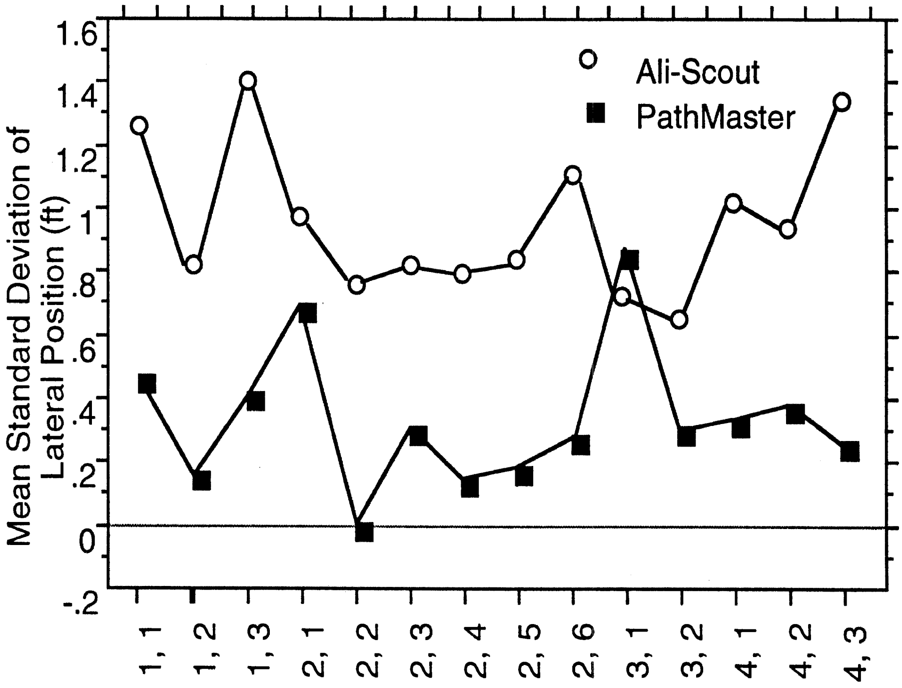


Figure 82. Mean standard deviation of lateral position by system and section.

Neither trial, nor the interaction between system by trial number was found to be significant. If one were to equalize the systems using the baseline data (whose values should be the same), the differences in standard deviation of lane position (due to interface) would be negligible. See Figure 83.

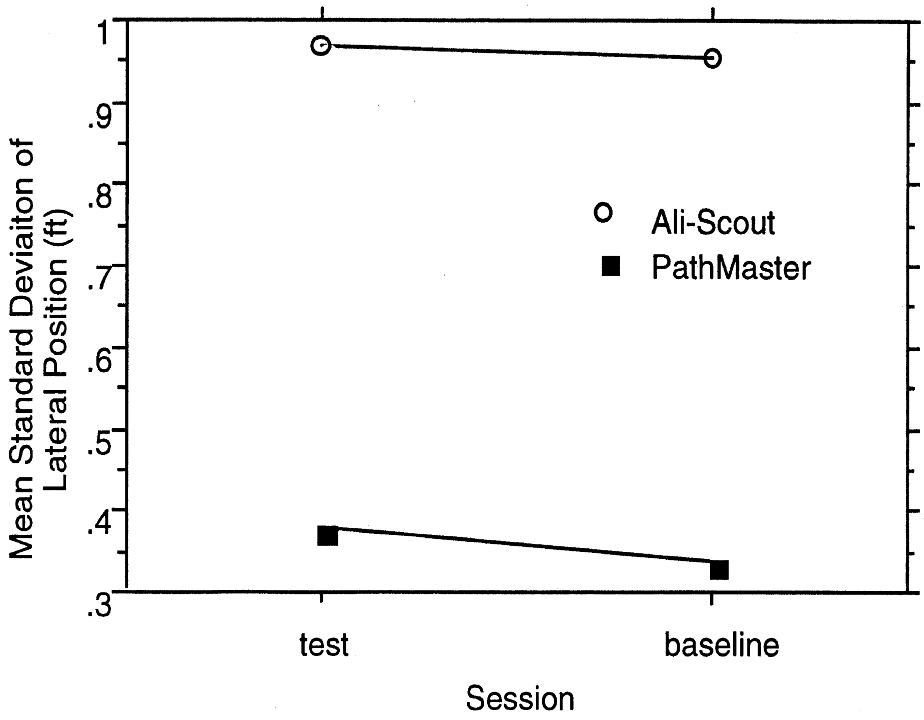


Figure 83. Mean standard deviation of lateral position by trial

Standard deviation of steering wheel angle

In the ANOVA of the standard deviation of steering wheel position, both gender and subject nested by gender and system were not found to be significant. Figure 84 shows the subject means.

Both destination (p=0.0001) and section within destination (p=0.0001) were found to be significant with respect to standard deviation of steering wheel angle. The large variance found in destination three is due to the short distance and relative number of turns performed. Figure 85 shows the mean standard deviation for system by section nested by destination.

While there were differences in lane position variability due to system, there were not statistically significant differences in standard deviation of steering wheel angle. However, the standard deviation was greater for the Ali-Scout (29 degrees vs. 27 degrees).

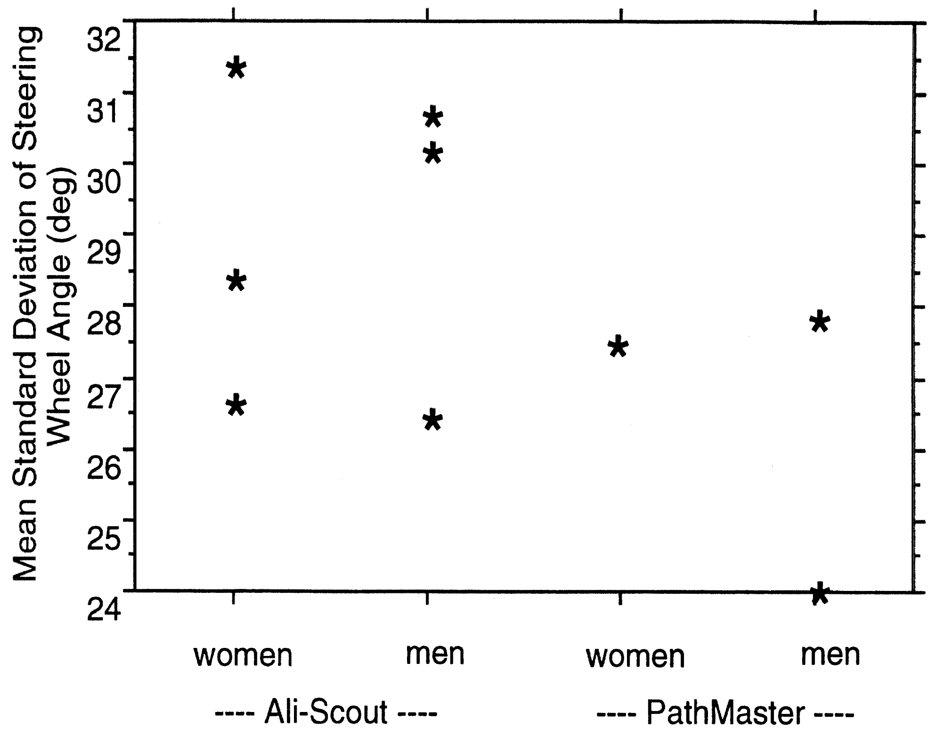


Figure 84. Mean standard deviation of steering wheel angle by subject and system.

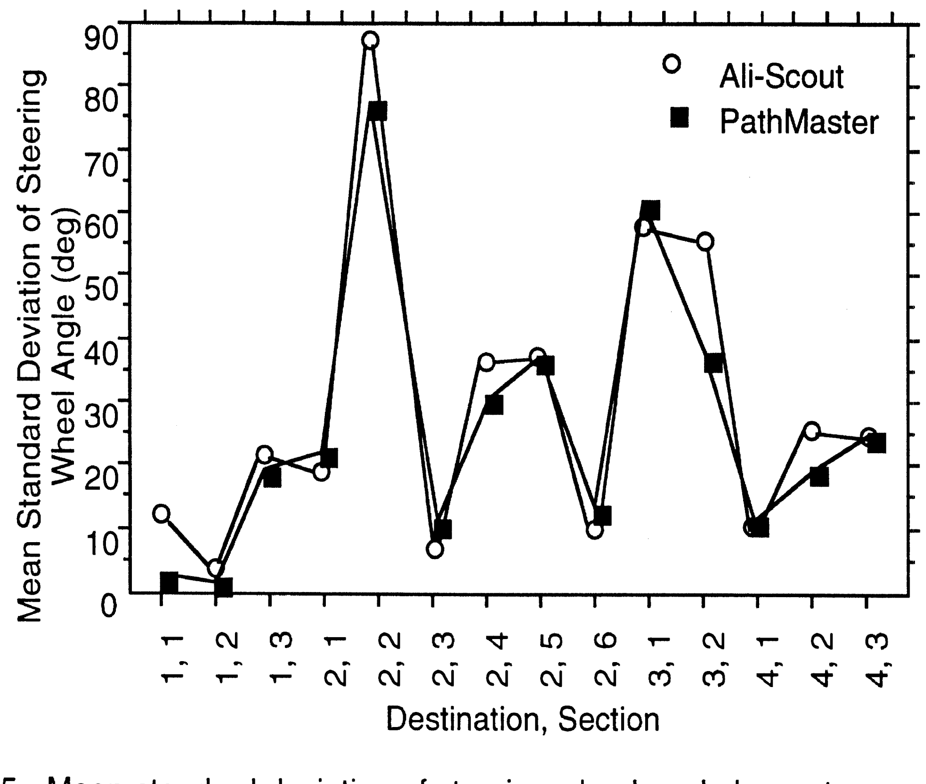


Figure 85. Mean standard deviation of steering wheel angle by system and section.

Although neither trial nor the interaction system by trial number were found to be significant, Figure 86 shows the interaction for the sake of completeness. Using the baseline data to equalize the two groups minimizes interface differences.

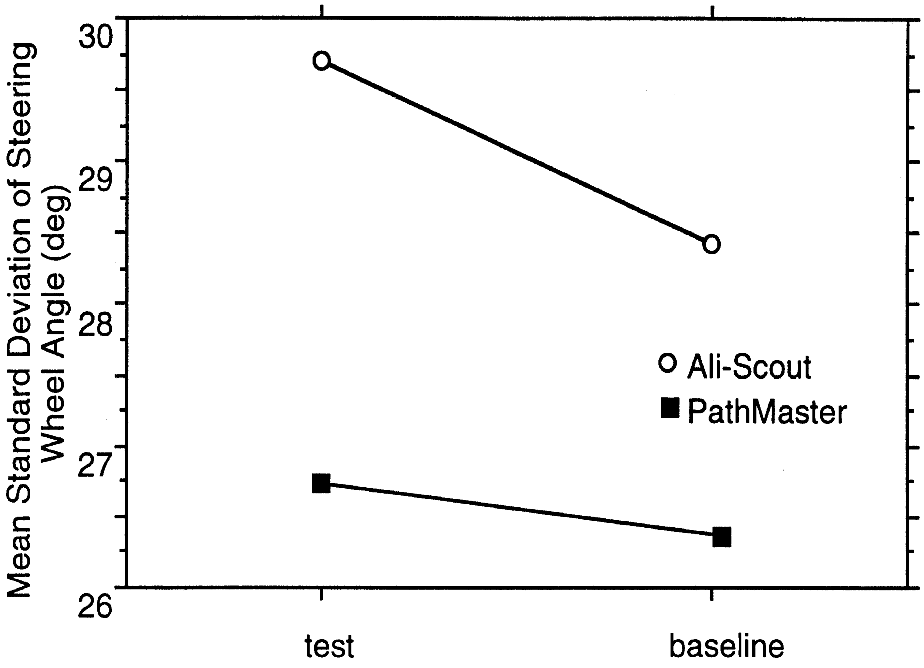


Figure 87. Mean standard deviation of steering wheel angle.

Summary of ANOVAs

To facilitate understanding of the results, summary tables are given listing p-values, significant or otherwise, for all driving behavior, longitudinal control, and lateral control measures. (See Tables 51, 52, and 53.) Statistically significant values are shown in bold. From a practical perspective, there were concerns regarding the reliability of the headway data. The problems encountered may reflect the specific difficulties with the particular sensor utilized, not general problems with sensitivity of those measures. Over the time period of this project, improvements in technology should have eliminated the concerns over sensor reliability.

Table 25. Compiled p-values for sample sizes.

Factor	Dependent Variable	
	Mean Number of Straight Points	Mean Number of Stopped Points
Sex	0.6171	0.7226
Subject (Sex, System)	0.2657	0.3482
Destination	**0.0001**	**0.0116**
Section (Destination)	**0.0001**	**0.0001**
System	0.1023	0.1201
Trial	0.2181	0.2011
System * Section (Destination)	0.0064	0.4396
System * Trial	0.6625	0.3365

Table 26. Compiled p-values for longitudinal control.

Factor	Dependent Variable							
	Duration	Mean Moving Speed	Standard Deviation of Moving Speed	Overall Mean Speed	Mean Throttle Position	Standard Deviation of Throttle Position	Mean Headway	Standard Deviation of Headway
Sex	0.8035	0.6596	0.8824	0.6566	**0.0490**	**0.0097**	0.1163	0.3372
Subject (Sex, System)	0.2567	**0.0315**	0.1427	0.1436	**0.0075**	**0.0089**	0.0868	0.5412
Destination	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0316**	**0.0002**	**0.0001**
Section (Destination)	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0001**
System	**0.0393**	0.0640	0.2197	**0.0285**	0.2011	**0.0444**	**0.0001**	**0.0001**
Trial	0.1629	**0.0035**	0.3681	**0.0128**	0.6283	0.7550	0.9446	0.5830
System * Section (Destination)	**0.0348**	0.4420	0.5214	0.3013	0.1915	0.1689	**0.0033**	**0.0001**
System * Trial	0.3521	0.1151	0.8421	0.0793	0.9735	0.1251	0.7473	0.9163

Table 27 Compiled p-values for lateral control.

Factor	Dependent Variable		
	Mean Lateral Position	Standard Deviation of Lateral Position	Standard Deviation of Steering Wheel Angle
Sex	0.2719	0.2573	0.0565
Subject (Sex, System)	**0.0017**	0.5141	0.7268
Destination	**0.0001**	**0.0035**	**0.0001**
Section (Destination)	**0.0098**	**0.0001**	**0.0001**
System	**0.0001**	**0.0001**	**0.0374**
Trial	0.5922	0.5660	0.7740
System * Section (Destination)	**0.0001**	**0.0001**	0.4548
System * Trial	0.2181	0.7985	0.2408

If the longitudinal control measures, trip duration overall mean speed, and the standard deviation of throttle position were all significantly affected by the interface used (though as has been repeatedly noted, these could be group differences). Of the lateral position measures, mean lateral position, the standard deviation of lateral position, and to a lesser degree, the standard deviation of steering wheel angle were all significantly affected by the interface used. The significance levels associated with lateral control measures were much greater than those for longitudinal control. Further, there was a tendency for output measures (standard deviation of lateral position) to be more sensitive than input measures (standard deviation of steering wheel angle). Further, lateral control measures tended to be less affected by subject-related factors (sex, individual differences) than longitudinal control measures.

CONCLUSIONS

How Well Did People Drive with the Ali-Scout and the PathMaster?

(1) What were typical values for driving performance and behavior while using the Ali-Scout interface? (2) How did those values change with driver age, sex, time of day, traffic, and experience with the system?

Independent variables in these two experiments fall into three categories: (1) those pertaining to test route (destination, section nested within destination, time of day), driver factors (sex, age, subject nested within sex and age), and interface design differences (either compared directly or as trial effects). Each of these groups of measures is discussed separately in the section that follows. Depending on the dependent measure, the largest source of variance was test route differences, followed by individual differences.

Test route characteristics

Test route characteristics include those related to the route itself and those relating to when the route is traveled. Because each destination within the test route had differing characteristics (speed limit, number of lanes, traffic density, number of stop lights, length, etc.), differences due to destination and sections were consistently found to be significant. For instance, destination three was the shortest destination in distance traveled and, therefore, produced the shortest mean duration, and the lowest mean moving speed. Destination two, on the other hand included several stop lights and produced the highest traffic density during rush hour. Thus, destination two had the greatest standard deviation in speed.

Each destination was also divided into sections, based on intersections where road characteristics changed and also on the mode in which the Ali-Scout was operating. Variations among sections due to road characteristics and traffic were at least as great as those between destinations, and consequently, section effects were consistently significant. For instance, the longest section of the test route (section 3, destination 2), which also happened to consist of a bottleneck where two lanes merge into one during rush hour traffic, had the longest duration, the highest standard deviation of speed, throttle position, and headway. The section of the test route with the highest speed limit (expressway driving), on the other hand, had the greatest mean speed and the smallest standard deviation of speed.

While differences in roads are interesting, those differences were not the focus of this experiment. It is uncertain how many of the differences found between roads are unique to the roads driven in this project.

Time of Day

In examining navigation systems, an important question is if the time of day affects the outcome of navigation experiments, and if it does, what time or time periods should be examined. Differences due to when testing occurred were less than effects due to the roads driven. The experiment was run at three different times: afternoon, rush hour, and night. The most important difference between the three times was traffic density. Differences in lighting levels (day versus night) did not seem to be a factor. The night sessions had the least amount of traffic, followed by the afternoon session, with rush hour being the heaviest traffic session. Therefore, the data provided by different time sessions indicates how well people drive under differing traffic conditions. Differences were found between session time and mean duration, mean moving speed, standard deviation of moving speed, standard deviation of throttle position, mean headway, and standard deviation of lateral position.

First of all, the mean session duration (total driving time) reflects the differences due to traffic. Means for afternoon, rush hour, and night were 22.7 minutes, 27.6 minutes, and 20.6 minutes respectively, roughly a 25 percent difference. As expected, the more traffic that was present, the longer trips took.

In this case, the primary effect of traffic was to cause participants to drive more slowly. The mean moving speed was 36.1 mi/hr for the afternoon session (moderate traffic), 35.0 mi/hr during rush hour (heavy traffic), and 35.7 mi/hr at night session (lightest traffic), a small but statistically significant difference. In addition to traffic, driving speed was also affected by visibility, poorest at night. This is one of the few instances where lighting was more important than traffic (night, light traffic conditions had a smaller mean moving speed than afternoon, moderate traffic conditions). Generally, the greater the mean moving speed, the greater the standard deviation of moving speed as was the case here (8.5 mi/hr for the afternoon, 8.9 for the rush hour, and 8.2 mi/hr at night). Notice how the stop and go nature of rush hour traffic elevated the standard deviation of moving speed. Since throttle position is the signal to control speed, one would expect the order of conditions for the standard deviation of throttle to match those for speed. This was the case (7.2 percent, 7.7 percent, and 6.8 percent for afternoon, rush hour and night sessions respectively). Note that the difference across conditions was less than 1 percent, suggesting the need for a high degree of accuracy in measuring this signal.

When a target was within range, the mean headway for the rush hour, afternoon, and night drivers was 82.7, 87.2 ft, and 89.8 ft respectively. (Cases where the lead vehicle was out of range were ignored.) With less traffic, there were fewer cars on the road, so the spacing between cars (headway) increased.

While there have been a number of studies in which lane position has been assessed, there has been little work on day-night differences. Here, the standard deviations of lane position for the daytime sessions (afternoon, rush hour) were identical (0.97 ft). At night, it was much less (0.73 ft). One would think that lane position maintenance would be poorer at night because it is more difficult to see.

Thus, greater traffic volume produced longer trip durations, lower speeds, smaller headways, and more variance in measures. This is reflected in the greater standard deviations for moving speed, throttle, and lane positions during rush hour sessions.

Individual differences

In most human factors experiments, individual differences are often the largest single source of variance. For example, there was a 50 to 100 percent difference between the fastest and slowest subject's total duration within each gender/age group category. While individual and time-of-day differences were partially confounded, individual differences were nonetheless considerable. Subject differences were primarily age-related and individual differences within age groups. Sex differences, while sometimes significant, were relatively minor.

Readers should recall that an equal number of drivers (balanced by sex) were tested from three age groups: young (19-30), middle-aged (40-55), and older (65-79). Age-related differences were found in mean moving speed, standard deviation of moving speed, mean throttle position, standard deviation of headway, and standard deviation of lateral position. Differences in driving speed were consistent with those typically found, young and middle-aged drivers had roughly the same mean moving speed (36.2 mi/hr and 36.0 mi/hr, respectively), while older individuals drove about 4 percent slower (34.6 mi/hr). Throttle differences were consistent with these results. As in other cases, speed variance was correlated with speed, so the variance was less for older drivers (means of 8.7 mi/hr, 8.6 mi/hr, and 8.2 mi/hr for young, middle-aged, and older drivers respectively). One interpretation of this result is that older drivers were more cautious.

In addition, differences in both mean and standard deviation of headway between age were found. Mean headway for young subjects was 96.5 ft, the mean for middle-aged drivers was 81.8 ft, and the mean for older drivers was 80.5 ft. Older subjects had the smallest mean headway, a finding in conflict with the proposition that older drivers are more cautious. However, the mean standard deviation of headway for young, middle-aged, and older subjects was 37.8 ft, 34.7 ft, and 35.2 ft respectively. Young subjects exhibit the greatest variability in headway, consistent with a more erratic driving pattern.

Clearly, the classification of drivers into three distinct categories is consistent with the results of this experiment. Younger drivers drove faster, and had more headway and speed variability than older drivers. Middle-aged driver performance was in between that of young and older drivers, though often differences between the young and middle-aged drivers were small. This supports the use of just two age groups (young, old) when resources are limited.

Interface design differences - Ali-Scout versus baseline

The focus of this project was on interface design differences. In this project, differences between Ali-Scout and the baseline experimenter verbal guidance occurred across trials (Ali-Scout 1, Ali-Scout 2, baseline). Session 2 was 1 week after the first session. Differences due to Ali-Scout mode (autonomous versus guided) were apparent within sessions but not between sections.

Experience with the Ali-Scout interface reduced trip durations, but never to the level of experimenter guidance. Times for the three trials were 24.0 minutes (initial exposure to Ali-Scout), 24.3 minutes (second exposure to Ali-Scout), and 22.6 minutes (experimenter guidance). This suggests that the unit is learned quickly, but there are still opportunities for reducing travel time further (by about 6 percent). In contrast to the trip duration data, subjects actually drove faster for the second Ali-Scout trial than the first (35.4 mi/hr versus 34.8 mi/hr), a 2 percent difference. When given experimenter guidance (trial 3), subjects' speed increased an additional 3 percent to 36.6 mi/hr. Thus, the benefits of guidance on reduced trip time are on the order of a few percent.

The differences in speed were consistent with the mean throttle data, with means of 8.8, 9.1, and 9.2 percent for the 3 trials. The standard deviations of throttle positions were correlated with their means (6.8, 7.3, and 7.6 percent respectively), although the differences in the standard deviations were quite small. Basically, as subjects became more familiar with the route, they drove more aggressively, increasing both the mean throttle, speed, and the standard deviation of both.

The theory that familiarity leads to more aggressive driving was also reflected in the headway data, with headways decreasing across trials (88.6 ft, 86.5 ft, and 83.8 ft respectively) as drivers became more familiar with the route. These differences are not large. Consistent with the mean-standard deviation correlations reported earlier, the standard deviations of headway were correlated with their means (36.5 ft, 35.8 ft, and 35.2 ft respectively for Ali-Scout trials 1 and 2, and the baseline trial).

Thus, the longitudinal control measures all show consistent changes with practice. Speed increases and headway decreases with practice, and standard deviations are correlated with their means. One would expect that the standard deviation of lateral position would decrease with practice. That was not the case, as values of 0.89 ft, 0.91 ft, and 0.88 ft respectively were obtained for the three trials. These differences are smaller than can be measured reliably. One possible explanation is that lane maintenance was a "protected" task. That is, subject drove to keep lane position at an optimum, something they could do this because the navigation task was not excessively challenging. As they became more familiar with the route, they devoted more attention to longitudinal control, which had room for improvement.

These data suggest that use of the Ali-Scout did effect driving performance, and that people drove better when provided with ideal (verbal) guidance. When provided with better guidance participants drove slightly more aggressively.

As was noted earlier, there were differences in driving performance due to Ali-Scout mode, although they were not examined in the same detail as between trial differences. The slowest mean moving speeds and lowest mean throttle position were obtained for autonomous mode sections but the largest values for the standard deviation of lane position and steering wheel position were obtained (in contrast with other situations where means and standard deviations were correlated). This indicates that autonomous mode requires the driver to pay more attention to the navigation system and less attention to driving behavior (an undesired situation).

Interface design differences - Ali-Scout versus PathMaster

Data from drivers who used the PathMaster interface was compared with drivers from the same age group (young) who had used the Ali-Scout interface at the same time of day (rush hour). The mean trip duration was 26.1 minutes for the Ali-Scout and 22.1 minutes for the PathMaster, a 15 percent difference. However, when the differences in the baseline trip durations are considered (both groups should have completed the baseline trips in equal time), the difference between interfaces is negligible.

Part of the reason for this difference is that when moving, PathMaster subjects drove faster (37.0 versus 35.1 mi/hr), but had a smaller standard deviation of moving speed. While increased driving speed is desired from the mobility perspective, it is not from the safety perspective. The greater speed of PathMaster subjects is reflected in the slightly greater mean throttle position (11.4 versus 10.6 percent).

Differences in lateral control between interfaces were considerable. The mean standard deviations of lateral position for the Ali-Scout and PathMaster were 1.0 feet and 0.4 feet respectively. As with the longitudinal control measures however, adjusting the measures to equate baseline performance removes the difference between interfaces. Thus, the data suggests that as a group the PathMaster subjects were better at maintaining lane position, not that the interface was less distracting. The small number of subjects who used the PathMaster makes this difficult to determine with much certainty.

Thus, unadjusted, these data suggest that the subjects using the PathMaster took considerably less time to reach a destination (by driving faster) and were more stable in holding a fixed lane position. However, when the baselines are equalized, the differences between interfaces are eliminated, suggesting little to no differences in driving performance.

Were the Ali-Scout and PathMaster Safe to Use?

Incidents

The most direct indicators of the safety of the Ali-Scout interface are the crash/near miss/critical incident data. There were no crashes in this experiment, and given the relatively low mileage accumulated across all subjects (a few thousand miles) relative to the typical mileage between collisions (approximately once every 100,000 miles), the probability of a collision was quite low. In the U.S., there is a police-reported collision for roughly 184,000 miles driven (U.S. Department of Transportation, 1996). Approximately 48 percent of all property-damage-only collisions are not reported (Wang, Knipling and Blincoe, 1996).

There were four critical incidents in the first experiment, all during initial use of the Ali-Scout. In those instances, the Ali-Scout gave a command to take the right or left hand lane prior to a turn and drivers immediately changed lanes without checking carefully if it was safe to do so. In response, other drivers honked and subjects swerved back into their own lane.

One cannot conclude much from the differences in the number of incidents between experiments. In the supplemental experiment there were no critical incidents involving either the Ali-Scout or the PathMaster. Using the results from the first experiment as a basis (which in itself is an estimate based on a small sample), only one incident was expected because of the even smaller sample.

Because of the types of incidents that occurred, these data suggest there are some safety concerns for the Ali-Scout unit. Voice systems can be easy to use because they do not demand visual attention, allowing drivers to remain focused on the road. However, some drivers may treat the voice instructions as commands rather than advice (even though the videotape offered precautions), and as a consequence, become involved in collisions. While the problem appears to go away with exposure, mechanisms for more effectively communicating the advisory nature of the guidance are needed (greater emphasis in the video and documentation, changing to a less forceful voice, etc.).

Ratings

A second perspective of the safety is how the interface was rated by drivers. Subjects generally agreed the Ali-Scout interface was safe for them to use (4.0 on a 5 point scale where 1=strongly disagree and 5=strongly agree scale), but slightly disagreed on average (2.8 on 5 point scale) that the interface was safe for an inexperienced driver. They generally agreed it was not distracting (3.9). By way of comparison, the PathMaster was rated as 4.5 in response to the "safe for me" question, 3.3 in terms of use by inexperienced drivers, and 4.3 for nondistraction, all values somewhat greater than the Ali-Scout. Interestingly, if only subjects from the same time of day and age category as the PathMaster are utilized for the Ali-Scout estimates, the mean ratings are 4.0 (safe for me), 2.4 (safe for inexperienced drivers), and 4.1 (no distracting), fairly close to the means from all drivers except for the mean rating for "safe for inexperienced drivers."

As a further comparison, transforming the "safe for me" data of Green, Williams, Hoekstra, George, and Wen (1993) yields values of 5.0, 4.7, and 4.5 for the auditory, instrument panel, and HUD guidance interfaces they evaluated, all at least as good PathMaster, but better than the Ali-Scout. (The scale in the previous study was reversed.) For the inexperienced driver question, Green, Williams, Hoekstra, George, and Wen (1993) report values of 3.7, 3.0, and 2.7 for the three interfaces (auditory, instrument panel, HUD). Those values are slightly greater, on average, than the values recorded here. As a footnote, each of the ratings in the previous study was typically based on only 11 drivers, so the values presented are only estimates. Also, readers should recall that the route used in the previous experiment is thought to be more difficult. Thus, as a whole, these ratings suggest the Ali-Scout is acceptable in terms of safety for experienced drivers, but marginal for inexperienced drivers. Further, the Ali-Scout is not as safe as several alternatives.

Were the Ali-Scout and PathMaster Useful?

Ratings

Several questions in the post-test evaluation concerned the usefulness of navigation systems overall. As with other ratings, evaluations were on a scale from 1 to 5 (where 1=strongly disagree, and 5=strongly agree). Drivers found the Ali-Scout to be useful (4.3), especially for a destination they had never visited before (4.6), and preferable to maps (4.3) and written instructions (4.1). They were not enthusiastic in using the Ali-Scout if they were in a hurry (3.7), for daily travel (3.2) or for trips to familiar destinations (2.6). For PathMaster, the results were quite similar in terms of comparison with alternative navigation aids and use for routine trips. Ali-Scout ratings did changed slightly depending upon whether the sample was all Ali-Scout subjects or the age-, time-of-day matched sample (young, rush-hour), typically by 0.1 or less. Overall, there was no difference in the usefulness of the two interfaces.

As a further comparison, ratings for the UMTRI interfaces were much higher. For example, the mean rating (across all three interfaces) was 4.9 in terms of information usefulness, 4.6 in terms of preference over maps, and 4.8 in terms of preference over written instructions. While this could indicate the UMTRI interface was more useful, it may also mean it was more useful for the test route, as the route used in the previous experiment was probably more challenging.

Thus, the rating data suggest the Ali-Scout interface is useful, and based on very limited data, rated as useful as the PathMaster. However, both systems may be rated as less useful than alternative electronic interfaces (the UMTRI simulations). All electronic systems evaluated are clearly more useful than paper maps or written directions.

Driving times

Driving times for the 3 trials (excluding stops) were 24 minutes, 2 seconds for the first trial, 24 minutes, 18 seconds for the second trial, and 22 minutes, 23 seconds for the baseline (third trial). Thus, Ali-Scout guidance led to driving times that were about 10 percent greater than what is thought to be optimal guidance (experimenter guidance). Interestingly, guidance provided by the PathMaster led to trip durations that were about 10 percent less than those for the Ali-Scout. While the two results are not directly comparable, as the original Ali-Scout data is for all trips and the PathMaster - Ali-Scout comparison is for rush hour driving by young drivers only, these limited data suggest that the PathMaster guidance is quite good.

It should be noted that there are no comparable data for the UMTRI interfaces as the IP, HUD, and auditory systems were not used by subjects to drive the route in Troy, and the route for which the UMTRI interfaces were used was quite different (e.g., very little traffic, more rural).

Turn errors

There were a large number of turn errors and near errors made in using the Ali-Scout interface. As a reminder, there were 8 turns enroute, plus an additional 4 for destinations (1 per destination entrance). For the 54 drivers there were 32 enroute errors for the first trial, 10 for the second. Thus, the probability of an enroute error at a turns was 7 and a half percent for the first trial, and just over 2 percent for the second. In addition, there were 46 confusions/uncertainties for the first trial, 22 for the second. Hence, the fraction of time the information provided was inadequate (errors + uncertainties) was found to be 10 and a half percent of the turns for the first trial, 5 percent for the second. About 3/4 of these errors occurred in autonomous mode, even though autonomous mode represented only a small fraction of the total trip. In contrast, there were no enroute errors when experimenter guidance was provided.

In terms of approaches to destinations (all in autonomous mode), errors were much more common (22 percent for the first trial, 8 percent for the second). Most errors were at the first destination. As most of the destinations were clearly marked (large signs and distinct entrances), this does not reflect favorably on the terminal guidance provided by the Ali-Scout. Taken as a whole, these data suggest that driving in autonomous mode is much worse than using turn-by-turn guidance. From the perspective of error rates between sessions, a difference by a factor of four seems typical.

In contrast, performance with the PathMaster led to no turn errors and no uncertainties. However, the sample size was quite small (3 drivers), and had the rate been the same as that for the Ali-Scout, only 2 enroute errors would have been expected for the first trial, and a roughly equal number of uncertainties.

By way of comparison, Green, Williams, Hoekstra, George, and Wen (1993) reported 5, 4, and 1 errors for auditory, instrument panel, and HUD-based navigation systems, each driven by 10 drivers over a 19-turn route. The associated turn error rates are approximately 3, 2, and 1 percent (rounded off to the nearest percent). Those error rates are well below those of the Ali-Scout for a route that was believed to be at least as difficult to drive, suggesting that the Ali-Scout was much less useful than the UMTRI prototype. Interestingly, Green, et al report 6, 4, and 5 near miss errors (equivalent to the uncertainties reported here) for the three types of navigation systems. Thus, in both studies, the number of near miss errors/uncertainties/confusions at intersections is about 50 percent greater than the actual number of turn errors.

Were the Ali-Scout and PathMaster Interface Features Useful and Usable?

Ratings

Ratings were also obtained for the usefulness of Ali-Scout and PathMaster features. From most to least useful, the ratings for the Ali-Scout were as follows: auditory messages (4.6), the "follow current path" and miles to destination graphics (4.5), guided mode and turn graphic in guided mode (4.4), the arrow in autonomous mode (4.2), the countdown bars (4.0), the autonomous mode (3.5). When feature ratings for the Ali-Scout were matched with PathMaster subjects for the same age, time-of-day group, there was essentially no difference. These ratings indicate drivers find auditory messages and specific guidance quite useful, and general guidance (crow-fly directions provided by the Ali-Scout) considerably less useful.

Interesting is the moderate rating given to the countdown bars. The senior author's experience is that the usefulness of countdown bars depends upon street spacing. Except in residential areas, streets in Troy are typically spaced a tenth of a mile apart, sometimes more. With that spacing, very general messages about when to turn can be unambiguously associated with a street on which to turn. When streets are closely spaced, (200 feet apart) additional information, such as is provided by countdown bars, is valuable.

Driver comments

Drivers were very willing to verbalize their impressions of the strengths and weaknesses of the navigation interfaces, both as stimulated by driving-related events and during a post-test briefing. Several questions arose concerning the options provided and interpretation of the graphics. For example, some subjects asked if the Ali-Scout came with a female voice to give instructions. Others asked if the Ali-Scout would direct them around accidents or traffic.

Some of the more common questions concerned the Ali-Scout's features. One of the most frequently asked questions (15 subjects) concerned the chime that the Ali-Scout provides when changing between autonomous and guided modes. Comments concerning the chime included: "That means I passed it, or I didn't find it?", "Does that mean you're there?", "Does that indicate that we get off at the exit?", and most regularly "What does that mean?".

Another common misconception among subjects was the miles to reach destination readout at the bottom right of the Ali-Scout's screen. Two subjects asked if the readout was given in meters, one added, "That's not the international symbol for miles, that's the international symbol for meters." Four older, female subjects thought that the readout was given in minutes. In addition, another seven subjects asked what units the readout was given in.

Additionally, subjects asked several questions concerning the graphics presented by the Ali-Scout. Four subjects asked what the destination zone graphic meant, six subjects asked what the "A" in the upper left of the screen meant, and another three subjects asked what the lane position graphic meant. Another frequently confused feature was the follow current path graphic (10 subjects). The most common misconception was that the graphic indicated that there were three lanes available to the driver.

How could the Ali-Scout driver interface be improved?

Very few problems were encountered in using the PathMaster interface. This reflects the quality of the interface and the very small sample size. While the senior author has numerous insights as to how that interface might be improved based on his personal experience, the data collected in this experiment does not provide much in the way of specific suggestions. For that reason, the focus of this section is on the Ali-Scout driver interface. However, to the extent that problems identified are common to navigation systems in general, these results also apply to improvements in the PathMaster interface.

Problem 1: Some voice messages occurred too late.

There were a number of situations in which voice instructions to turn occurred later than they should have. This led to turn errors and near turn errors, driver comments, and low ratings for message timing ("ratings were given in ample time"=3.7). While drivers utilized the visual display to develop a general maneuver plan, the actual execution of the plan was based on the voice messages. In traffic, drivers had difficulty looking away from the road scene to examine the navigation display.

Since the Ali-Scout was designed, several studies have been completed that provide detailed recommendations as to when turn messages should be provided based on traffic, the time of day, driver age and sex, and the type of turn to be completed (Ross, Nicolle, and Brade, 1994; George, Green, and Fleming, 1995; Green and George, 1995). Missing from the literature are cross-cultural comparisons of message timing, data needed to tailor message timing to different user populations. (For example, the largest market for route guidance system is Japan, but there is no published research that provides detailed timing equations for voice guidance instructions.) Further insights could also be gained from examining foot control use and deceleration profiles of drivers planning actual maneuvers (such as drivers in this experiment). Voice messages to turn need to occur in time for the driver to hear the message, react to the message, and then release the throttle in order to decelerate smoothly. The results of this experiment show that message timing is critical.

Problem 2: Lane change instructions were misinterpreted.

All four critical incidents in this project involved drivers learning to use the Ali-Scout mistaking guidance to change lanes for a command to immediately do so. Those drivers changed lanes without checking traffic, creating what could have been a collision in other circumstances. Fortunately, in these instances nearby drivers were able to avoid them. As was noted earlier, strengthening the warnings in documentation is a partial solution. However, the most effective solutions are likely to involve changing the voice message (e.g., get in the right hand lane when traffic permits). Over time, dropping the end phrase may be possible as drivers become familiar with the system and realize messages are advisory rather than directive. Shortening messages will reduce driver complaints that the system is too chatty.

Problem 3. Drivers did not know what to do in autonomous mode.

The autonomous mode only indicated the crow-fly distance to the destination and the direction, but not where to turn, an interface similar to the Delco Telepath 100. This problem was highlighted in comments from drivers and from a review of the turn error and related data. Approximately 3/4 of all errors and near errors occurred in the autonomous mode, but that mode represented only a small fraction of the duration of a trip and the number of turns made.

One strategy drivers might use would be to wait until the direction arrow was horizontal and then turn. In this strategy, the distance to any destination is the sum of the length of the sides of a triangle, not the shortest distance, the hypotenuse. While knowing the general direction of a destination was better than being completely lost, drivers needed more specific guidance as to where to turn. While crow-fly systems are much less expensive to produce than turn-by-turn guidance systems, these data suggest, at least indirectly, that crow-fly systems are not very useful. More generally, these data suggest that even systems with autonomous modes are not desired. When the navigation system is on, it should always be able to provide turn-by-turn guidance (except for the brief periods required for route calculation).

Problem 4: Chimes to indicate mode changes were not understood.

The Ali-Scout sounded a tone when changing from autonomous to guided mode or from guided to autonomous mode. In response, drivers invariably looked at the display. This same chime was used to signal a beacon was passed, causing drivers to glance at the display. While the problem may become less severe as a user becomes familiar with the Ali-Scout, a better design would have a sound that is unique to the mode change. More generally, this suggests that all sounds should be uniquely coded so that users can determine if they need to look at the display or perform some other action solely based on what they hear. When unique coding is not provided, drivers will look at the display for more information, diverting their attention from the road ahead, a potentially unsafe situation. The use of earcons for coding information should be considered.

Problem 5: The follow the main road graphic was not understood.

Drivers did not know what the three-headed vector meant (follow the road as it changes direction). In part, this problem occurred because the display technology chosen was capable of showing only a limited number of graphic forms. The solution to this problem is uncertain. However, this is the kind of problem that could have been identified and corrected in simple laboratory studies of the interface graphics.

Problem 6: The destination description message was too general.

Neither the Ali-Scout nor the PathMaster indicated the exact location of the destination. In some sense, this is an extension of the autonomous mode problem described previously. Both the Ali-Scout and PathMaster provided graphics which indicated the driver was in the destination area. Neither, however, indicated the relative location of the destination (on the left or right), something that could be done if the destination was a street address. This was the only negative comment received about the PathMaster. Specifying this additional detail (left or right) would reduce the user's search area by 50 percent and enhance safety considerably. Typically, when drivers come close to the destination, they would slow down considerably and begin to search for it. In this situation, drivers were paying less attention to traffic and driving slowly, inviting a rear-end collision.

How Much Were Drivers Willing to Pay for a Navigation System?

In some sense, the ultimate measure of the usefulness and usability of a product is how much people are willing to pay for that product. On average, drivers were willing to pay $593 for the Ali-Scout unit. The quantitative data were reinforced by driver comments regarding the Ali-Scout. ("How soon can I put one of these in my car?" This is cool!".)

For the PathMaster, subjects were not willing to pay as much (mean of $300.00 with a range from $0 to $500.). However, that sample size is extremely small. By comparison, drivers were willing to pay $1125 for the instrument panel-based guidance system, $723 for the HUD implementation, and $937 for the auditory interface evaluated by Green, Williams, Hoekstra, George, and Wen (1993). Ignoring the PathMaster data (because of the small sample size), drivers may have been willing to pay more for the UMTRI prototype interface than the Ali-Scout product because the interface was better. An alternative explanation is that the route used by Green, et al. was more challenging, so the perceived value of any navigation aid was elevated.

What Should Be Done in Future Driving Studies?

What should be measured and how?

In determining what to measure, one first needs to consider what is being measured and why. For navigation experiments such as this one, the issues are usefulness, safety, and ease of use/usability. Information is desired both concerning how well the interface performs with regard to those characteristics and how the interface might be improved.

The characteristics of desirable measures follow. (See Green (1993) for additional ideas.)

- Indicative - The measures should somehow reflect usefulness, usability, or safety. Some measures do that but in an ambiguous manner. For example, a navigation system might allow people to driver faster, enhancing mobility. (That is good.)

However, if they are driving faster, the risk of a serious injury in a collision is greater. (That is bad.).

- Reliable - Poor reliability can occur for subjective measures where the decision rules are not clear and for objective measures where technology limitations lead to inconsistency.
- Accepted by researchers and practitioners - In some cases, there may be excellent scientific evidence supporting a particular measure, but if the measure is not understood or believed by those who will be applying the results, the measure is of little value.
- Easy to measure - Practical constraints have a major impact on how studies are conducted. Clearly, knowing where drivers are looking when they drive is important. However, obtaining that information automatically and in real time is a major technical challenge. Such systems are too expensive for most research teams to afford.
- Easy to analyze - Here again, eye fixations are a good example. The most direct way to collect eye fixation data is to aim a camera at the subject's face. Analysis involves frame-by-frame playback, with an analyst manually recording where the subject looks. Analysis can take 30-40 hours for each hour of videotape, a very slow and boring process.

Collisions and incidents. Three crash-related measures were examined: crashes, near misses, and critical incidents. Crashes and near misses are indeed rare events. Even in large operational field tests, there may only be one or two, too few for statistical analysis (or even case studies). In this particular project, critical incidents were rare and treated as case studies as well. The critical incidents pointed to weaknesses in the Ali-Scout interface. In future studies, a more structured manner for defining and tracking critical incidents is suggested, as was the case for the TravTek project. Most important is the provision of a form for recording the specifics of the event (vehicle paths, speeds, etc.), information readily available in the accident literature. Most of the critical information is collected by the forward scene camera and the camera on the driver's face. Thus, the authors believe the emphasis will be on critical incidents, but except for very large studies, there will be too few from which to draw any conclusions.

Turn errors. In this and previous UMTRI research both actual turn errors and near errors (confusions and uncertainties) have been collected. Except with very good interfaces, there are usually enough of errors and near errors to draw distinctions between interfaces. Additional effort to more precisely define uncertainties and confusions is desired so identification of them across experiments is consistent. These comments and confusions were recorded by the camera on the subject's face and the audio track of the video tape. In an early modification to the test vehicle as part of this project, the single microphone located in the center console was replaced by two lavaliere microphones, a directional unit on the A-pillar and a microphone near the inside rear mirror. A critical change was routing the central microphone cable through the headliner instead of over the transmission housing. This reduced the annoying speed-related whine to zero, and made the audio track very easy to understand. If subject comments are to be utilized, high quality microphones and attention to the location of microphone cabling is critical.

Subject Comments. A high quality audio system enabled the research team to be able to understand comments subjects made while driving. In preproduction product evaluations, these comments will be particularly useful to designers as they indicate where an interface needs improvement.

Ratings. One of the more useful approaches for evaluating the usefulness, usability, and safety of navigation interfaces have been ratings. In this and in previous experiments, drivers rated their response to various statements ("It is safe for me to use this system while driving. It is safe for inexperienced drivers to use this system while driving.") on a 1 to 5 scale. Such measures are easy to collect, though a reasonable sample size is required for such measures to be stable.

However, use of this approach to date has been somewhat ad hoc. More careful thought needs to be given to the dimensions and characteristics that underlie all navigation interfaces. To the extent possible, dimensions should be independent. A standard set of questions would facilitate comparative evaluations of navigation interfaces. Should that not occur, reusing the questions posed here is suggested.

Driving performance data. One of the questions that many navigation studies consider is if the navigation system causes people to drive abnormally, and if that abnormal performance is dangerous. However, given the limited amount of normative data currently available, deciding when a measure is out of bounds is very difficult. (See Green, 1993c for a discussion.)

In the first experiment examining repeated use of the Ali-Scout followed by experimenter guidance (the baseline), there were statistically significant differences for almost every measure explored. In the Ali-Scout/PathMaster comparison, about half of the measures reflect statistically significant differences. However, it is unclear if those are differences in the interfaces or the groups that used them.

In the first experiment, the rank order of measures (in terms of their sensitive to trial differences) is shown in Table 28. Notice that the most sensitive measures are speed related, with output measures being more sensitive than input measures.

Table 28. Significance levels from the first experiment.

Rank	Significance	Measures
1	.0001	mean moving speed, overall mean speed, standard deviation of throttle position
4	.0002	standard deviation of speed
5	.0009	mean throttle position
6	.0043	duration
7	.0254	mean lateral position
8	.0291	standard deviation of steering wheel angle

Table 29 shows similar results for the supplemental experiment. From those data, one can conclude that lateral measures may be more sensitive than longitudinal measures. The authors are puzzled by the lack of consistency across studies, other than the explanation that the PathMaster sample was very small. The only measures that achieved consistently high significance levels in both studies were trip duration and mean speed. Given the lack of knowledge of just what happens when navigation systems are used, the authors would argue for continuing to collect all measures reported here in future studies.

Table 29. Significance levels from the second experiment.

Rank	Significance	Measures
1	.0001	mean headway, standard deviation of headway, mean and standard deviation of lateral position
5	.0285	overall mean speed
6	.0374	standard deviation of steering wheel angle
7	.0393	duration
8	.0444	standard deviation of throttle position

With so many measures, some of them will be significant just by chance. One possible explanation for these results is that the focus of the analysis was on the wrong sections of road. This report lumps together both normal enroute driving and driving near the decision point/turn point, a distinction made by Walker, Sedney, Alicandri, and Roberts (1989) and Walker, Alicandri, Sedney, and Roberts (1991). Had the authors had the opportunity to reanalyze the data, that distinction would have been made.

Time-to-line crossing. In future studies, the authors would argue for also collecting Time-to-Line Crossing (TLC). For forward-looking lane sensors (such as the UMTRI system of cameras embedded in the outside mirrors, dual cameras mounted in the bumper, or single cameras mounted in front of the inside mirror), computing TLC in real time is reasonable. Now that the reliability of UMTRI's dual lane tracker system has been established, collection of this measure makes sense. However, many researchers use cameras either mounted on the rear bumper or, for those with station wagons, on the roof, in both cases looking at the ground behind the test vehicle. In such cases, TLC cannot be determined in real time (but it might be determined by post processing of the videotape).

Time-to-collision. The next step in processing headway data is to determine the Time-to-collision (TTC) in real time, something that is now feasible given the enhanced reliability of headway sensors. TTC computations in real time will require integration of the data from the headway, steering wheel angle, and lane tracking sensors, something that can readily be done with the instrumented car. TTC data may not only be useful in comparing alternative navigation systems, but may provide useful baseline data for the development of collision-avoidance systems.

Quality of driving. Quality of driving measures were not collected in this research project. The reliability of such measures between experimenters and cultures (U.S. versus Europe versus Japan) has yet to be assessed. At the outset of this project such measures were dismissed as being too unreliable. However, experimenter observations suggested many situations where driving events of concern occurred that were not captured by other measures. This has caused the research team to review consideration of quality of driving measures. However, before such measures are utilized, additional basic research is needed on the reliability of such measures between individuals, laboratories, and test sites. Once better established, quality of driving measures should be useful in application-oriented experiments.

What data collection problems are of concern and how can they be overcome?

Most of the data collected was highly reliable. The identification of throttle position and steering wheel angle was straightforward, though not calibrating the wheel angle sensor (so straight ahead was zero degrees) led to some confusion. The test vehicle had problems with missed wheel pulse signals, with the data recorded suggesting instantaneous two mi/hr decreases and then increases in speed over two successive samples (30 ms each). While these errors were easily corrected in the analysis, they were annoying. Nonetheless it is suggested that speed data supplied to the engine computer be generally used to measure speed (instead of a fifth wheel or radar sensor) because the sensor remains concealed, is low cost, and in spite of the challenges experienced here, is highly reliable.

Until now, accurate measurements of lane position were extremely difficult to obtain, something that advances in ITS technology have changed. In this experiment, both lanes were tracked, not one as was the case in previous UMTRI studies (Green, Williams, Hoekstra, George, and Wen, 1993; Green, Hoekstra, and Williams, 1993) and studies conducted elsewhere. While detailed comparisons of lane position as estimated by one or two sensors were not conducted, the variations in lane width found (due to where lines were painted) suggests, at least for Michigan roads, that two lane trackers are needed. The impression is that the automatic trackers were much easier to use (and more reliable) than a situation in which experimenters manually monitor lane position and record all lane exceedances.

The authors had been advised by others to minimize intrusion of the equipment, especially video equipment. The solution was to use partially concealed lipstick cameras to record the forward scene, the driver's face, and the instrument panel. At night, larger cameras were used, but since it was dark, they were difficult to see. While the lipstick cameras are relatively expensive, the relaxed behavior of subjects suggests they encouraged drivers to behave naturally, not as if they were being monitored. For that reason, use of such equipment is encouraged.

Recording headway proved to be quite problematic, primarily because of an unreliable headway sensor (and sensor cost). Over the course of this project, both technical problems have been solved by the automotive suppliers. However, further evaluation of software algorithms to process headway sensor data are desired. Some comparisons could be done using the video records from this experiment and the vehicle data logs (which include headway lock and headway data fields).

Accurate recording of glance direction continues to be a problem. The original plan was to use an on-head recording system that would provide coordinates for the direction of gaze. Most systems illuminate the eyes with infrared light and use the reflected image (as sensed by cameras) to determine the direction of gaze. Such systems are often overwhelmed by sunlight in the daytime. Increasing the IR emitter output can bother drivers. An alternative is to mount the sensor and emitter inside a face shield the driver wears. That, however, can change the apparent luminance, contrast, and color of objects viewed (the road, navigation displays, etc.), not a desired outcome.

The second challenge is to record head position so the direction of gaze in vehicle coordinates (not just relative to the head) can be determined. Most high quality head trackers are magnetically based. They work wonderfully in a virtual reality laboratory, but poorly inside of a metal car body, especially if the head clearance is small. For over one year at the beginning of this project the research team worked with one vendor on evaluating eye fixation system prototypes. The prototypes never worked reliably. Since then the team has been working with a second vendor. After eight months, that second vendor has yet to deliver a working system as promised. A system that will work, the Dornier Eye Tracking System (now sold by Applied Science Laboratories) originally priced $170,000, was beyond the project's budget.

For this particular project, the fall back position was to record eye fixations by aiming a camera at the driver's face and recording how often the driver looked at the navigation display (mounted coaxially with the camera). To facilitate this analysis, special software was developed to provide direct control of frame-accurate VCRs. The development of this software, while requiring some effort, reduced the time to analyze tapes (a very boring task) considerably. Some believe that the quickest way to cause a student to lose interest in human factors is to ask students to manually reduce eye fixation data from videotape without computer support. In estimating the cost of such systems, developers should not forget that frame-accurate VCRs are quite expensive, and one may not be enough.

Within the next year or so, the authors believe that reliable lower-cost eye fixation recording systems will be developed and these problems will go away.

How can experiments be designed to minimize the impact of route variations and individual differences?

In this experiment and in previous experiments, there were huge differences due to the route and when the route is driven and, differences between individuals, even within age and sex categories. Those sources of variation can overwhelm interface differences in a small experiment, making it difficult to tell which interface or interface feature is best. This suggests that experiments should be conducted within subjects, that is each subject uses all interface alternatives. The problem is that once subjects have driven a route, they begin to memorize it, and rely upon their memory rather than the navigation system, to guide them on a trip. In this experiment, depending upon the measure, improvements between trial one and two on the same route were about three percent, for sessions separated by a week. This suggests that repeating the same route is a viable approach in some cases. However, when more than two alternatives are to be considered, it is uncertain how performance will change over an originally unknown route.

An alternative approach might be to run the route backwards. This will probably work well in strictly open road driving, but in navigation studies where turning is required, left and right turns are not equally difficult, and the geometry of turn lanes and exit ramps are not mere mirror images of each other. Traffic signal provisions are often quite different.

The approach used in this experiment was to have everyone complete a common baseline trip where the navigation (experimenter verbal guidance), roads, time of day, and level of familiarity were all the same. Those data can then be used to adjust the performance of groups, within which each person only experiences one navigation interface. It is assumed that adjustments to departures from the baseline are linear, but that assumption was not checked.

What were the data reduction and analysis problems and how can they be overcome?

Driving experiments generate a huge amount of data, in this case 3/4 of a gigabyte. Often data reduction is not given much thought. As a consequence, most of the data is often discarded because it is too difficult to analyze. Further, the tendency is to focus only on straight road sections.

The key to rapid data reduction is software that automatically checks the data for unusual data points (and flags them), partitions the route into segments, and computes means and standard deviations for each measure for each segment. Typically the effort to reduce the data far exceeds that to collect it. Using the special data reduction software was developed for this project led to a huge time savings in data reduction time.

The original plan was to use experimenter entered codes to partition the route. Unfortunately the codes were not entered consistently and sometimes forgotten. This coupled with problems of handling off-route errors led to a more automated procedure to partition the route into segments. Experimenters must realize that even good data reduction software will have to be tailored for each experiment, and programmer time for such should be included in the project schedule.

Key Lessons Learned

There were eight key lessons that emerged from this research.

1. Current technology allows for reasonable collection of most driving performance measures of interest except eye fixations. Prior to this project the collection of control positions and vehicle speed was practical. Over the course of this project multiple line lane trackers and reliable headway sensors have been developed. Lower cost eye fixation recorders will be available within a year or so. Subminiature low-light cameras may become available in the U.S. sometime after that. Thus, at this point, except for recording and analyzing eye fixations, there are not major equipment hurdles to be overcome.

2. It is not clear which driving performance measures are most sensitive to differences in navigation interface design. A different conclusion might have been reached had the performance along portions of the route been subjected to microanalysis.

3. Standardized rating scales for usefulness and usability are desired. Standard evaluation protocols would facilitate the comparison of results both within operational field tests in the U.S. and with similar studies ongoing in Europe and Japan.

4. Data reduction should be via custom-written routines, not via manual analysis. In previous studies, Microsoft Excel and other applications have been used to compute means and standard deviations that were aggregated across subjects and trials. For larger studies, that approach is inefficient and error-prone.

5. Developing approaches for comparing navigation systems continues to be a problem. In this particular project, subjects drove a common baseline (a repetition of the original route) and the performance of groups across baselines was compared. Subjects were matched by age, sex, and the time of day at which they were tested. Even with this matching, differences between interfaces were difficult to identify because of the small sample size. The authors believe that finding truly matched routes for within subject comparison will be impossible.

6. Subjects found the autonomous mode (crow-fly directions) far less useful than guided mode. They made at least four times more errors and uncertainties at autonomous turns, rated the mode poorly, and complained about it. Further, when autonomous-like guidance at destinations was provided (destination area reached), subjects had trouble navigating. One solution might be to indicate on which side of a street a destination is located when a street address is entered.

7. Voice instructions may initially be interpreted as commands to be immediately executed without reference to traffic. While this problem went away as subjects became accustomed to the Ali-Scout, this problem is nonetheless serious. One potential solution is to include brief caveats in the instructions ("get in the right hand lane as traffic permits") or make them more suggestive ("approaching ...turn right") instead of ("turn right').

8. The second serious problem is that of message timing. The primary information source for planning a maneuver, especially in heavy traffic, are voice messages. If those messages are presented too late, drivers are likely to stop abruptly, and could be rear-ended. The timing problem is not something one becomes accustomed to with practice.

Thus, this research effort identified both methodological concerns in evaluating navigation interfaces and interface design issues. The technical problems in measuring driving performance will be overcome, while the problems of what to compare will persist.

In terms of design, the key principles are making sure that (1) the driver is always guided, (2) drivers check traffic before following auditory guidance, and (3) turn messages are never too late. Following these principles is key in designing safe and easy to use navigation systems.

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APPENDIX A - ADDITIONAL LITERATURE SUMMARIES

Burnette and Joyner (1993)

Burnett and Joyner (1993) describe an experiment in which 24 subjects drove an instrumented car over two test routes in a counterbalanced order, one using an unspecified electronic map-based route guidance system, a second using either verbal guidance from the experimenter, or paper maps with a highlighted route.

There were no navigation errors for the verbal guidance condition. Navigation errors for other conditions are shown in the table below. Notice that the largest number of errors is associated with the route guidance system. In part, this was because the displayed position lagged the vehicle's actual position. Also, the electronic map display rotated in a direction opposite to the direction the subject was turning, adding to the confusion.

Table 30. Navigation errors reported by Burnett and Joyner, 1993.

	Maps/notes (n=12)	Route guidance (n=24)
Route 1	0.67 (0.82)	1.42 (1.10)
Route 2	0.40 (0.55)	0.92 (0.79)

Data on glances to navigation aids (while the vehicle was in motion) are shown in the table that follows. A glance was defined as the time from when the eyes left the road until they returned to the road. The percentage of glance time to the navigation aid was much greater for the electronic guidance system than the map/notes combination. However, the percentage of glances to the road was only slightly less. Thus, subjects maintained a consistent fraction of glances to the road ahead, even though the devices had very different attentional demands. The major cost was a reduction in the frequency of glances to the sides and mirrors.

Table 31. Percentage of glances while moving.

	Verbal instructions	Map/notes	Electronic route guidance
road	49.8	50.6	49.7
display		15.1	35.1
inside mirror	22.6	11.2	5.9
instrument panel	7.7	6.1	2.1
left side	1.7	1.4	0.5
right side	9.2	9.4	3.3
left mirror	0.5	0.3	0.2
right mirror	9.5	6.9	3.2

In terms of glance durations (Table 32), differences between durations to the road were considerable (2.9 s for electronic guidance, versus 6.84 s for the map and 9.35 s for verbal guidance). Glance duration differences to other areas were minor, except for those to the navigation aid (1.2 s for map/notes, 1.12 s for electronic route guidance). Glance durations are consistent with those in the literature for electronic maps (1.28 s reported by Labiale, 1989; 1.37 s reported by Wierwille, Hulse, Fischer, and Dingus, 1988).

Table 32. Mean duration of glances while moving.

	Verbal instructions	Map/notes	Electronic route guidance
road	9.35	6.84	2.90
display		1.20	1.12
inside mirror	0.68	0.71	0.69
instrument panel	0.84	0.90	0.86
left side	1.25	1.13	1.16
right side	1.24	1.18	1.23
left mirror	0.78	0.82	0.89
right mirror	0.94	0.91	0.94

In terms of driving performance, only the last minute for exiting a divided highway (when glancing at the navigation aid was required) was examined. There was more variability for the electronic route guidance system than the other navigation aids, but for only one of the two routes.

Table 33 shows scores from a tailored (raw) version of the NASA TLX subjective workload ratings. Notice that the driving performance with the map/notes combination was better (more frequent glances to the road, etc.), but use of the map/notes combination was viewed as having a higher workload. In contrast, performance was consistently good and workload consistently low with the verbal instructions.

Table 33. TLX scores from Burnett and Joyner (1993).

TLX Component	Verbal instructions	Map/notes	Electronic route guidance
mental demand	28.7	60.0	37.1
mental effort	38.8	48.8	45.0
physical demand	10.8	29.8	15.0
time pressure	6.4	36.0	15.8
distraction	13.3	49.6	32.5
stress level	13.7	39.1	15.5
Mean	18.6	43.8	26.8

Thus, this experiment supports the use of turn error data, eye glance data, and TLX workload ratings as indicators of interface usability.

Parkes and Burnett (1993)

In Parkes and Burnett (1993) 16 participants drove two routes, one with visual guidance only, a second with both visual and auditory guidance. In addition, each visual and auditory message was preceded by a beep. Three graphics could be shown on the visual display. (See Figure 88.)

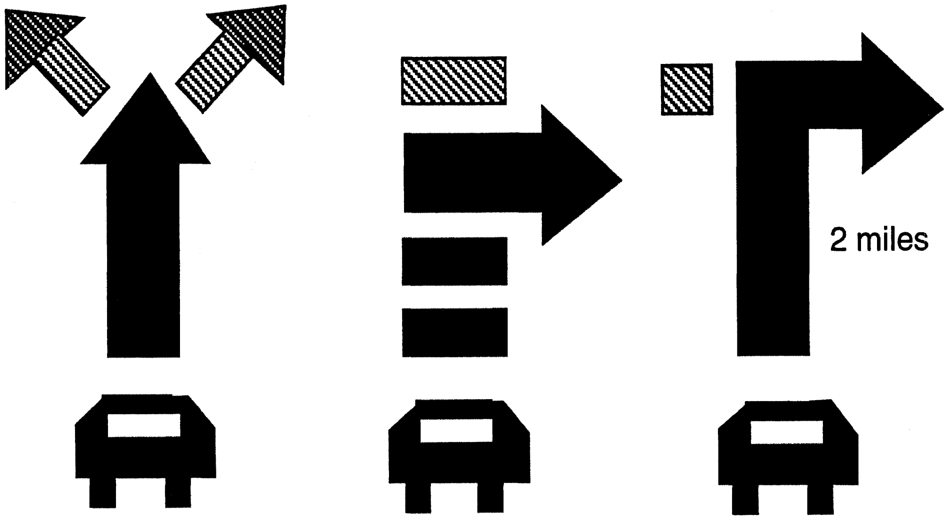


Figure 88. Visual display graphics.

As shown in Table 34, subjects spent significantly more time looking and made more glances to the route guidance display when only visual information was presented (versus when both visual and auditory information were provided) and when advance information was provided (versus when it was not). Glances to advance information systems (0.93 s) were longer than glances for all symbols types (0.78 s).

Table 34. Glance data from Parkes and Burnett (1993).

Advance info. given?	Format	Glance frequency	Time looking at display (%)
yes	visual	66	6.5
yes	visual & auditory	49	4.0
no	visual	55	3.6
no	visual & auditory	19	1.5

Drivers rated driving and navigation tasks as significantly less demanding when both visual and auditory information were provided (as opposed to just visual) with mean TLX scores of 22 (versus 29) and median Modified Cooper-Harper ratings of controllability of 0.5 (versus 2.0 on a 1 to 9 scale). Subjects preferred both visual and auditory information over visual alone (81 percent). They found the advance information message to be helpful or very helpful. Thus, auditory information was both helpful and improved performance. Advance information messages, while desired, did not improve performance (either navigation or by reducing attentional demands). Form the perspective of what to measure, glance frequency, TLX scores, and Modified Cooper-Harper ratings were indicative of interface differences.

Daimon (1992)

Daimon (1992) reports two experiments concerning the use of navigation systems, a laboratory experiment using a low-fidelity driving simulator and, an on-road experiment. Two cars were used, one with an unspecified navigation system, one without. Dependent measures of interest included heart rate variability, utterances from thinking aloud data and, eye fixation frequencies and distributions. While there appear to be clear differences between interfaces as assessed by heart rate variability and the percentage of time spent looking at in-vehicle displays, statistics are not provided. (For further information on verbal protocol analysis, see Obata, Daimon, and Kawashima, 1993.)

Daimon and Kawashima (1996)

A subsequent experiment (Daimon and Kawashima, 1996), had five subjects drive a route using either a navigation system or a paper map. The navigation system showed the current location and the distance and direction to the destination. It did not provide route guidance. The electronic navigation system required more than twice as many eye fixations as the paper map. Also collected were measures of heart rate variability, this time favoring the electronic navigation system. Detailed verbal protocol data was also collected. The results suggest that the eye fixation measures and heart rate variability were useful measures of interface performance. As with previous studies, it shows that electronic navigation systems without guidance (point-on-a-map displays) have little, if any, advantages over paper maps.

TravTek

In the camera car experiment (Dingus, McGehee, Hulse, Jahns, Manakkal, Mollenhauer, and Fleischman, 1995), subjects drove an instrumented test vehicle (the camera car) under six different conditions: turn by turn guidance (with and without voice), map (with and without voice), paper directions, and a paper map. Subjects each drove six different routes, once each with a different navigation interface. There were 18 visitors to the test area and 12 local high-mileage drivers. The high mileage drivers drove the route twice, once after having just received an equipped vehicle, and a month later.

Of particular interest are which interfaces were sensitive to variations in interface design and which interface design was best. Four classes of measures were collected: (1) measures of driving (e.g., mean speed) and driver performance (e.g., glance duration to the navigation display), (2) measures of workload, (3) navigation measures (e.g., trip planning time), and (4) measures of unsafe driving (e.g., number of accidents). Workload was rated on 3 dimensions (times stress, visual effort, psychological stress) on 3 point scales (low, medium, high). Only the measures of unsafe driving (some of which were also measures of driving and driver performance) were not subjected to statistical analysis, primarily because of small samples sizes and concerns regarding the selection of the appropriate statistical procedure.

Table 35 shows the result of these analyses for the driving and driver performance data. In terms of the eye fixation data, better interfaces had shorter glance times to them and longer glance times to the road (Table 36), suggesting they were easier to read and less distracting. Also, when voice was provided, the number of glances required decreased.

Table 35. TravTek driving and driver performance measures.

Measure	p-value	Comment
number of glances to the nav display		fewer glances with voice
glance duration to nav display	0.0001	130,000 total glances, shorter glances with better displays
glance duration to road	0.0001	better systems had longer road glance durations
mean speed	0.0001	drove slower with paper map
variance of speed	0.0005	less variance with paper map
number of lane deviations		better systems had fewer deviations, also a safety item
variance of lateral acceleration	0.015	no consistent pattern
variance of steering wheel angle	ns	
variance of longitudinal acceleration	0.0193	no consistent pattern
mean negative longitudinal acceleration	ns	
variance of negative longitudinal acceleration	ns	
number of steering wheel reversals (>6 deg.) corrected by time	ns	
number of abrupt braking incidents (also safety issue)		more for poorer systems
time brake is pressed	0.0001	longer for poorer interfaces

Table 36. TravTek glance times.

Interface	Duration of Glances to Road	Duration of Glances to Nav Aid
turn-by-turn with voice	1.80	0.95
turn-by-turn without voice	1.55	0.98
route map with voice	1.65	1.05
route map without voice	1.42	1.16
paper direction	1.80	1.15
paper map	1.90	1.15

If a system is easy to use, one should be able to drive faster while using it and drive at a more constant/less variable speed (because more attention is available to monitor speed). In the TravTek data, the speed for the paper map condition was less than for other conditions. The paper map was more difficult to use, so drivers slowed down to compensate for this. However, speed and speed variance are correlated, so the speed variance also decreased.

None of the acceleration measures were reflective of differences in interface design, though there were fewer lane deviations (Table 37) and fewer abrupt braking incidents for better interfaces. The brake was depressed less time for better interfaces. While full statistics were not provided, this suggests that incident measures (e.g., counts of abrupt braking) are more sensitive to interface differences than continuous measures of the same characteristic (e.g., variance of negative longitudinal acceleration).

Table 37. Number of lane deviations by interface type.

Interface	Number of Lane Deviations
turn-by-turn with voice	20
turn-by-turn without voice	18
route map with voice	30
route map without voice	26
paper direction	31
paper map	27

Table 38 shows the result of the workload analysis. In brief, all of the workload ratings were sensitive to differences in interface design.

Table 38. TravTek workload ratings.

Measure	p-value
overall workload	0.001
workload-time stress	0.001
workload-visual effort	0.001
workload-psychological stress	0.001
all high workload ratings	no test

Note: All high workload ratings refers to those instances where the ratings on all three dimensions were high (=3) for some situation.

Table 39 shows the navigation measures, all of which were highly significant. In brief, drivers took less time to plan and drive to destinations with better interfaces (Table 40), stopped less often while enroute (Table 41), and had shorter stops.

Table 39. TravTek navigation measures.

Measure	Significance	Better interfaces required...
trip planning time	0.0001	less time to plan
time to drive to a destination	0.0001	less time to drive
time to plan and drive	0.0001	less time to plan and drive
number of stops	0.0003	fewer stops enroute
mean duration of stops	0.0001	shorter stops enroute

Table 40. Driving time.

Interface	Drive Time (s)
turn-by-turn with voice	1200
turn-by-turn without voice	1250
route map with voice	1300
route map without voice	1400
paper direction	1250
paper map	1500

Table 41. Number of stops.

Interface	Number of Stops
turn-by-turn with voice	9.0
turn-by-turn without voice	9.5
route map with voice	10.0
route map without voice	11.4
paper direction	10.1
paper map	14.0

Table 42 shows the measures of unsafe driving, all of which were counts. Two other measures of unsafe driving that also fit in other categories (lane deviations, all high workload ratings) were described previously. Particularly noteworthy was the sensitivity of the driver error measures to interface differences. More direct measures of safety (accidents, near misses) were not able to detect differences because of the lack of data.

Table 42. TravTek measures of unsafe driving.

Unsafe driving (number of..)	Outcome
accidents	no accidents recorded
near misses	too few to distinguish
driver errors-hazard present	fewer with better interfaces
driver errors-hazard absent	fewer with better interfaces
driver errors-severe incident	fewer with better interfaces
single glances>2.5 s	fewer with better interfaces
reactions to external events	too few to distinguish
slow speed errors	fewer with better interfaces
stopping in unsafe circumstance errors	too few to distinguish
dangerously close headways	too few to distinguish
combined risk assessment (not number of...)	some diffs

One of the more interesting extensions of the TravTek work is a comparison of the eye fixation data from that experiment with another experiment examining the Etak navigator, a point on a map navigation system. Four conditions were compared. (See Table 43.) There were a moderate number of similarities in the findings.

Table 43. Eye fixation data comparison - TravTek versus Etak.

Comparison	Comment
paper map conditions with each other	very slight differences in the frequency of use of paper maps between the two studies (7 percent for Etak, 3 percent for TravTek), mostly because of methodological differences in the data collection protocol and the interface design, also differences in scanning off road
the Etak navigator condition with the TravTek route map without voice	similar, but more time on road with TravTek as it provided guidance.
the Etak memorized route with the TravTek printed list of directions	major differences between the Etak navigator and TravTek route map conditions, primarily because the first involved an unknown destination
three TravTek conditions with each other (turn-by-turn with voice, turn-by-turn without voice, route map with voice)	voice reduces glances to the display and increases them to the road (center)

In the Orlando Test Network experiment in the TravTek field test (Inman, Fleischman, Dingus, and Lee, 1993), subjects drove three different routes using the six navigation aids. Providing the TravTek interface in any form reduced trip planning time by 81 percent (from about 7 minutes to just over 1), though differences between the various TravTek implementations were absent. Travel time was also reduced from 27 minutes to 22, though differences between navigation aids were not statistically significant. In terms of the number of wrong turns, no statistically significant differences were found.

Perez, Fleischman, Golembiewski, and Dennard (1993) (see also Fleischman, Thelen, and Dennard, 1993) describe results from the Rental User Evaluation of the TravTek project. Three navigation configurations were examined: (1) services (which provides a services and attractions directory and maps of the local area and emergency services), (2) navigation (which includes services functions plus turn-by-turn display-based guidance with a voice) and (3) navigation plus (everything in condition 2 plus real-time traffic information. Data were obtained from a sample of 1012 rental drivers. When provided, TravTek features were used on 70 percent of the trips by drivers, whereas services-only functions were used on only 30 percent of the trips. Turn-by-turn displays were present about 80 to 85 percent of the time, route map displays the remaining time.

Drivers found the TravTek interface to be reasonably easy to learn and understand, and helpful in finding their way. They were positive, but less so in terms of its interference with driving (1=strongly disagree, 6=strongly agree; 2.19 for services, 2.08 for navigation, 2.09 for navigation plus). In terms of helping with driving, the mean ratings were 2.45, 4.52, and 4.60 respectively. Thus, providing voice consistently improved ratings. In fact, 70 to 75 percent of the drivers pressed the repeat voice key at least once during the rental period, though it was repeatedly used on only 12 percent of the trips.

UMTRI on-road experiments

In this project, three on-road experiments were conducted, a pilot test and two major evaluations (Green, Williams, Serafin, and Paelke, 1991 and Green, 1993a). In the first large experiment 43 drivers were guided over a 19-turn, 35-minute route by one of three turn-by-turn navigation systems (instrument panel-based, HUD-based, or auditory). Table 44 shows some of the measures collected and their significance levels. Note that very few measures were significant.

Table 44. P-values from the second experiment

Measure	Age	Sex	Age* Sex	Int'face	Location (6)	Loc. * Int'face	Loc* Age	Loc* Sex	Age* Int'face	Sex* Int'face
Mean steering wheel angle (deg.)	0.22	0.13	0.08	0.60	0.0001		0.17	0.72		
Standard deviation of steering wheel angle (deg.)	0.14	0.07	0.06	0.004	0.0001	0.09	0.75	0.31	0.51	0.40
Mean throttle position (%)	0.075	0.36	0.04	0.055	0.0001	0.62	0.004	0.35	0.018	0.17
Standard deviation of throttle position (%)	0.78	0.16	0.21	0.17	0.31		0.71	0.89		
Mean lateral position (ft)	0.69	0.13		0.005	0.17	0.79	0.20	0.85		0.01
Standard deviation of lateral position	0.78	0.75		0.88	0.79	0.49	0.90	0.88		0.34
Mean speed (mi/h)	0.76	0.83	0.50	0.32	0.0001	0.34	0.08	0.22	0.17	0.29
Standard deviation of speed (mi/h)	0.33	0.99	0.40	0.21	0.42	0.42	0.23	0.35	0.89	0.012

Note: Empty cells indicate factors not included in some of the models. Location refers to the road segment differences.

In a third experiment (see Green, Hoekstra, and Williams, 1993), 8 drivers drove an enlargement of the route used in the previous experiment. The route contained additional baseline sections. The sections involving use of the navigation interface were unchanged. Table 45 shows the significance levels of the performance variables examined.

Table 45. Levels of significance achieved in the third experiment.

Measure	Age	Location (6)	Age * Loc.
Mean steering wheel angle (deg.)	0.19	0.0002	0.96
Standard deviation of steering wheel angle (deg.)	0.04	0.03	0.91
Mean throttle position (%)	0.76	0.0001	0.32
Standard deviation of throttle position (%)	0.71	0.85	0.76
Mean lateral position (ft)	0.0001	0.009	0.96
Standard deviation of lateral position	0.82	0.24	0.89
Mean speed (mi/h)	0.04	0.0001	0.85
Standard deviation of speed (mi/h)	0.95	0.74	0.40

Because it is a more direct measure of driver behavior, the standard deviation of steering wheel angle may be a more sensitive measure of attentional demands than lateral standard deviation, though, as noted in the introduction, the lane tracker data are not as sensitive as they could be because only one edge marking was tracked. That measure was affected by driver age (30 and younger versus over 60) and the speed limit of the road on which the data was collected. The standard deviation of steering wheel angle was 0.8 degrees for the baseline condition and slightly larger, 0.9 degrees, for segments where the navigation system was used. These data suggest that use of the navigation system had only a minor effect on driving behavior.

APPENDIX B - INSTRUMENTED CAR ILLUSTRATIONS

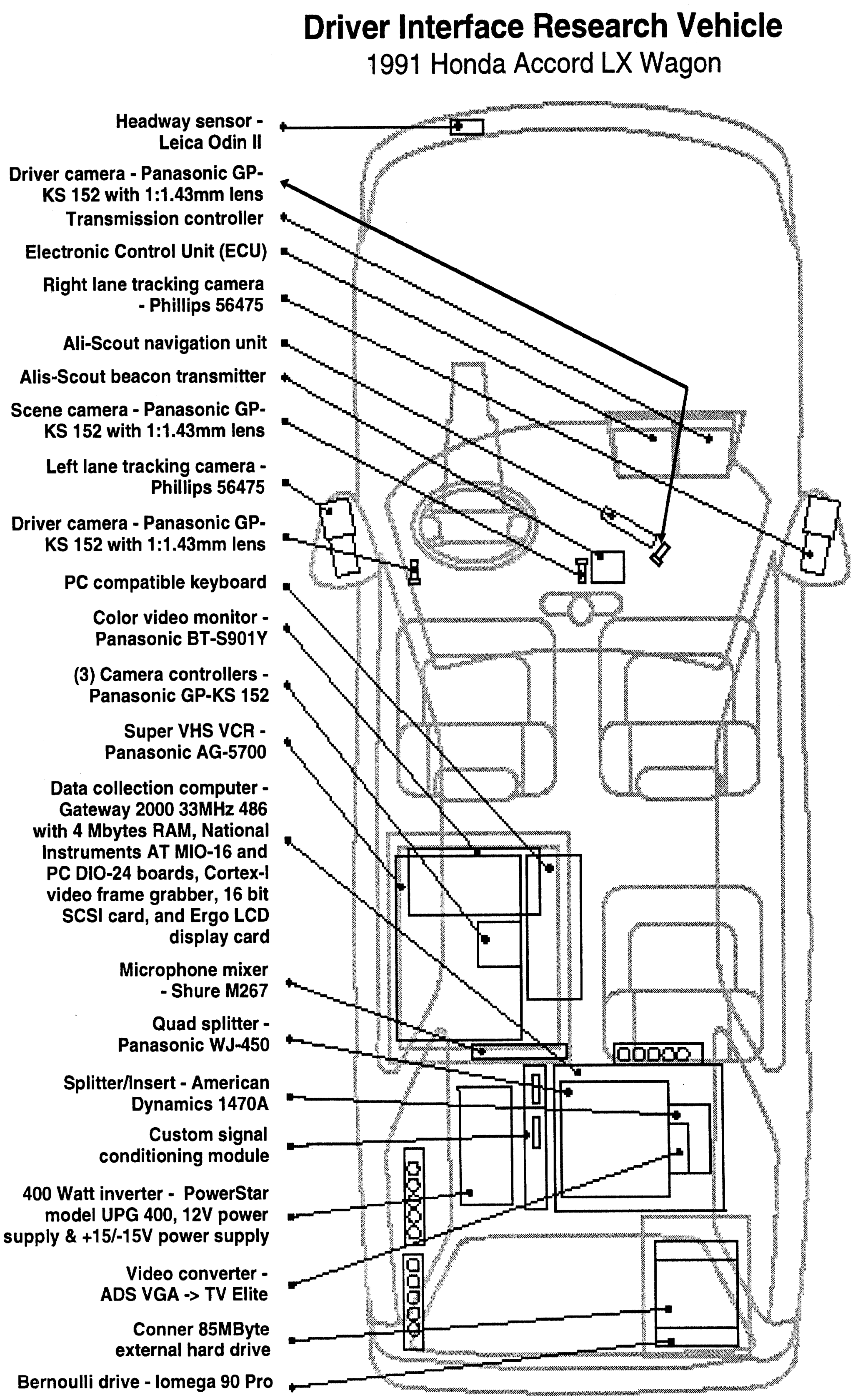


Figure 89. Equipment installed in the test vehicle during main experiment.

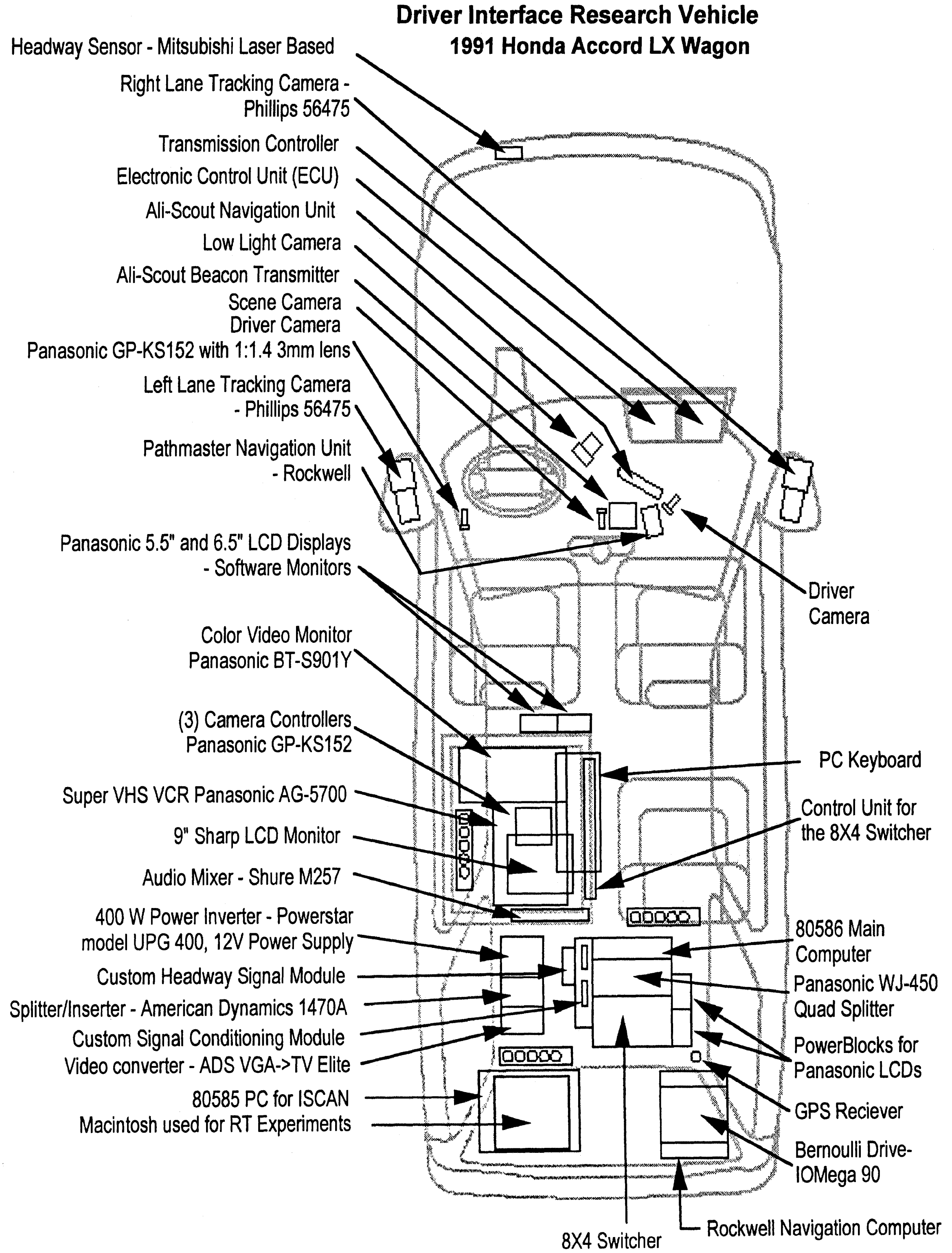
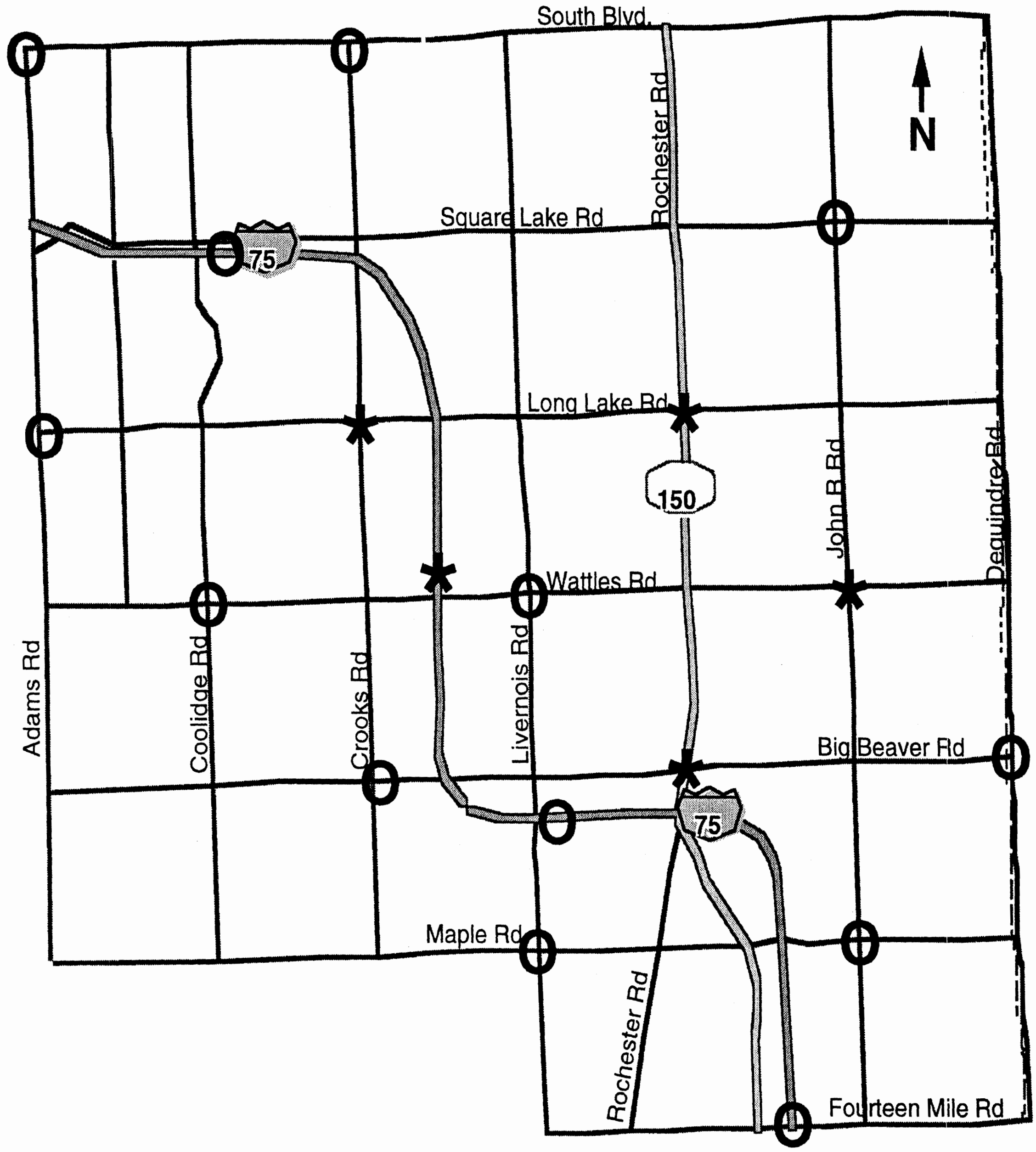


Figure 90. Equipment installed in the test vehicle during supplemental experiment.

APPENDIX C- ACTIVE BEACONS IN TROY

Eighteen beacons were active in the city of Troy at the time the experiment began, five of these were used on the test route of this experiment. Beacons that were active at the time of experimentation, but not used on the test route of this experiment are indicated with an **O** in the figure below. Beacons used on the test route of this experiment are indicated with an asterisk (✱).



APPENDIX D - CRITERIA FOR SELECTING DESTINATIONS

Several variables were taken into consideration when determining a test route for this experiment. Destination selection was mainly dependent on Ali-Scout performance. The following are a list of factors considered when selecting destinations:

1. Each destination had to be located near a beacon to maximize the guided information provided by the Ali-Scout. The closer to the starting point that the beacon was located, the less time the Ali-Scout remained in autonomous mode.
2. A variety of left and right turns were desired to test Ali-Scout performance.
3. A variety of road types, including highway, one-lane residential streets, and heavy traffic two-lane roads were desired, to determine under which conditions the unit would be most effective.
4. To avoid midtest route changes, roads with construction were avoided. The city of Troy provided help in identifying ongoing construction on city roads.
5. To make the results generalizable, a variety of destinations were desired including residential, small commercial, and large industrial locations.
6. The size and location of the destination's label (sign/ name) should be reasonably visible. Some destinations had large, prominent labels, while others were small. All signs were clearly visible from the road and were back-lit at night, with the exception of the Cumberland Dr. street sign which had large street lights overhead so that the sign was illuminated from the road.
7. The destination should be well lit. To enhance the safety and comfort of both the subject and the experimenter for night testing, each destination was near parking lot or street lights.

APPENDIX E - DESTINATION APPEARANCE AND ATTRIBUTES

The building and sign attributes of each destination are described in Table 46 below.

Table 46. Destination building and sign attributes

Destination Name	Building type, height, and dist. from Rd. (ft)	Sign size, location, and dist. from Rd. (ft)
SOC Credit Union	•Large industrial •3 floors •298 ft from road	•Large sign located on 3rd floor of building. •298 ft from road
Honeybaked Ham	•Large industrial •2 floors •80 ft from road	•Large sign located on 2nd floor of building. •80 ft from road
Harlan Plaza	•Small commercial •1 floor •174 ft from road	•Large sign located at the side of the road. •31 ft from road
Cumberland Dr.	•Residential street •1 lane	•Small street sign located at the side of the road at the intersection. •21 ft from road
Maplewood Plaza	•Small commercial •1 floor •61 ft from road	•Small sign located at the side of the road. •39 ft from road

Subjects were asked to meet experimenters in front of Liberty Center office building. The Liberty Center consists of two identical buildings next to one another. Figure 91. shows the building where the FAST-TRAC office was located as well as the area where experimenters waited outside to meet each subject.

Figure 91. Liberty Center, experiment headquarters

The first destination of the original experiment was SOC Credit Union. Figure 92. shows the building and the driveway leading into the parking lot. The building's sign is located on the top, left corner of the building. In addition, there is a street (Corporate Dr.) not pictured in Figure 92, which leads to the back of the SOC Credit Union. Corporate Dr. is to the right of the building's parking lot.

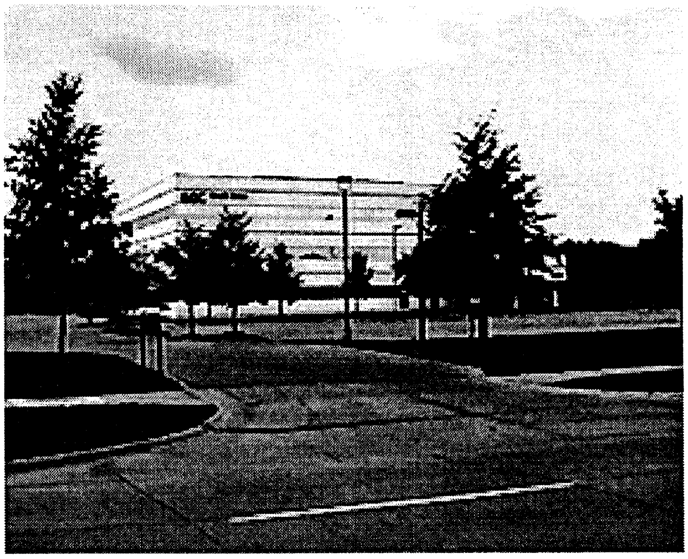


Figure 92. SOC Credit Union

The first destination of the supplement experiment was changed from SOC Credit Union to Honeybaked Ham, for reasons described in the test plan of the supplemental experiment. Figure 93 shows the building and the driveway leading into the parking lot. The building's sign is located on the top floor of the building.

Figure 93. Honeybaked Ham

The second destination of the experiment was Harlan Plaza. Figure 94 shows the building, sign, and one of the driveways leading into the parking lot. There is a second driveway leading into the parking lot directly to the right of the Harlan Plaza sign. Figure 95 shows Harlan Plaza's sign more closely.

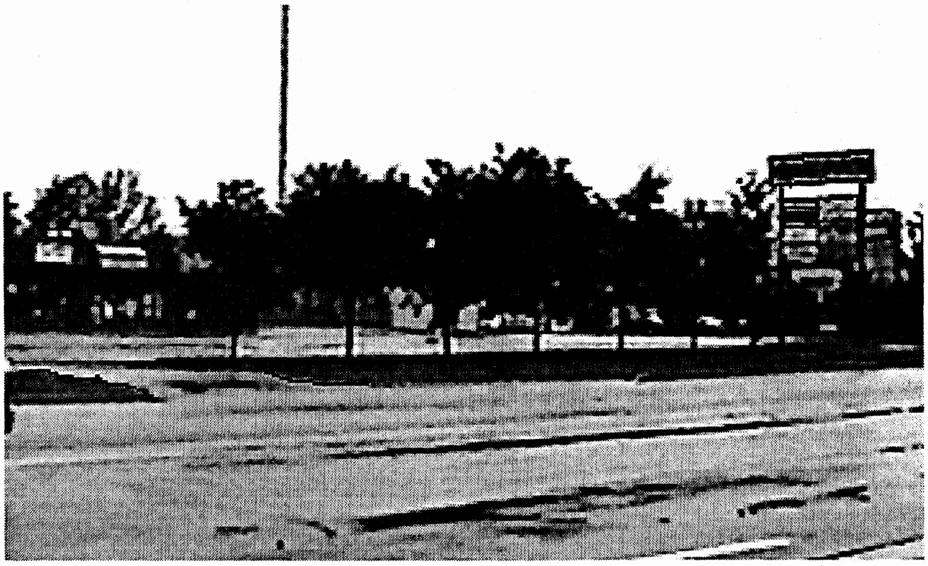


Figure 94. Harlan Plaza

Figure 95. Sign for Harlan Plaza

The third destination of the experiment was Cumberland Dr., a residential street. Figure 96 shows the intersection between John R Rd. and Cumberland Dr. There is a traffic light which is located directly above the intersection. The street sign for Cumberland Dr. is located to the left of the intersection and is shown more closely in Figure 97.

Figure 96. John R Rd. and Cumberland Dr. intersection

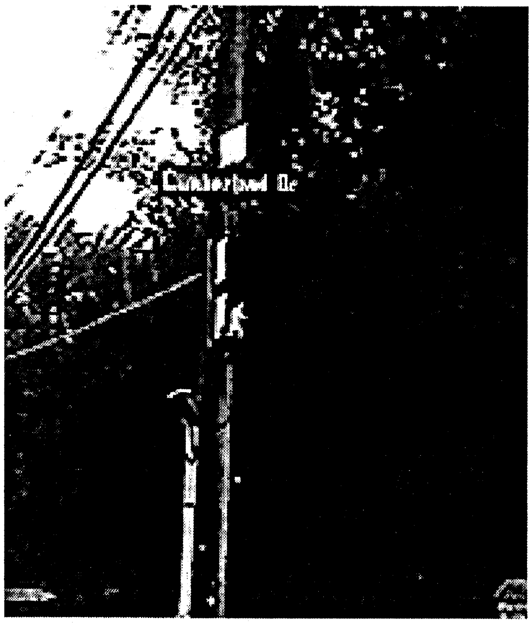


Figure 97. Cumberland Dr. street sign

The final destination of the experiment was Maplewood Plaza. Figure 98 shows the front half of the building, it's sign, and the driveway leading into the parking lot. Figure 99 shows Maplewood Plaza's sign more closely.

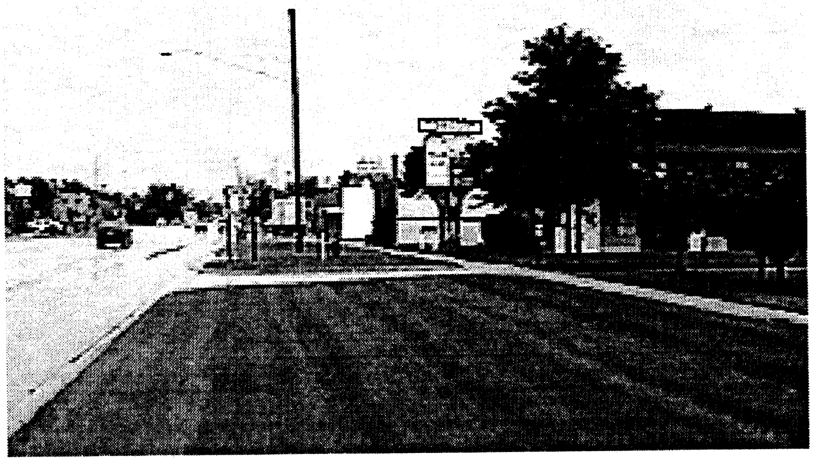


Figure 98. Maplewood Plaza

Figure 99. Maplewood Plaza sign

APPENDIX F - DETAILED DESCRIPTION OF THE TEST ROUTE

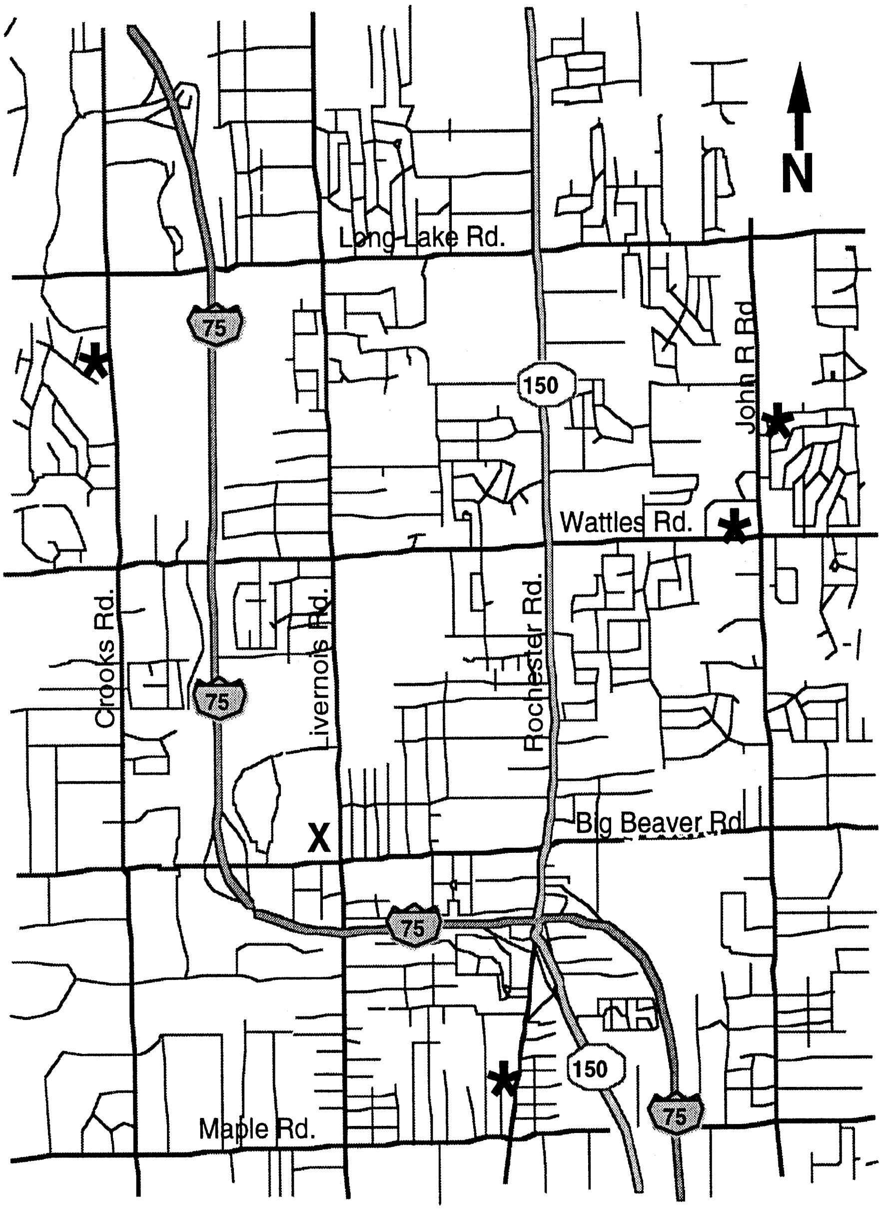


Figure 100. Map of the Troy area where testing took place.

Note: Destinations are identified with a star (*) and test headquarters with an x .

Destination 1

The first destination route began once the driver had merged onto the highway (see Figure 101). The Ali-Scout remained in autonomous mode for 3029 feet until the first beacon was passed. The Ali-Scout then switched into guided mode on the highway for 6724 feet. The driver was instructed by the Ali-Scout to exit the highway at Crooks Rd. The Ali-Scout gave instructions to turn left at the light at the end of the exit ramp. The driver then drove straight on a two-lane urban road which included one traffic light. The Ali-Scout switched into autonomous mode 925 feet prior to the right turn into the original destination 1 (SOC Credit Union) and 300 feet prior to the right turn into the supplement destination 1 (Honeybaked Ham). Route segment descriptions are given in Table 41.

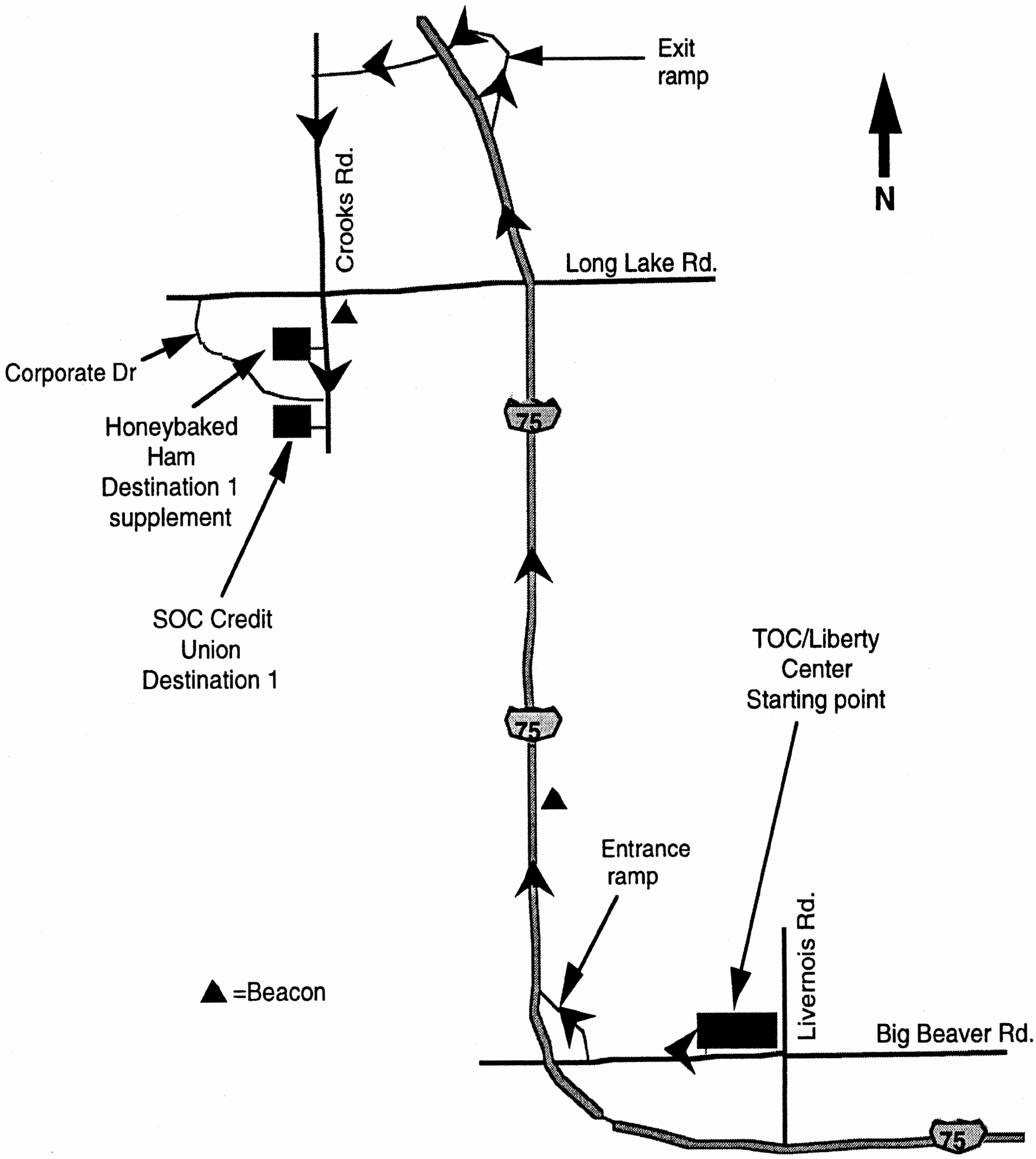


Figure 101. Map of test route to destination 1

Table 47. Route segment descriptions for the original destination one.

Route part	Road/ Direction traveled	Road Type	Road Description	Turn from road	Speed limit (mph)	Dist (ft)	# of traffic lights
1	I-75 north	3 lane freeway	Fairly straight	right	65	11592	0
2	I-75 exit ramp west	1 lane exit ramp off of freeway	Short, mild curve to the right , followed by a large loop to the left, straight jog to a traffic light at the intersection with Crooks	left	25	3781	1
3	Crooks Rd. south	2 lane heavily traveled	Straight to driveway into SOC Credit Union	right	45	3439	1

The parking lot of SOC Credit Union can be accessed by either of two drives. The first of these is a small one-lane road which the driver takes to enter the parking lot behind the building. The second entrance feeds directly into the parking lot. SOC Credit Union is a large 3-story commercial building. The structure stands 298 feet from Crooks Rd. and is 605 feet from the nearest building to either side. The SOC Credit Union sign is located on the third floor of the building and is illuminated at night.

Table 48. Route segment descriptions for the supplement destination one.

Route Part	Road/ Direction traveled	Road Type	Road Description	Turn from road	Speed limit (mph)	Dist (ft)	# of traffic lights
1	I-75 north	3 lane freeway	Fairly straight	right	65	11592	0
2	I-75 exit ramp west	1 lane exit ramp off of freeway	Short, mild curve to the right , followed by a large loop to the left, straight jog to a traffic light at the intersection with Crooks	left	25	3781	1
3	Crooks Rd. south	2 lane heavily traveled	Straight to driveway into Honeybaked Ham	right	45	2514	1

There is only one drive which accesses the parking lot of Honeybaked Ham. Honeybaked Ham is a two story large industrial building. The structure stands 80 feet from the road. The Honeybaked Ham sign is located on the second floor of the building and is illuminated at night.

Destination 2

The second destination route begins once the driver is headed northbound on Crooks Rd. (see Figure 102). The driver must travel in autonomous mode to a traffic light, where he/she must decide to turn right onto Long Lake Rd., which is also a two-lane urban road. The Ali-Scout switches into guided mode approximately 463 feet after turning onto the road. The road consists of two additional traffic lights, and merges into a one-lane road after the intersection at Livernois Rd. The Ali-Scout instructs the driver to turn right onto Rochester Rd. which is a heavily-traveled two-lane road. At the intersection between Rochester Rd. and Wattles Rd. the Ali-Scout tells the driver to turn left onto Wattles Rd. Wattles Rd. is a one-lane urban road. The subject travels along this road for 2337 feet in guided mode, and 1987 feet in autonomous mode. The driver must then turn left into the parking lot of destination 2 (Harlan Plaza). Route segment descriptions are given in Table 49.

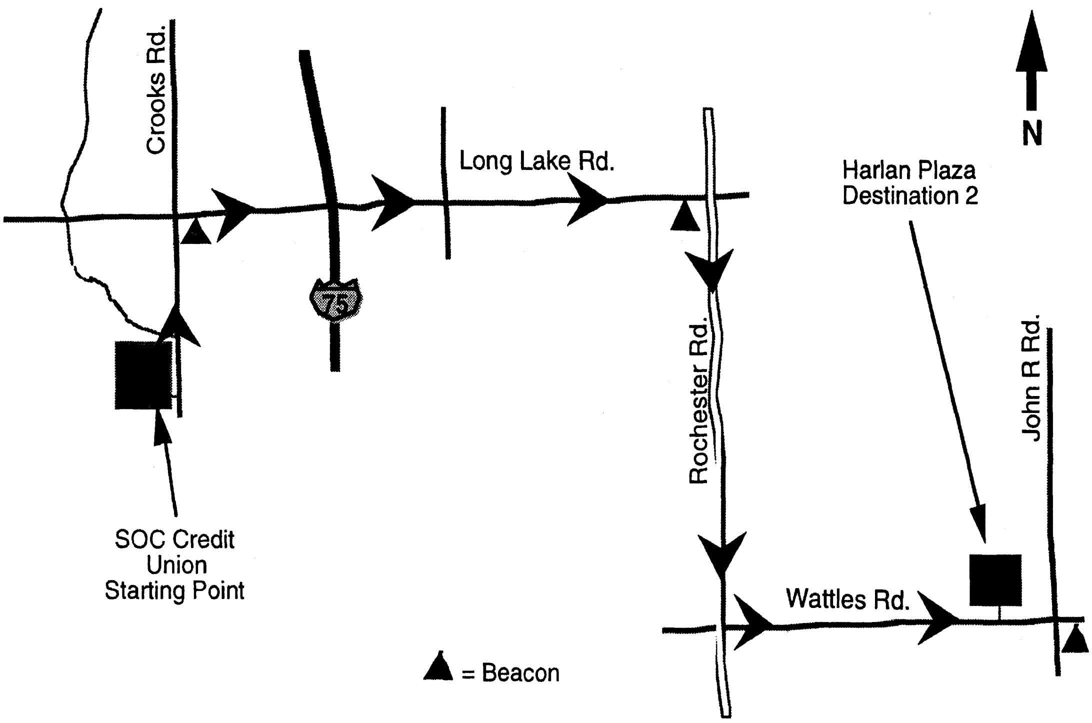


Figure 102. Map of Test Route to Destination 2

Table 49. Route segment descriptions for Destination 2.

Route part	Road/ Direction traveled	Road Type	Road Description	Turn from road	Speed limit (mph)	Dist (ft)	# of traffic lights
1	Crooks Rd. north	2 lane heavily traveled	Straight to traffic light at the intersection with Long Lake	right	45	1227	1
2	Long Lake Rd. east	2 lane/1 lane heavily traveled	Straight, merges into one lane after second traffic light. Leads to traffic light at intersection with Rochester Rd.	right	45	10560	3
3	Rochester Rd. south	2 lane heavily traveled	Straight to traffic light at intersection with Wattles	left	45	5280	2
4	Wattles Rd. east	1 lane moderately traveled	Straight to driveway into Harlan Plaza	left	40	4324	0

The parking lot of Harlan Plaza may be accessed by either of two drives, both lead directly into the parking lot. Harlan Plaza is a single story small commercial building, consisting of 6 small stores. The structure stands 174 feet from the road and is only 75 feet from the nearest building to either side. The Harlan Plaza sign stands separately in front of the building, 31 feet from the side of the road. It is quite large and is illuminated at night.

Destination 3

The third destination route begins once the driver makes a left turn out of Harlan Plaza's parking lot (see Figure 103). This destination differs from all others because it consists entirely of the Ali-Scout's autonomous mode. The driver travels to the traffic light at the corner of Wattles Rd. and John R Rd. where a left turn is made onto John R Rd. This is a two-lane urban road. The subject then makes a right turn onto destination 3 (Cumberland Dr.). Route segment descriptions are given in Table 50.

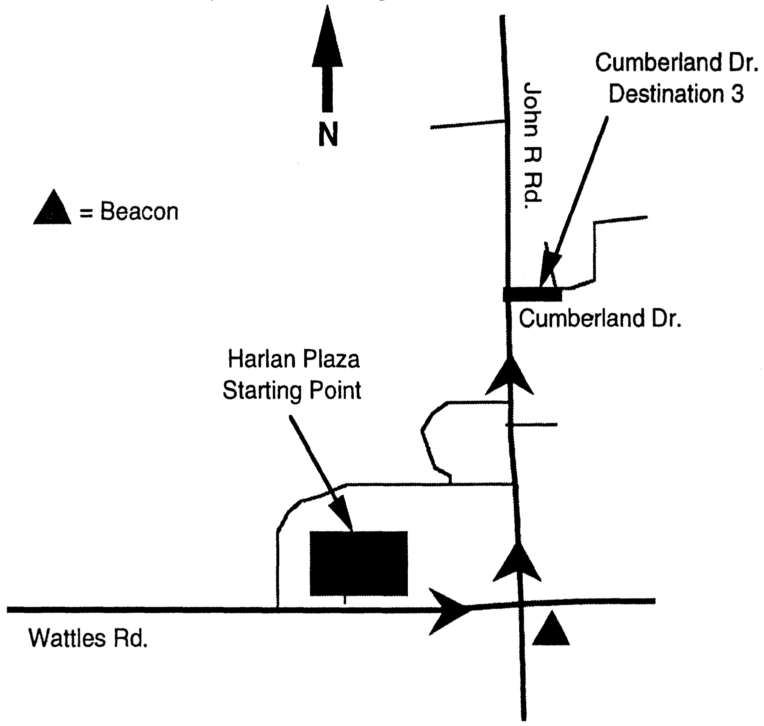


Figure 103. Map of test route to destination 3

Table 50. Route segment descriptions for Destination 3.

Route part	Road/ Direction traveled	Road Type	Road Description	Turn from road	Speed limit (mph)	Dist (ft)	# of traffic lights
1	Wattles Rd. east	1 lane moderately traveled	Straight to traffic light at intersection with John R	left	40	384	1
2	John R Rd. north	2 lane moderately traveled	Straight to traffic light at intersection with Cumberland Dr.	right	45	1641	1
3	Cumberland Dr. east	1 lane residential	Straight until parked		25		0

Cumberland Dr. travels strictly eastbound, and therefore, may only be accessed by making a right turn at the traffic light on John R Rd. Cumberland Dr. is a small one-lane residential road located about 800 feet from the nearest drive on either side. The Cumberland Dr. sign is located 21 feet from the street, and is the size of a standard street sign. Although the sign is not illuminated, overhead street lights are located at the intersection and the sign is easily visible at night.

Destination 4

The fourth destination route begins after the driver has already made a right turn onto Wattles Rd. from John R Rd. (see Figure 104). The Ali-Scout switches into guided mode almost immediately upon beginning the route. The driver then travels on Wattles Rd. to the traffic light at Rochester Rd. The Ali-Scout instructs the driver to make a left turn onto Rochester Rd. This stretch consists of four traffic lights. The driver then is instructed by the Ali-Scout to make a right turn onto a continuation of Rochester Rd., this is a large right curve, followed by a large left curve which turns into a straight two-lane urban road. The driver makes a right turn into destination four (Maplewood Plaza). Route segment descriptions are given in Table 51.

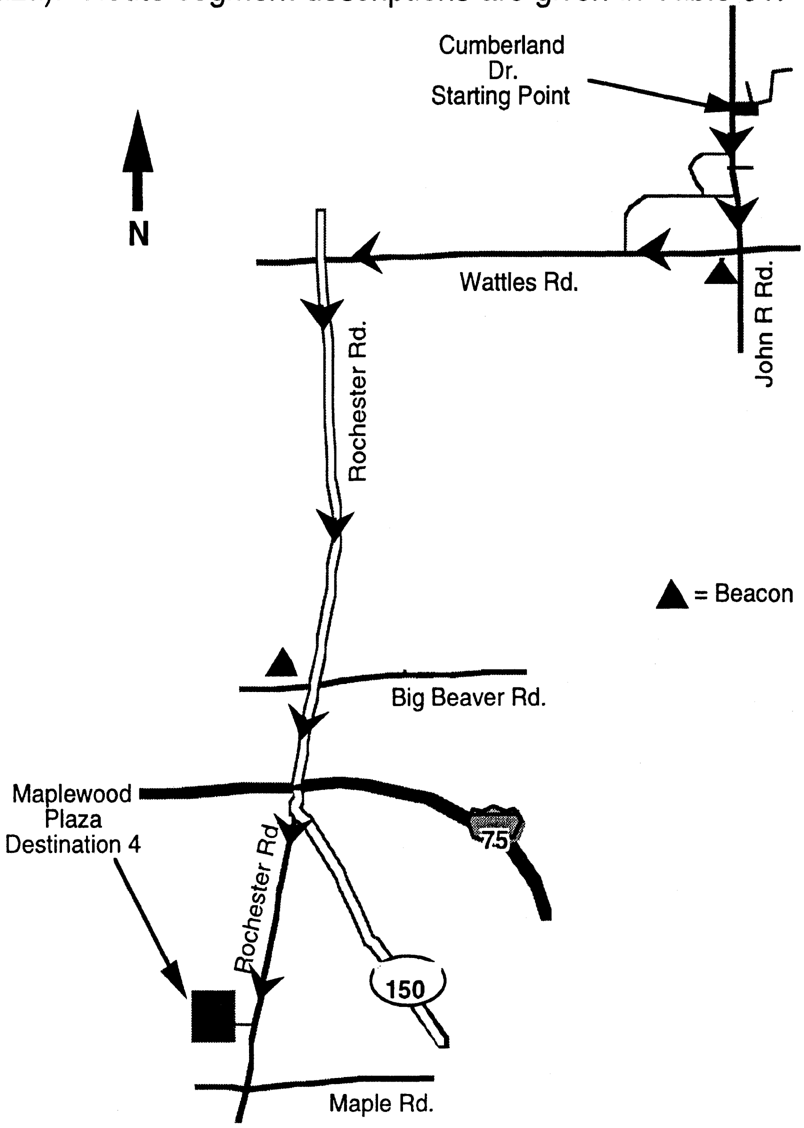


Figure 104. Map of test route to destination four.

Table 51. Route segment descriptions for destination four.

Route part	Road/ Direction traveled	Road Type	Road Description	Turn from road	Speed limit (mph)	Dist (ft)	# of traffic lights
1	Wattles Rd. west	1 lane moderately traveled	Straight to traffic light at the intersection with Rochester Rd.	left	40	4461	1
2	Rochester Rd., prior to becoming Stevenson Highway south	2 lane heavily traveled	Straight to a split between Stevenson Hwy. and Rochester Rd.	right	45	7566	4
3	Rochester Rd. south	2 lane moderately traveled	Large curve to the right, followed by a large left curve, then straight to driveway into Maplewood Plaza	right	35	4475	0

There is only one drive which accesses the parking lot of Maplewood Plaza. Maplewood Plaza is a single story small commercial building, consisting of 4 small stores and one larger store. The structure stands 61 feet from the road and is only 75 feet from the nearest building to either side. The Maplewood Plaza sign stands separately in front of the building, 39 feet from the side of the road. It is a moderate size and is illuminated at night.

APPENDIX G - INSTRUCTIONS TO SUBJECTS FOR SESSION 1

When subjects arrive at Liberty Center

Hi, My name is (experimenter's name). **Thank you for coming today. Let's go to the office and get started.**

Before we begin I would like to show you a videotape so that you may become familiarized with the FAST-TRAC project and the Ali-Scout unit itself. Please pay close attention to the section that describes Ali-Scout's use on the road.
Show video

Overview
This study will consist of two on-the-road sessions that take about an hour each. You will be paid a total of $50 for your time. After each session you will receive $15, and upon completion you will receive a bonus of $20. During your second session we will ask you to drive the route twice, once with the Ali-Scout, and once with explicit directions given to you by the experimenter. You will be driving an automatic transmission Honda Accord station wagon on public roads in Troy. We ask that you follow all traffic laws and speed limits while driving, if you do not comply with these safety measures, the experiment may be stopped by the experimenter.

The ALI-SCOUT system will give you spoken instructions, as well as visual cues to reach a certain destination. At some points during the experiment, the ALI-SCOUT may go into autonomous mode, and will not give you specific directions. We would like you to make your own decisions on where to turn when the system is in autonomous mode. We are interested in the driver's accuracy in reaching destinations using the ALI-SCOUT.

We ask that you simply follow the instructions that the navigation system gives to you. If you have passed the destination and circle the area, or become lost trying to locate the destination, we will stop you and enter the next destination.

You will be videotaped throughout the entire experiment, for analysis purposes. One camera is mounted below the Ali-Scout unit, and the other is mounted to the A-pillar frame on your left.

Consent and Bio Forms
First, please read and sign this consent form, and then fill out the biographical form. If you have any questions feel free to ask them at any time.
Provide consent and biographical forms. Check that it is legible and complete.

It is necessary that we check your eyesight before we begin the experiment.
Check eyesight with Titmus Vision tester.

I also need to see your driver's license.
Check license.

<u>At the test vehicle</u>
Let me reiterate a few important points from the consent form. First of all, driving safely is your main priority. If you feel unsafe or unable to make any turn, please don't. Second, if you are uncomfortable or wish to stop at any time, please let me know right away. You are expected to obey all speed limits and driving laws.

Let me stress a couple of points about driving with the ALI-SCOUT system. Remember that the bars on the upper right side of the screen are there to indicate how far away you are from a turn, please use the bars to help you when coming up on a turn. Secondly, watch the miles on the bottom right of the screen, which indicate how far you are from your destination, this will especially help you in autonomous mode. Remember that when the system is in autonomous mode an arrow will appear pointed in the general direction of your destination, as if it were looking down on a map and pointing in a straight line from your current position to your destination. Please remember that when you start out and when you get within a quarter mile of your destination the ALI-SCOUT will be in autonomous mode. This means that the system will not give you turn by turn directions and we ask that you make your best judgment concerning where to turn. The Ali-Scout will not give you specific directions to your destination, therefore, you must look for the destination once the Ali-Scout switches into autonomous mode (i.e. quarter mile).

Please fasten your seat belt, adjust the seat, mirrors, steering wheel height, as you feel necessary.

- Adjust the car seat, steering wheel height, and side and rear-view mirrors.
- Fasten seat belt.
- Point out climate controls, the radio may not be operating during experimentation.
- Adjust eye fixation camera once subject is comfortable.
- Remind about following speed limit.

Let me enter the first destination into the ALI-SCOUT and enter the correct filename into the computer.
Update file name in computer.
Press record on the VCR.

- **You can now exit the parking lot to your left. Make a left at the end of the parking lot.**
- **Make a right turn at the stop sign ahead. There is a lot of construction in this area so please drive carefully.**
- **There is an orange 75-sign on your left just ahead. I would like you to make a right turn there to get onto I-75 north.**
- **From here on out I will ask that you follow the Ali-Scout's directions.**

start to collect data.

<u>At Destination 1</u>
Please pull into a parking space. I must save data and change the filename which will take me just a couple of minutes.
Update file name in computer.

Let me change the destination on the ALI-SCOUT.
Change destination.

- **You may exit the parking lot. We are going to turn right, but I would like you to get all the way over into the left hand lane where we will turn around, otherwise known as a Michigan Left.**
- **Please turn around here.**
- **From here on out please follow the Ali-Scout.**

start to collect data.

<u>At Destination 2</u>
Please pull into a parking space. I must save data and change the filename which will take me just a couple of minutes.
Update file name in computer.

Let me change the destination on the ALI-SCOUT.
Change destination.

Because the next destination is so close to Harlan Plaza, the Ali-Scout will not have time to go into guided mode. Therefore, you will be driving in autonomous mode during the entire trip to Cumberland Dr. You may now exit the parking lot and follow the Ali-Scout.
start to collect data.

<u>At Destination 3</u>
Please turn left onto Lancashire Ct. and go all the way around the cul-de-sac at the end of the road. You can pull over on the side of the road while I save data and change the filename which will take me just a couple of minutes.
Update file name in computer.

Let me change the destination on the ALI-SCOUT.
Change destination.

- **You can take a right at the yield sign.**

- **Make a left turn at the light ahead. Please take note of the "stop here to activate light" sign.**
- **I'm going to ask you to make a right at the next intersection, you probably wouldn't guess that just by looking at the Ali-Scout.**
- **You may now follow the Ali-Scout.**

start to collect data.

<u>At Destination 4</u>
Please pull into a parking space so I can save data.

At this point we are finished with the first session, so you can take the passenger seat and I will drive us back to our starting point.

<u>At TOC-Test Headquarters</u>
If you could come up to the office with me, I would like you to fill out a survey and a payment form, so that I can get you your money for today.
Fill out forms.
Schedule next appointment for session 2.

Thank you for participating today, I will see you next week.

APPENDIX H - ALI-SCOUT MANEUVER INSTRUCTIONS

Table 52. Ali-Scout guidance to destination one.

Ali-Scout Mode	Ali-Scout Audio Cues and Instructions	Location/Starting Point Along Test Route	Direction Traveling	Section Length (miles)
Autonomous		Entrance ramp, 0.35 miles prior to merging onto I-75	North on I-75	1.09
Guided	Chime indicating change from autonomous to guided	1.2 miles prior to exit ramp off I-75 at Crooks Rd.	North on I-75	0.64
Guided	"Take the right hand lane"	0.56 miles prior to exit ramp off I-75 at Crooks Rd.	North on I-75	0.46
Guided	"Turn right"	0.1 miles prior to exit ramp off I-75 at Crooks Rd.	North on I-75 to west on exit ramp	0.75
Guided	"Take one of the left hand lanes"	0.23 miles prior to intersection between exit ramp and Crooks Rd.	West on exit ramp off I-75	0.18
Guided	"Turn left"	0.05 miles prior to intersection between exit ramp and Crooks	West on exit ramp off I-75 to south on Crooks Rd.	0.69
Autonomous	Chime indicating change from guided to autonomous	0.29 miles prior to driveway leading into SOC Credit Union	South on Crooks to west into SOC Credit Union	0.29

Table 53. Ali-Scout guidance to destination two.

Ali-Scout Mode	Ali-Scout Audio Cues and Instructions	Location/Starting Point Along Test Route	Direction Traveling	Section Length (miles)
Autonomous		0.28 miles prior to intersection between Crooks Rd. and Long Lake Rd.	North on Crooks Rd. to east on Long Lake Rd.	0.37
Guided	Chime indicating change from autonomous to guided	0.09 miles after intersection between Crooks Rd. and Long Lake Rd.	East on Long Lake Rd.	1.86
Guided	"Right turn ahead"	0.21 miles prior to intersection between Long Lake Rd. and Rochester Rd.	East on Long Lake Rd.	0.16
Guided	"Turn right"	0.05 miles prior to intersection between Long Lake Rd. and Rochester Rd.	East on Long Lake to south on Rochester Rd.	0.85
Guided	"Take the left hand lane"	0.2 miles prior to intersection between Rochester Rd. and Wattles Rd.	South on Rochester Rd.	0.18
Guided	"Turn left"	0.05 miles prior to intersection between Rochester Rd. and Wattles Rd.	South on Rochester Rd. to east on Wattles Rd.	0.52
Autonomous	Chime indicating change from guided to autonomous	0.52 miles prior to first driveway into Harlan Plaza	East on Wattles Rd. to north into Harlan Plaza	0.52

Table 54. Ali-Scout guidance to destination three.

Ali-Scout Mode	Ali-Scout Audio Cues and Instructions	Location/Starting Point Along Test Route	Direction Traveling	Section Length (miles)
Autonomous		Turn out of Harlan Plaza onto Wattles Rd.	East on Wattles to north on John R Rd. to east on Cumberland Dr.	0.46

Table 55. Ali-Scout guidance to destination four.

Ali-Scout Mode	Ali-Scout Audio Cues and Instructions	Location/Starting Point Along Test Route	Direction Traveling	Section Length (miles)
Autonomous		0.1 miles after intersection between John R Rd. and Wattles Rd.	West on Wattles Rd.	0.06
Guided	Chime indicating change from autonomous to guided	0.16 miles after intersection between John R Rd. and Wattles Rd.	West on Wattles Rd.	0.75
Guided	"Take the left hand lane"	0.2 miles prior to intersection between Wattles Rd. and Rochester Rd.	West on Wattles Rd.	0.17
Guided	"Turn left"	0.03 miles prior to intersection between Wattles Rd. and Rochester Rd.	West on Wattles to South on Rochester Rd. to Southeast on Stevenson Hwy.	1.48
Guided	"Take the right hand lane"	0.2 miles prior to split between Rochester Rd. and Stevenson Hwy.	Southeast on Rochester Rd.	0.14
Guided	"Turn right"	0.06 miles prior to split between Rochester Rd. and Stevenson Hwy.	Southeast on Rochester Rd.	0.05
Autonomous	Chime indicating change from guided to autonomous	At turn onto Rochester Rd. from split between Rochester Rd. and Stevenson Hwy.	Southwest on Rochester Rd.	0.53

APPENDIX I - SUBJECT BIOGRAPHICAL FORM

University of Michigan Transportation Research Institute
Human Factors Division
Biographical Form

Subject: [ ]

Date: [ ]

Name: ______________________________

Male Female (circle one) Age: ________

Occupation: ______________________________

Retired or student: Note your former occupation or major ______________

Education (circle highest level completed):

some high school	high school degree
some trade/tech school	trade/tech school degree
some college	college degree
some graduate school	graduate school degree

What kind of car do you drive most often?

Year: ________ Make: __________ Model: __________

Approximate annual mileage: ______________

Do you know where Maplewood Plaza is located?	Yes	No
Do you know where Harlan Plaza is located?	Yes	No
Do you know where Cumberland Dr. is located?	Yes	No
Do you know where SOC Credit Union is located?	Yes	No

How often do you use a computer?

Daily A few times a week A few times a month Once in a while Never

Corrected Vision:

20/15 20/20 20/25 20/30 20/40 20/50

APPENDIX J - SUBJECT CONSENT FORM

Subject #: ____________

ALI-SCOUT NAVIGATION STUDY
PARTICIPANT CONSENT FORM

The purpose of this experiment is to determine driver's ability to utilize the Ali-Scout navigation unit to reach a destination. The Ali-Scout is an in-car route guidance system which has a display that shows drivers where to turn, as well as auditory instructions. In this experiment, you will be driving to four destinations in Troy with the aid of the Ali-Scout. This experiment will be conducted in two different sessions. If you think you will be unable to attend both sessions, please tell the experimenter before the experiment begins. You will be driving in Troy.

During the two sessions you will be driving the same route, including four predetermined destinations. This experiment will test your ability to reach the correct destination with the aid of only the navigational unit and the address or name of the destination. You will not be asked to enter destinations into the Ali-Scout. You will be videotaped throughout the duration of the experiment by two small cameras located underneath the Ali-Scout unit, and on the frame of the car.

The complete experiment consists of two on-the-road tests. You will be paid $15 for the first part, $15 for the second part, and a $20 bonus upon the completion of both parts (a total of $50). Each session will take approximately 1 hour.

****

This experiment concerns the Ali-Scout navigation unit and is <u>not</u> a test of your driving skills. Remember, your priority is always to drive **safely.** You are expected to **obey all traffic and speed laws**. If you are not driving safely, you will be given one warning, after which the experiment can be stopped. Please tell the experimenter at any time if you feel you are unable to complete the study. Thank you for your participation.

****

I HAVE READ AND UNDERSTAND THIS DOCUMENT.

______________________	______________________
Print your name	Date
______________________	______________________
Sign your name	Witness (experimenter)

APPENDIX K - ROUTE KNOWLEDGE SURVEY

Subject # ________ Name: ________________________

Post-Drive Ali-Scout Route Knowledge Survey

	not at all				very
1) How familiar are you with driving in the city of Troy?	1	2	3	4	5
2) How familiar are you with the FAST-TRAC project in Oakland County?	1	2	3	4	5
3) Previous to today, how familiar were you with the Ali-Scout navigation system?	1	2	3	4	5

4) Have you ever driven a vehicle with another in-vehicle navigation system?

Yes No

4a) If yes, what system have you used? ________________________

5) Previous to today, did you know where Maplewood Plaza was located?

Yes No

6) Previous to today, did you know where Harlan Plaza was located?

Yes No

7) Previous to today, did you know where Cumberland Drive was located?

Yes No

8) Previous to today, did you know where Honeybaked Ham was located?

Yes No

9) When do you plan on buying your next (new or used) car?

Within 5 months 6-11 months 1-2 years 3-5 years 6+ years

9a) How much do you plan on spending? $________

10) How much would you pay for a route guidance system (like the Ali-Scout)?

$__________

Additional comments (optional)

____

____

____

____

Using all of your driving experience (not just what you did today), please rate the difficulty of performing each of these tasks while driving, using the scale below.

	not difficult							very	difficult
Reading the speed on the speedometer.........	1	2	3	4	5	6	7	8	9	10
Drinking a beverage..	1	2	3	4	5	6	7	8	9	10
Reading street names..	1	2	3	4	5	6	7	8	9	10
or air conditioner...	1	2	3	4	5	6	7	8	9	10

APPENDIX L - USABILITY SURVEY

Post-Drive Usability and Utility Questionnaire

		Strongly disagree				Strongly agree
1)	It is safe for me to use this system while driving.	1	2	3	4	5
2)	I would likely use this system for my daily travel.	1	2	3	4	5
3)	I would use this system if I were in a hurry.	1	2	3	4	5
4)	It is safe for an inexperienced driver to use this system while driving.	1	2	3	4	5
5)	The route guidance information provided is useful.	1	2	3	4	5
6)	The Ali-Scout was distracting.	1	2	3	4	5
7)	I would rather use a route guidance system similar to this one than use a standard paper road map to find my way.	1	2	3	4	5
8)	I would rather use a route guidance system similar to this than use written instructions to find my way.	1	2	3	4	5
9)	The Ali-Scout would be helpful in locating a destination that I have never visited before.	1	2	3	4	5
10)	The Ali-Scout would be helpful in driving to familiar locations.	1	2	3	4	5
11)	The Ali-Scout's autonomous mode was useful.	1	2	3	4	5
12)	The Ali-Scout's guided mode was useful.	1	2	3	4	5
13)	The arrow given in autonomous mode was useful.	1	2	3	4	5
14)	The miles to reach destination readout was useful.	1	2	3	4	5
15)	The auditory messages given in guided mode are useful.	1	2	3	4	5
16)	The auditory messages are given in ample time before a turn is to be made.	1	2	3	4	5
17)	The countdown bars to a turn in guided mode are useful.	1	2	3	4	5
18)	The turn graphics in guided mode are useful.	1	2	3	4	5
19)	The "follow current path"  graphic in guided mode is useful.	1	2	3	4	5

APPENDIX M - SUBJECT PAYMENT FORM

THE UNIVERSITY OF MICHIGAN
SUBJECT FEE PAYMENT FORM
NON-EMPLOYEE

DATE: ___/___/___

UNIVERSITY DEPARTMENT: **UMTRI (Human Factors)**

DEPARTMENTAL CONTACT PERSON & TELEPHONE #: **Denise Creque, 4-6506**

DEPARTMENTAL REFERENCE NUMBER: ACCOUNT NO. **032868**

UNIVERSITY ACCOUNT NUMBER: **ICF 2095**

STUDY NAME: **Ali-Scout Navigation Study**

TO BE COMPLETED BY VOLUNTEER:

____
Volunteer Name

____
Social Security #

____
Street Address

____
City, State, Zip

Are you a University of Michigan employee? Yes _____ No _____

I hereby acknowledge that I have received the below stated amount as full payment for my participation in the above described project.

____
Volunteer's signature

TO BE COMPLETED BY DEPARTMENT:

Amount: $_________Given from Cash Receipt Number (if applicable): _________

Authorized Signature: ______________________________
Paul Green

APPENDIX N - BASELINE GUIDANCE INSTRUCTIONS

We are now going to drive the same route a second time. This time I will give you explicit directions to each destination.

<u>Destination 1</u>
You may pull out and we are going to make a left turn out of the parking lot, onto Rochester Rd.
Subject turns left and follows Rochester Rd.
We will make a left turn up ahead at the light onto Stevenson Hwy., get into the right lane when you make this turn because we will make a right turn shortly.
Subject turns left.
We are going to get onto I-75 North up ahead, this entrance ramp will make a large loop to the right.
Subject enters highway.
Now we are going to stay on I-75 North until we reach Crooks Rd. which is exit #71 at which point you will exit to the right.
Following exit # 69 at Big Beaver Rd. the experimenter begins to save data.
The Crooks Rd. exit is just ahead. Exit to your right there.
Subject loops around on exit ramp towards Crooks Rd.
At the light ahead we will turn left onto Crooks Rd. You may turn from either one of the two farthest left lanes.
Subject turns left.
Our destination, SOC Credit Union, is on the right side of the road after this light at Long Lake Rd. You may pull into the parking lot from the farthest right lane.
Subject turns into destination 1.
Please pull into a parking space so I can save data.
experimenter saves date and enters new test parameters.

<u>Destination 2</u>
Okay, you may pull out. We are going to make a right out of the parking lot, but I want you to get all the way over into the left hand lane because we are going to turn around right away at a break in the median.
Subject turns at median.
We will make a right turn up at the light onto Long Lake Rd.
Subject turns right.
We will be driving straight along this road for about 2 miles.
Subject drives straight.
Make a right turn up at the light onto Rochester Rd.
Subject turns right.
We will make a left turn up ahead at the light onto Wattles Rd.
Subject turns left.
Harlan Plaza will be up ahead on the left side of the road. There is a big sign for the plaza just past this clump of trees. You can turn into the parking lot there.
Subject turns into destination 2.

Please pull into a parking space so I can save data.
experimenter saves data and enters new test parameters.

Destination 3
Okay, you may pull out. We are going to make a left turn out of the parking lot, but stay in the left lane of the road because we will make another left turn at the light just up the road.
Subject turns left out of parking lot.
Make a left turn at the light onto John R. Rd.
Subject turns left.
Cumberland Dr. is up ahead at the light. We will make a right turn onto Cumberland Dr.
Subject turns right.
Make a left turn here onto Lancashire Ct.. and go to the end of the street to turn around at the cul-de-sac. You may then pull over at the side of the road.
experimenter saves data and enters new test parameters.

Destination 4
Okay, we can make a right turn up ahead at the yield sign.
Subject turns right.
We are going to make a left turn out of the subdivision at the light ahead. Notice the "Stop here to activate light" sign.
Subject turns left.
We are going to make a right turn at the light up ahead onto Wattles Rd.
Subject turns right.
At the next light we will turn left onto Rochester Rd.
Subject turns left. Rochester Rd. turns into Stevenson Hwy.
We are going to turn right onto Rochester Rd. before the light up ahead. Please get into the farthest right lane.
Subject turns right.
Maplewood Plaza is up ahead on your right. The drive into the parking lot is right after the green Maple Rd. sign.
Subject turns into Maplewood Plaza.
Please park anywhere.
Experimenter saves data.

The experiment is now over. We can switch seats and I will drive us back to our starting point, the Liberty Center.

APPENDIX O - DETAILED ROUTE SECTION DESCRIPTIONS

Table 56. Section descriptions for destination one.

	Section One	Section Two	Section Three	Section Four	Section Five
Point begin	Entrance ramp to I-75 north	Ali-Scout change mode	Turn onto exit ramp	After left turn onto Crooks Rd.	Ali-Scout change mode
Point ends	Ali-Scout change mode	Turn onto exit ramp	Intersection between exit ramp and Crooks Rd.	Ali-Scout change mode	Turn into destination
Ali-Scout Mode	autonomous	guided	guided	guided	autonomous
Distance (miles)	1.09	1.11	0.72	0.36	0.29
speed limit (mi/hr)	65	65	25	45	45
direction traveling	north	north	northwest	south	south
# of traffic lights	0	0	0	1	0
Ali-Scout commands	none	"take the right hand lane" "turn right"	"take one of the left hand lanes" "turn left"	none	none
Other Characteristics	Driver must speed up to merge with traffic	Driver must slow down upon approaching exit ramp	Driver must slow down when exiting. The exit ramp curves		Driver must slow down to look for destination

Table 57. Section descriptions for destination two.

	Section 1	Section 2	Section 3	Section 4	Section 5	Section 6
Point begin	Directed by experimenter to Crooks Rd.	After right turn onto Long Lake Rd.	Ali-Scout change mode	After right turn onto Rochester Rd.	After left turn onto Wattles Rd.	Ali-Scout change mode
Point end	Intersection between Crooks Rd. and Long Lake Rd.	Ali-Scout change mode	Intersection between Long Lake Rd. and Rochester Rd.	Intersection between Rochester Rd. and Wattles Rd.	Ali-Scout change mode	Turn into destination
Ali-Scout Mode	autonomous	autonomous	guided	guided	guided	autonomous
Distance (miles)	0.23	0.09	1.91	1	0.44	0.38
speed limit (mi/hr)	45	45	45	45	40	40
direction traveling	north	east	east	south	east	east
# of traffic lights	0	0	2	1	0	0
Ali-Scout commands	none	none	"right turn ahead" "turn right"	"take the left hand lane" "turn left"	none	none
Other Charac-teristics			Road merges from two lanes to one lane			Driver must slow down to look for destination

Table 58. Section descriptions for destination three.

	Section 1	Section 2
Point begin	After left turn out of Harlan Plaza parking lot	After left turn onto John R Rd.
Point end	Intersection between Wattles Rd. and John R Rd.	Intersection between John R Rd. and Cumberland Dr.
Ali-Scout Mode	autonomous	autonomous
Distance (miles)	0.07	0.31
speed limit (mi/hr)	40	45
direction traveling	east	north
# of traffic lights	0	0
Ali-Scout commands	none	none
Other Characteristics		Driver must slow down to look for destination

Table 59. Section descriptions for destination four.

	Section 1	Section 2	Section 3
Point begin	After right turn onto Wattles Rd.	After left turn onto Rochester Rd.	After right turn onto Rochester Rd. split
Point end	Intersection between Wattles Rd. and Rochester Rd.	Intersection where Rochester Rd. splits into Stevenson Hwy.	Turn into destination
Ali-Scout Mode	guided	guided	autonomous
Distance (miles)	1	1.43	0.42
speed limit (mi/hr)	40	45	35
direction traveling	west	south	southwest
# of traffic lights	0	4	0
Ali-Scout commands	"take the left hand lane" "turn left"	"take the right hand lane" "turn right"	none
Other Characteristics			Driver must slow down to look for destination

APPENDIX P - QUESTIONNAIRE ANOVAS

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Time	2	.013	.007	.011	.9894
Sex	1	.599	.599	.981	.3241
Age Group	2	6.446	3.223	5.277	.0065
S-Nest (Sex, Age Group)	45	69.039	1.534	2.512	.0001
Question	2	56.924	28.462	46.598	.0001
Sex * Age Group	2	2.014	1.007	1.648	.1970
Time * Age Group	4	3.695	.924	1.512	.2034
Residual	112	68.409	.611		

Dependent: Safety

Since Time * Age Group was not significant, that factor was not included in subsequent models. The revised table for safety ratings follows.

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Time	2	.011	.006	.009	.9910
Sex	1	.630	.630	1.032	.3119
Age Group	2	6.734	3.367	5.513	.0052
S-Nest (Sex, Age Group)	49	72.733	1.484	2.430	.0001
Question	2	56.924	28.462	46.598	.0001
Sex * Age Group	2	2.181	1.091	1.786	.1724
Residual	112	68.409	.611		

Dependent: Safety

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Time	2	1.632	.816	1.147	.3189
Sex	1	.978	.978	1.374	.2419
Age Group	2	.264	.132	.186	.8305
S-Nest (Sex, Age Group)	49	149.523	3.051	4.289	.0001
Question	6	168.942	28.157	39.575	.0001
Sex * Age Group	2	14.920	7.460	10.485	.0001
Residual	336	239.058	.711		

Dependent: System Usefulness

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Time	2	1.159	.580	1.151	.3172
Sex	1	.004	.004	.007	.9322
Age Group	2	16.959	8.480	16.842	.0001
S-Nest (Sex, Age Group)	49	105.520	2.153	4.277	.0001
Question	8	52.881	6.610	13.129	.0001
Sex * Age Group	2	2.294	1.147	2.278	.1037
Residual	448	225.563	.503		

Dependent: Feature Usability

Note: S-Nest is subject nested within sex and age group

APPENDIX Q - SUMMARIZED ALI-SCOUT SUBJECT COMMENTS AND ERRORS

People were confused or unsure about these features or maneuvers	Session One						Session Two					
Missed right turn onto Long Lake Rd.	YF	YM	MF	MM	OF	OM	YF	YM	MF	MM	OF	OM
Missed left turn out of Harlan Plaza	5	4	2	5	3	3	1			1	1	2
Missed left turn onto Wattles Rd.	1		1			1						
Missed left turn onto John R Rd.	1	1	1					1				
Missed right turn onto Rochester Rd. split from Stevenson Hwy.			1							1		
Unsure about right turn onto Long Lake Rd.		1		1								
Unsure about left turn out of Harlan Plaza	5	1	3	3	4	5		2	2		3	1
Unsure abt left turn onto Wattles Rd.	3			1		2						
Unsure abt left turn onto John R Rd.	2	3		2	1			1			2	
Unsure about right turn onto Rochester Rd. split off of Stevenson Hwy.	2	1	1		4	1		1		1		1
Unsure about left turn onto Rochester Rd. from Wattles		1		1	1						2	
Chime signifying change from autonomous to guided or from guided to autonomous modes					1							
Destination area graphic	2		2	4	6	1	1			1	4	
Thought miles were meters	1			1	1	1	1					
Thought miles were minutes				1		1				1		
Miles to destination readout					4							
Didn't like "take the right/left lane" command	1	2		1		1						
"follow current path" graphic	2			2	1		1	1		1	1	2
Asked if 'turn right' meant exit the highway	2	2		2	4							
Confused on where Ali-Scout tells them to turn (major intersection or not)	2	1			2	2		1			1	
A in top left corner	1		1	1								
Lane position graphics	1	1	3			1						
Thought that 'left/right turn' command was too late			2	1					1	1		
Turned or tried to turn too early into shopping plaza before Wattles Rd. when commanded to 'turn left'	1				1	3		1		1		2
Turned into subdivision before right on Rochester Rd.		1	1						1			
TOTALS	33	19	18	26	33	23	4	8	4	8	14	8

APPENDIX R - ANOVA TABLES FROM THE MAIN EXPERIMENT

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
age group	2	4175303.469	2087651.734	7.050	.0009
Sex	1	3932.978	3932.978	.013	.9083
S-nest (Sex, age group)	46	27291795.907	593299.911	2.004	.0001
Destination	3	922488726.009	307496242.003	1038.487	.0001
Session	2	4709165.701	2354582.851	7.952	.0004
Section (Destination)	12	4.81E9	400815323.146	1353.647	.0001
time slot	2	9989489.295	4994744.648	16.868	.0001
Destination * Session	6	1038623.771	173103.962	.585	.7429
Sex * age group	2	941658.532	470829.266	1.590	.2041
time slot * Destination	6	17606834.951	2934472.492	9.910	.0001
Residual	2483	735217040.293	296100.298		

Dependent: straight points

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
age group	2	285897.155	142948.577	.226	.7975
Sex	1	2755.569	2755.569	.004	.9473
S-nest (Sex, age group)	46	38302602.363	832665.269	1.318	.0749
Destination	3	179462340.762	59820780.254	94.714	.0001
Session	2	3543300.855	1771650.428	2.805	.0607
Section (Destination)	12	1.218E9	101461959.587	160.644	.0001
time slot	2	116048948.974	58024474.487	91.870	.0001
Destination * Session	6	4272770.124	712128.354	1.128	.3435
Sex * age group	2	4520311.583	2260155.791	3.578	.0281
time slot * Destination	6	26659533.833	4443255.639	7.035	.0001
Residual	2483	1.568E9	631593.511		

Dependent: stop points

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
age group	2	2477.033	1238.517	.992	.3708
Sex	1	17.356	17.356	.014	.9061
S-nest (Sex, age group)	46	98035.828	2131.214	1.708	.0022
Destination	3	1789606.498	596535.499	478.001	.0001
Session	2	13627.869	6813.935	5.460	.0043
Section (Destination)	12	9815848.319	817987.360	655.449	.0001
time slot	2	220990.471	110495.236	88.539	.0001
Destination * time slot	6	78512.694	13085.449	10.485	.0001
Destination * Session	6	8251.242	1375.207	1.102	.3586
Sex * age group	2	6430.985	3215.493	2.577	.0762
Residual	2483	3098735.841	1247.981		

Dependent: Duration

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
age group	2	1042.180	521.090	11.606	.0001
Sex	1	89.125	89.125	1.985	.1590
S-nest (Sex, age group)	46	6650.694	144.580	3.220	.0001
Destination	3	129119.341	43039.780	958.591	.0001
Session	2	977.060	488.530	10.881	.0001
Section (Destination)	12	183634.133	15302.844	340.828	.0001
time slot	2	2027.323	1013.661	22.576	.0001
Destination * Session	6	258.716	43.119	.960	.4506
Sex * age group	2	4.988	2.494	.056	.9460
time slot * Destination	6	694.540	115.757	2.578	.0171
Residual	2483	111484.184	44.899		

Dependent: Overall Mean speed

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
age group	2	1342.915	671.457	26.192	.0001
Sex	1	20.035	20.035	.782	.3768
S-nest (Sex, age group)	46	6272.680	136.363	5.319	.0001
Destination	3	107926.116	35975.372	1403.304	.0001
Session	2	1308.631	654.316	25.523	.0001
Section (Destination)	12	123825.494	10318.791	402.509	.0001
time slot	2	265.877	132.938	5.186	.0057
Destination * Session	6	215.388	35.898	1.400	.2106
Sex * age group	2	89.530	44.765	1.746	.1747
time slot * Destination	6	328.493	54.749	2.136	.0465
Residual	2482	63629.031	25.636		

Dependent: speed Mean moving

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
age group	2	100.255	50.128	10.411	.0001
Sex	1	.766	.766	.159	.6901
S-nest (Sex, age group)	46	963.500	20.946	4.350	.0001
Destination	3	2006.230	668.743	138.897	.0001
Session	2	83.882	41.941	8.711	.0002
Section (Destination)	12	11855.499	987.958	205.198	.0001
time slot	2	121.555	60.777	12.623	.0001
Destination * Session	6	70.741	11.790	2.449	.0231
Sex * age group	2	14.978	7.489	1.555	.2113
time slot * Destination	6	73.722	12.287	2.552	.0182
Residual	2482	11950.005	4.815		

Dependent: speed SD

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
age group	2	506.058	253.029	32.473	.0001
Sex	1	3.833	3.833	.492	.4832
S-nest (Sex, age group)	46	4356.326	94.703	12.154	.0001
Destination	3	3175.710	1058.570	135.853	.0001
Session	2	109.302	54.651	7.014	.0009
Section (Destination)	12	53846.066	4487.172	575.868	.0001
time slot	2	117.336	58.668	7.529	.0005
Destination * Session	6	318.957	53.160	6.822	.0001
Sex * age group	2	100.595	50.297	6.455	.0016
time slot * Destination	6	15.311	2.552	.327	.9228
Residual	2475	19285.232	7.792		

Dependent: mean throttle

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
age group	2	23.241	11.621	2.076	.1256
Sex	1	1.301	1.301	.232	.6297
S-nest (Sex, age group)	46	5734.165	124.656	22.272	.0001
Destination	3	364.051	121.350	21.681	.0001
Session	2	304.792	152.396	27.228	.0001
Section (Destination)	12	5774.503	481.209	85.975	.0001
time slot	2	247.761	123.880	22.133	.0001
Destination * Session	6	167.195	27.866	4.979	.0001
Sex * age group	2	332.393	166.196	29.693	.0001
time slot * Destination	6	35.619	5.936	1.061	.3840
Residual	2473	13841.543	5.597		

Dependent: sd throttle

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
age group	2	49291.219	24645.610	77.761	.0001
Sex	1	247.918	247.918	.782	.3766
S-nest (Sex, age group)	32	186969.524	5842.798	18.435	.0001
Destination	3	4830.118	1610.039	5.080	.0017
Session	2	1372.223	686.111	2.165	.1152
Section (Destination)	12	36200.191	3016.683	9.518	.0001
time slot	2	5562.431	2781.215	8.775	.0002
Destination * Session	6	1040.235	173.373	.547	.7726
Sex * age group	2	4069.751	2034.876	6.420	.0017
time slot * Destination	6	2631.106	438.518	1.384	.2177
Residual	1373	435157.380	316.939		

Dependent: mean range

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
age group	2	1811.362	905.681	10.167	.0001
Sex	1	28.122	28.122	.316	.5743
S-nest (Sex, age group)	32	6915.856	216.121	2.426	.0001
Destination	3	2234.283	744.761	8.360	.0001
Session	2	335.529	167.764	1.883	.1525
Section (Destination)	12	23307.760	1942.313	21.804	.0001
time slot	2	724.282	362.141	4.065	.0174
Destination * Session	6	515.903	85.984	.965	.4474
Sex * age group	2	310.993	155.496	1.746	.1749
time slot * Destination	6	936.609	156.101	1.752	.1055
Residual	1367	121773.665	89.081		

Dependent: sd range

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
age group	2	4.949	2.474	6.601	.0014
Sex	1	.966	.966	2.576	.1086
S-nest (Sex, age group)	46	142.033	3.088	8.237	.0001
Destination	3	56.824	18.941	50.531	.0001
Session	2	2.759	1.379	3.680	.0254
Section (Destination)	12	172.451	14.371	38.338	.0001
time slot	2	26.524	13.262	35.380	.0001
Destination * Session	6	2.453	.409	1.091	.3655
Sex * age group	2	.616	.308	.822	.4395
time slot * Destination	6	35.465	5.911	15.769	.0001
Residual	2481	929.997	.375		

Dependent: mean lat pos

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
age group	2	.115	.058	.723	.4854
Sex	1	1.011	1.011	12.701	.0004
S-nest (Sex, age group)	46	13.740	.299	3.752	.0001
Destination	3	6.344	2.115	26.562	.0001
Session	2	.383	.192	2.408	.0902
Section (Destination)	12	55.946	4.662	58.564	.0001
time slot	2	25.766	12.883	161.833	.0001
Destination * Session	6	.667	.111	1.397	.2119
Sex * age group	2	.020	.010	.127	.8810
time slot * Destination	6	2.837	.473	5.939	.0001
Residual	2477	197.189	.080		

Dependent: sd lat pos

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
age group	2	571.725	285.863	1.722	.1789
Sex	1	94.253	94.253	.568	.4512
S-nest (Sex, age group)	46	10479.858	227.823	1.373	.0494
Destination	3	403330.210	134443.403	809.963	.0001
Session	2	1175.992	587.996	3.542	.0291
Section (Destination)	12	709180.345	59098.362	356.042	.0001
time slot	2	319.666	159.833	.963	.3819
Destination * Session	6	2716.199	452.700	2.727	.0121
Sex * age group	2	150.137	75.068	.452	.6362
time slot * Destination	6	1381.141	230.190	1.387	.2160
Residual	2474	410651.847	165.987		

Dependent: sd wheel

Note: S-Nest is subject nested within sex and age group

APPENDIX S - DESCRIPTION OF THE DATA SET FROM THE MAIN EXPERIMENT

Straight driving points

Typically, driving studies are conducted on open roads. However, this experiment involved both expressway and city street driving. On streets speed, trip times, and other performance measures are not only determined by driver behavior, but by traffic and random-appearing variations in traffic signals. As a consequence, it is important to consider both how participants drove averaged across a trip and, how they drove when they were actually moving. The test vehicle was considered stopped when its speed was below 3.5 mi/hr. Because of the design of the wheel pulse mechanism, detecting movement at slower speeds was very difficult.

A second important distinction is driving on straight sections and driving curves. In many studies, only driving on straight sections is examined because curve radii and length influence driving behavior, but curve geometry's vary so widely between studies that matching sections for the purpose of comparison is almost impossible. For the purpose of this report, drivers were considered to be going straight when the wheel angle was within a specified threshold (between -134.5° and 96.93° with the center point at -18.8°). This might seem to be an unusually large range. However, the test vehicle has a variable ratio steering system, so moderate changes in steering wheel angle around center result in only small changes in tire angle (and vehicle path). The threshold values were derived from data reported in the test vehicle calibration report (Katz, Green, and Fleming, 1995).

In the ANOVA of the number of straight driving points, age group was found to be a significant ($p=0.0009$). Sex, on the other hand, had no significant effect. The mean number of straight data points (per section) for young subjects was 1972 points, 2033 points for middle-aged subjects, and 2066 points for older subjects. One possible explanation for this effect is that older people have a tendency to drive slower and, thus, would spend more time driving and have more data points overall. Since the data were sampled at 30 Hz, this corresponds to approximately 68 seconds of data, clearly enough for accurate estimates.

Subjects nested with sex and age group were found to be significant ($p=0.0001$). Figure 105 shows the mean number of straight driving points for subjects by sex and age group. Nine data points are given for each sex, age group category, although some points may be overlapping. No explanation can be found for the young female outlier.

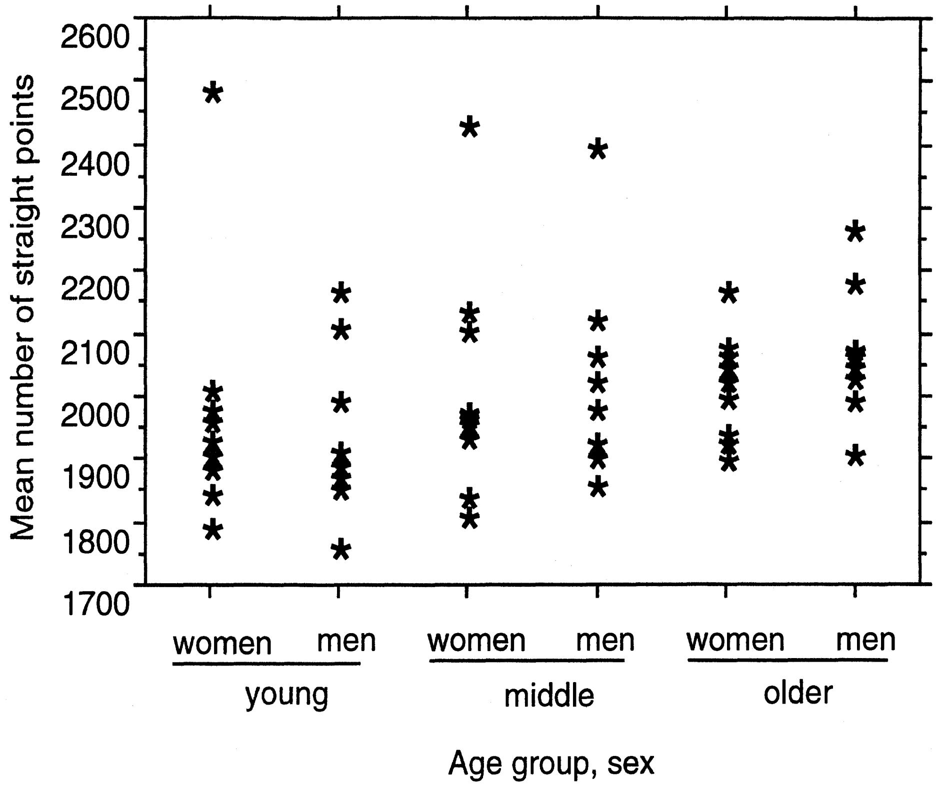


Figure 105. Mean number of straight driving data points for subjects by sex and age.

In addition, both destination (p=0.0001) and section within destination (p=0.0001) were found to be significant. The mean number of straight driving points for destinations 1, 2, 3, and 4 were 1817 points, 2088 points, 864 points, and 3011 points, respectively. The number of straight driving points (equivalent to 28.8 seconds) for destination three is much less because this was a very short link. Figure 106 shows the mean number of straight driving points for sections within each destination.

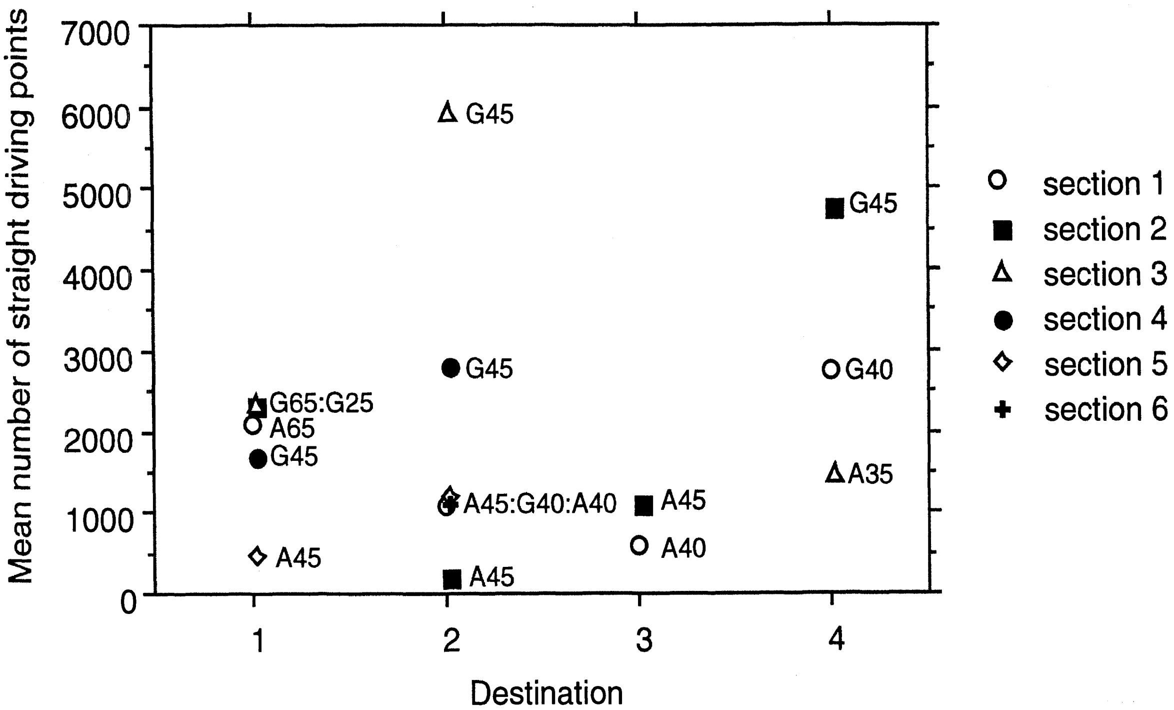


Figure 106. Mean number of straight driving data sections within each destination.

Note: In this and all subsequent figures, A and G represent autonomous and guided mode, the two digits indicate the posted speed.

The trial number was also found to have a significant effect on straight driving points (p=0.0004). Trial 1 had a mean number of straight driving points of 2077 points, trial 2 had a mean of 2041 points, and the baseline trial had a mean of 1952 points. The progression toward fewer straight data points indicates subjects will drive faster along straight sections over consecutive trials. This indicates that familiarity with the route is a contributing factor to faster speeds on straight sections.

In addition, session time was found to be significant (p=0.0001). The mean number of straight driving points for the afternoon session was 1965 points, the mean for the rush hour session was 2156 points, and the mean for the night session was 1953 points. There was a direct relationship between speed and traffic as well as traffic and session time. Thus, as speed decreased subjects spent more time on the road and had more straight data points.

One interaction (between session time and destination) was found to be significant (p=0.0001). Figure 107 shows the mean number of straight driving points for each destination by session time. There was a merge from two lanes to one lane during destination two. During heavy traffic conditions this caused a backup which slowed drivers and thereby increased the number of straight data points.

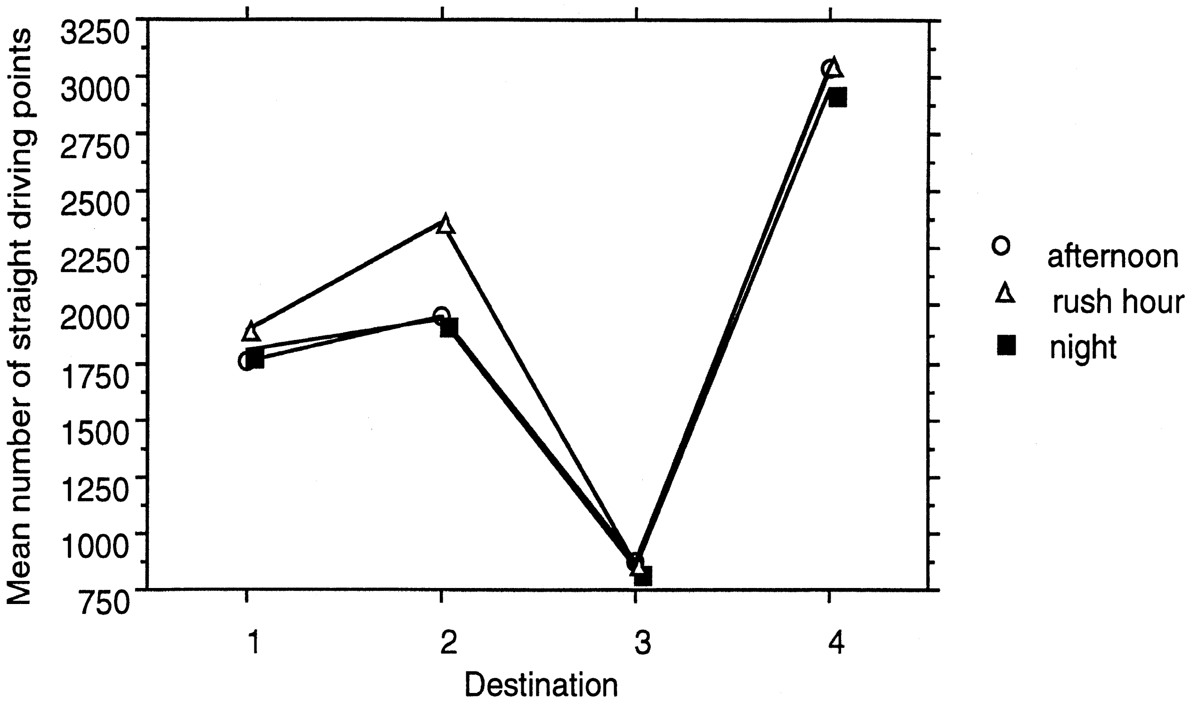


Figure 107. Mean number of straight driving points for destination by session time.

Stopped points

The time subjects were not moving (stop points) did not significantly vary between individuals (subjects nested within sex and age, Figure 108). Neither age group nor sex were found to be significant. However, there was an age by sex interaction (p=0.0281, Figure 109). There is no obvious explanation for this odd interaction.

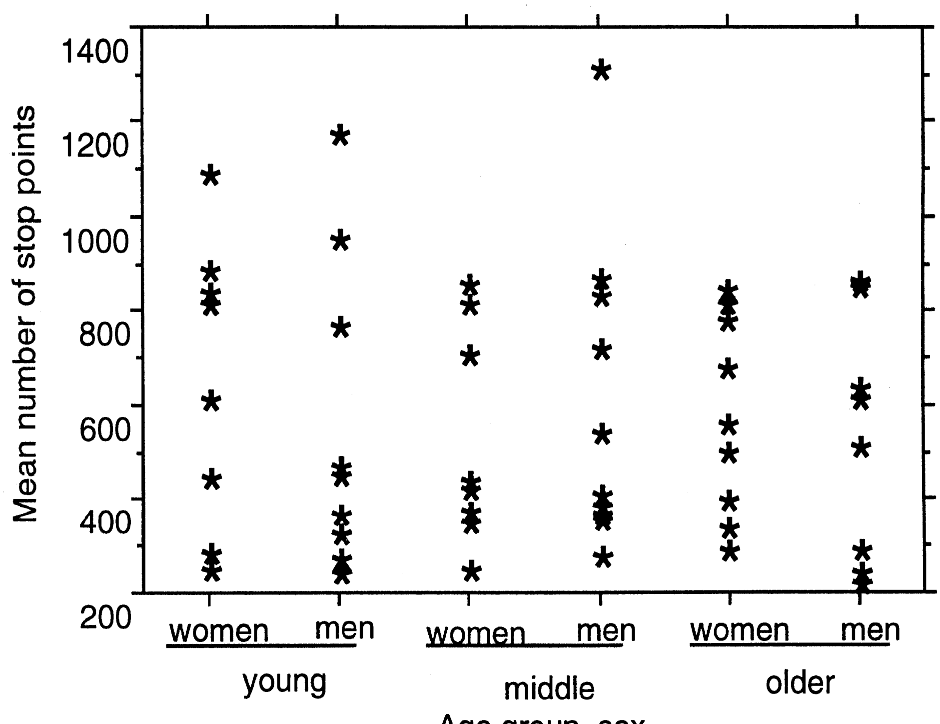


Figure 108. Mean number of stop data points for subjects by sex and age group.

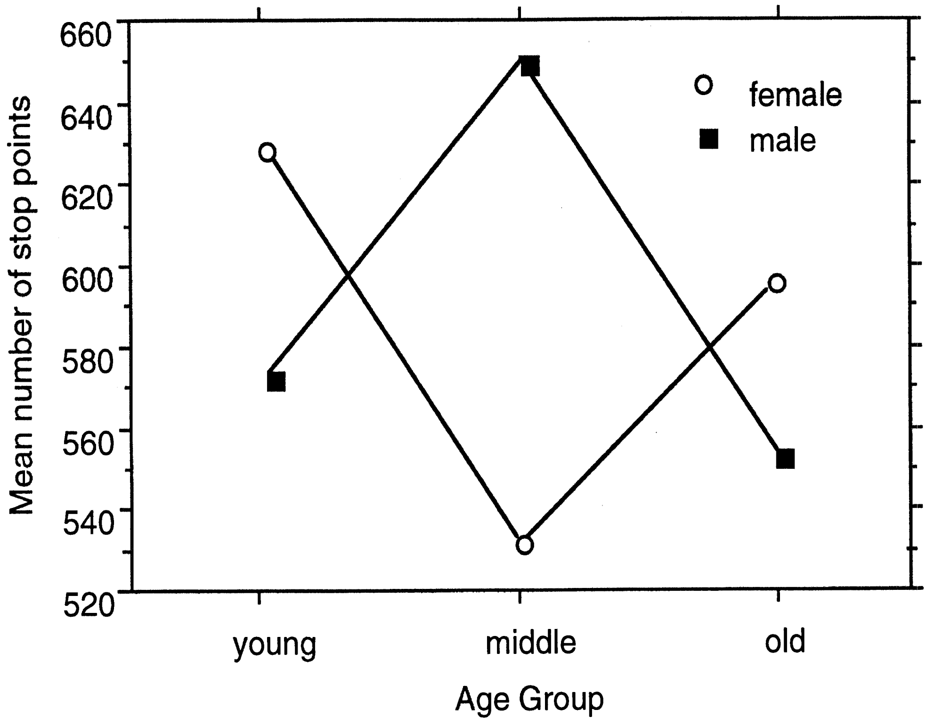


Figure 109. Mean number of stop points for each age group by sex.

Although trial number was not found to be significant, it is included for completion. The mean number of stop points for trials one, two, and baseline were 576 points, 647 points, and 542 points, respectively. The number of stop points was least for the baseline trial (equivalent to 18 seconds/section) when the experimenter provided guidance. This raises the possibility that subjects were less hesitant, and hence stopped less when given close to ideal navigation. The large increase in mean number of stop points between trials one and two can not be explained other than as random variation due to traffic and traffic signals.

Both destination (p=0.0001) and section within destination (p=0.0001) were found to be significant. The mean number of stop points for destination 1, 2, 3, and 4 were 242 points, 696 points, 565 points, and 974 points (equivalent to 33 seconds), respectively. Figure 110 shows the mean number of stop points for sections within each destination. Sections 1 and 2 of destination 1 are highway driving, which would explain why the mean stop points for these sections are so low. The bottleneck in destination two, section 3 contributes to the high number of stop points. The intersection at Wattles and Rochester is the major contributing factor in the number of stop points for destination 2, section 4, and destination 4, section 1.

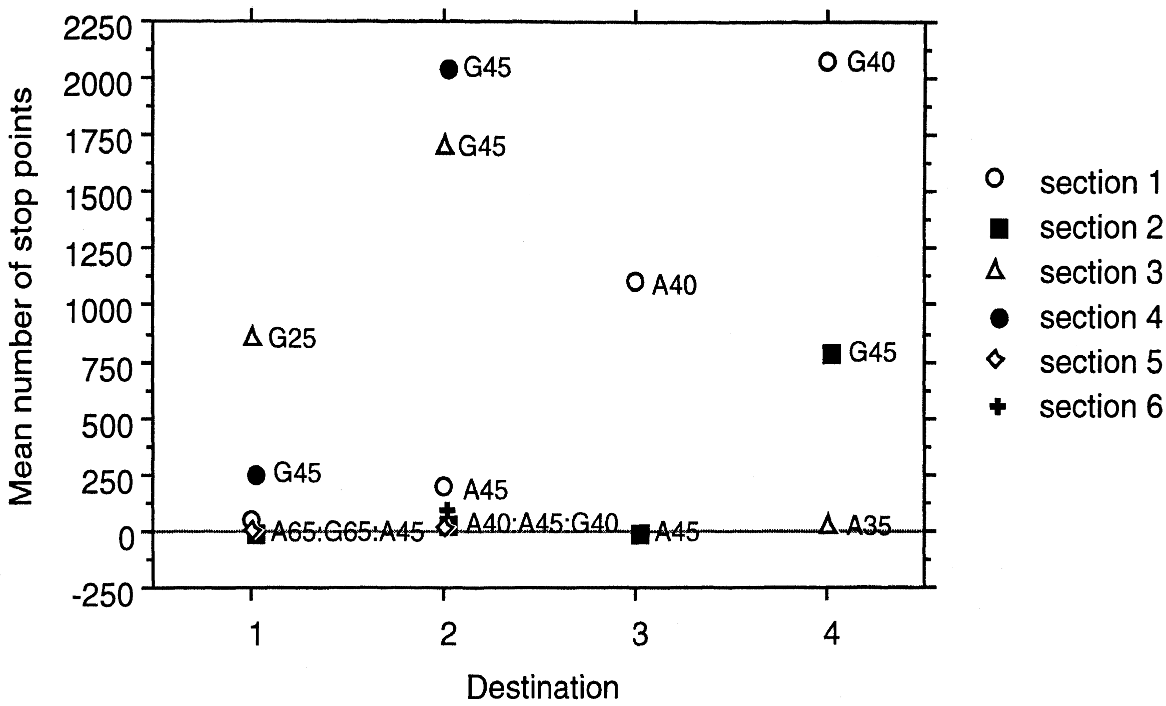


Figure 110. Mean number of stop points for each section.

In addition, session time was found to be significant (p=0.0001). The mean number of stop points for the afternoon session was 558 points, the mean for the rush hour session was 891 points, and the mean for the night session was 322 points. It should be obvious that the greatest number of stop points (equal to 30 seconds) was during the rush hour session because subjects had to stop for traffic and lights more frequently. An interaction (between session time and destination) was found to be significant (p=0.0001). The aforementioned bottleneck in section three of destination two was a major contributor toward this interaction. Figure 111 shows the mean number of stop points for each destination by session time.

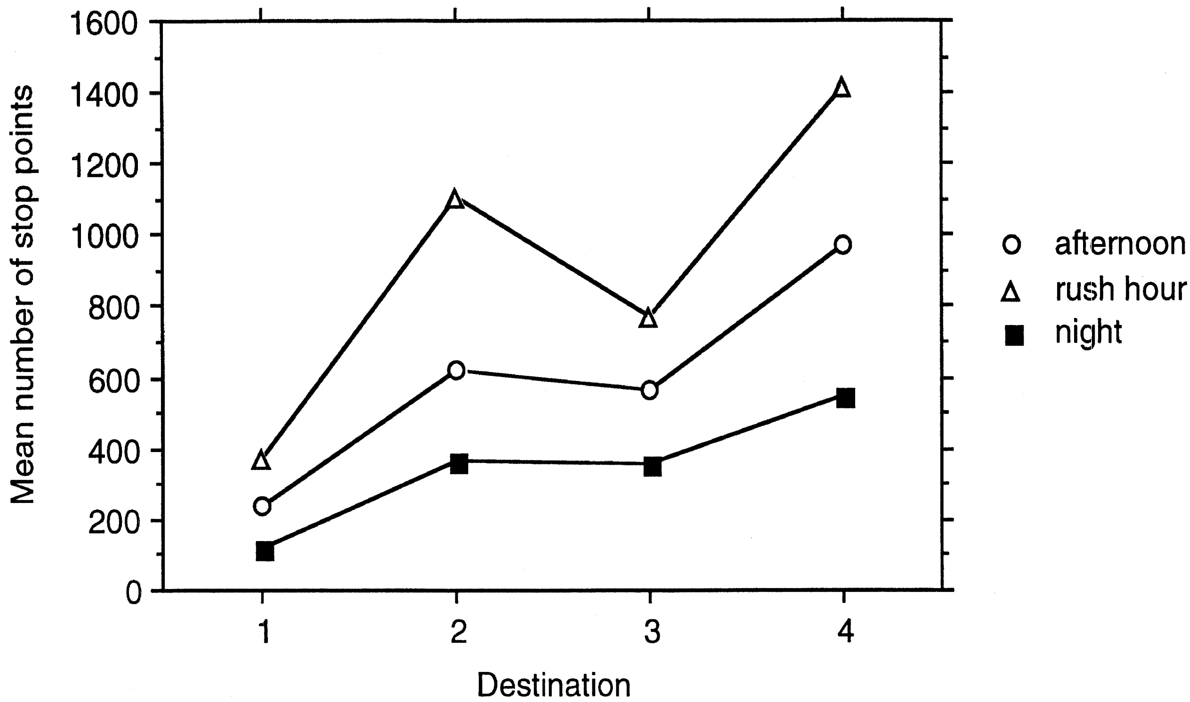


Figure 111. Mean number of stop points for each destination by session time

APPENDIX T - SUPPLEMENTAL EXPERIMENT SUBJECT INSTRUCTIONS - ALI-SCOUT

Hi, My name is (experimenter's name). **Thank you for coming today. Let me show you to the car.**

Please be seated in the back seat of the car and notice the video monitor beside you on your left. Now, before we begin I would like to show you a videotape so that you may become familiarized with the FAST-TRAC project and the Ali-Scout unit itself. Please pay close attention to the section that describes Ali-Scout's use on-the-road.

Show video

Overview

This study will consist of one on-the-road session that will take about two hours. You will be paid a total of $40 for your time. We will ask you to drive the route twice, once with the Ali-Scout, and once with explicit directions given to you by the experimenter. You will be driving an automatic transmission Honda Accord station wagon on public roads in Troy. We ask that you follow all traffic laws and speed limits while driving, if you do not comply with these safety measures, the experiment may be stopped by the experimenter.

The Ali-Scout system will give you spoken instructions, as well as visual cues to reach a certain destination. At some points during the experiment, the Ali-Scout may go into autonomous mode, and will not give you specific directions. We would like you to make your own decisions on where to turn when the system is in autonomous mode. We are interested in the driver's accuracy in reaching destinations using the Ali-Scout.

We ask that you simply follow the instructions that the navigation system gives to you. If you have passed the destination and circle the area, or become lost trying to locate the destination, we will stop you and enter the next destination.

You will be videotaped throughout the entire experiment, for analysis purposes. One camera is mounted next to the Ali-Scout unit.

All subsequent directions given to subjects were identical to those given in original experimentation, see Appendix E.

APPENDIX U - ALI-SCOUT SUPPLEMENTAL CONSENT FORM

Subject #: ____________

ALI-SCOUT NAVIGATION STUDY
PARTICIPANT CONSENT FORM

The purpose of this experiment is to determine driver's ability to utilize the Ali-Scout navigation unit to reach a destination. The Ali-Scout is an in-car route guidance system which has a display that shows drivers where to turn, as well as auditory instructions. In this experiment, you will be driving to four destinations in Troy with the aid of the Ali-Scout.

This experiment will test your ability to reach the correct destination with the aid of only the navigational unit and the address or name of the destination. You will not be asked to enter destinations into the Ali-Scout. You will be videotaped throughout the duration of the experiment by two small cameras located near the navigation unit, and on the frame of the car. You will be asked to drive the same route twice: once using the Ali-Scout and a second time using oral instructions provided to you by the experimenter. Upon completion of the experiment, you will be paid $40 for your time.

****

This experiment concerns the Ali-Scout navigation unit and is <u>not</u> a test of your driving skills. Remember, your priority is always to drive **safely.** You are expected to **obey all traffic and speed laws**. If you are not driving safely, you will be given one warning, after which the experiment can be stopped. Please tell the experimenter at any time if you feel you are unable to complete the study, you will be paid regardless. Thank you for your participation.

****

I HAVE READ AND UNDERSTAND THIS DOCUMENT.

______________________ Print your name	______________________ Date
______________________ Sign your name	______________________ Witness (experimenter)

APPENDIX V - MANEUVER INSTRUCTIONS FOR THE SUPPLEMENTAL EXPERIMENT

Table 60. Ali-Scout guidance to destination one.

Ali-Scout Mode	Ali-Scout Audio Cues and Instructions	Location/Starting Point Along Test Route	Direction Traveling	Section Length (miles)
Autonomous		Entrance ramp, 0.35 miles prior to merging onto I-75	North on I-75	1.09
Guided	Chime indicating change from autonomous to guided	1.2 miles prior to exit ramp off I-75 at Crooks Rd.	North on I-75	0.64
Guided	"Take the right hand lane"	0.56 miles prior to exit ramp off I-75 at Crooks Rd.	North on I-75	0.46
Guided	"Turn right"	0.1 miles prior to exit ramp off I-75 at Crooks Rd.	North on I-75 to west on exit ramp	0.75
Guided	"Take one of the left hand lanes"	0.23 miles prior to intersection between exit ramp and Crooks Rd.	West on exit ramp off I-75	0.18
Guided	"Turn left"	0.05 miles prior to intersection between exit ramp and Crooks	West on exit ramp off I-75 to south on Crooks	0.69
Autonomous	Chime indicating change from guided to autonomous	0.1 miles prior to driveway leading into Honeybaked Ham	South on Crooks to west into Honeybaked Ham	0.58

Table 61. Ali-Scout guidance to destination two.

Ali-Scout Mode	Ali-Scout Audio Cues and Instructions	Location/Starting Point Along Test Route	Direction Traveling	Section Length (miles)
Autonomous		0.28 miles prior to intersection between Crooks Rd. and Long Lake Rd.	North on Crooks Rd. to east on Long Lake Rd.	0.37
Guided	Chime indicating change from autonomous to guided	0.09 miles after intersection between Crooks Rd. and Long Lake Rd.	East on Long Lake Rd.	1.86
Experimenter	"Turn right at the next light"	0.2 - 0.1 miles prior to intersection between Long Lake Rd. and Rochester Rd.	East on Long Lake to south on Rochester Rd.	0.95 - 1.0
Guided	"Take the left hand lane"	0.2 miles prior to intersection between Rochester Rd. and Wattles Rd.	South on Rochester Rd.	0.18
Guided	"Turn left"	0.05 miles prior to intersection between Rochester Rd. and Wattles Rd.	South on Rochester Rd. to east on Wattles Rd.	0.52
Autonomous	Chime indicating Change from guided to autonomous	0.52 miles prior to first driveway into Harlan Plaza	East on Wattles Rd. to north into Harlan Plaza	0.52

Table 62. PathMaster behavior for destination one.

PathMaster Audio Cues and Instructions	Location/Starting Point Along Test Route	Direction Traveling
	Entrance ramp, 0.5 miles prior to merging onto I-75	North on I-75
"Prepare to exit"	0.8 miles prior to exit ramp off I-75 at Crooks Rd.	North on I-75
"Next exit on the right"	0.3 miles prior to exit ramp off I-75 at Crooks Rd.	North on I-75
Beep indicating turn	0.1 miles prior to exit ramp off I-75 at Crooks Rd.	North on I-75 to west on exit ramp
"Left turn ahead"	0.6 miles prior to intersection between exit ramp and Crooks Rd.	West on exit ramp off I-75
Beep indicating turn	0.2 miles prior to intersection between exit ramp and Crooks	West on exit ramp off I-75 to south on Crooks
"Destination ahead"	0.2 miles prior to intersection between Long Lake and Crooks Rd.	South on Crooks
Beep indicating destination driveway	0.1 miles prior to driveway leading into Honeybaked Ham	South on Crooks to west into Honeybaked Ham

Table 63. PathMaster behavior for destination two.

PathMaster Audio Cues and Instructions	Location/Starting Point Along Test Route	Direction Traveling
	0.8 miles prior to intersection between Crooks and Long Lake Rd.	North on Crooks
"Right turn ahead"	0.7 miles prior to intersection between Crooks and Long Lake Rd.	North on Crooks
Beep indicating turn	0.1 miles prior to intersection between Crooks and Long Lake Rd.	North on Crooks to east on Long Lake
"Right turn ahead"	0.8 miles prior to intersection between Long Lake and Rochester Rd.	East on Long Lake
Beep indicating turn	0.1 miles prior to intersection between Long Lake and Rochester Rd.	East on Long Lake to South on Rochester Rd.
"Left turn ahead'	0.8 miles prior to intersection between Rochester Rd. and Wattles Rd.	South on Rochester Rd.
Beep indicating turn	0.2 miles prior to intersection between Rochester Rd. and Wattles Rd.	South on Rochester Rd. to east on Wattles
"Destination ahead"	0.4 miles prior to driveway into Harlan Plaza	East on Wattles Rd.
Beep indicating destination driveway	0.1 miles prior to driveway into Harlan Plaza	East on Wattles to north into Harlan Plaza

Table 64. PathMaster behavior for destination three.

PathMaster Audio Cues and Instructions	Location/Starting Point Along Test Route	Direction Traveling
	0.9 miles prior to intersection between Wattles and John R Rd.	East on Wattles
"Left turn ahead"	0.8 miles prior to intersection between Wattles and John R Rd.	East on Wattles
Beep indicating turn	0.2 miles prior to intersection between Wattles and John R Rd.	East on Wattles to north on John R
"Right turn ahead"	0.8 miles prior to intersection between John R and Cumberland Dr.	North on John R
Beep indicating turn	0.2 miles prior to intersection between John R and Cumberland Dr.	North on John R to east on Cumberland Dr.

Table 65. PathMaster behavior for destination four.

PathMaster Audio Cues and Instructions	Location/Starting Point Along Test Route	Direction Traveling
	0.1 miles after intersection between John R and Wattles Rd.	West on Wattles
"Left turn ahead"	0.8 miles prior to intersection between Wattles and Rochester Rd.	West on Wattles
Beep indicating turn	0.2 miles prior to intersection between Wattles and Rochester Rd.	West on Wattles to south on Rochester Rd.
"Right turn ahead	0.8 miles prior to split between Rochester Rd. and Stevenson Hwy.	Southeast on Rochester Rd.
Beep indicating turn	0.2 miles prior to split between Rochester Rd. and Stevenson Hwy.	Southeast on Rochester Rd.
"Destination ahead"	0.8 miles prior to driveway into Maplewood Plaza	South on Rochester Rd.
Beep indicating destination driveway	0.2 miles prior to driveway into Maplewood Plaza	South on Rochester Rd. to west into destination driveway

APPENDIX W - SUPPLEMENTAL EXPERIMENT SUBJECT INSTRUCTIONS-PATHMASTER

Hi, My name is (experimenter's name). **Thank you for coming today. Let me show you to the car.**

Overview

This study will consist of one on-the-road session that will take about two hours. You will be paid a total of $40 for your time. We will ask you to drive the route twice, once with the PathMaster, and once with explicit directions given to you by the experimenter. You will be driving an automatic transmission Honda Accord station wagon on public roads in Troy. We ask that you follow all traffic laws and speed limits while driving, if you do not comply with these safety measures, the experiment may be stopped by the experimenter.

The system will give you spoken instructions, as well as visual cues to reach a certain destination. We are interested in the driver's accuracy in reaching destinations using the PathMaster.

We ask that you simply follow the instructions that the navigation system gives to you. If you have passed the destination and circle the area, or become lost trying to locate the destination, we will stop you and enter the next destination. You will be videotaped throughout the entire experiment, for analysis purposes. One camera is mounted near the PathMaster unit.

Consent and Bio Forms

First, please read and sign this consent form, and then fill out the biographical form. If you have any questions feel free to ask them at any time.

Provide consent and biographical forms. Check that it is legible and complete.

It is necessary that we check your eyesight before we begin the experiment.

Check eyesight

I also need to see your driver's license.

Check license.

At the test vehicle

Let me reiterate a few important points from the consent form. First of all, driving safely is your main priority. If you feel unsafe or unable to make any turn, please don't. Second, if you are uncomfortable or wish to stop at any time, please let me know right away. You are expected to obey all speed limits and driving laws.

Let me stress a couple of points about driving with the system. Remember that the bar on the bottom of the screen is there to indicate

how far away you are from a turn, please use the bar to help you when coming up on a turn. Secondly, watch the miles on the bottom right of the screen, which indicate how far you are from your destination. You must look for the destination once the PathMaster indicates that you are near your destination (i.e. quarter mile).

All subsequent directions are exact to that given in the original Ali-Scout subject directions, see Appendix E.

APPENDIX X - SUPPLEMENTAL CONSENT FORM

Subject #: ___________

NAVIGATION STUDY
PARTICIPANT CONSENT FORM

The purpose of this experiment is to determine driver's ability to utilize the navigation unit to reach a destination. The PathMaster is an in-car route guidance system which has a display that shows drivers where and when to turn, as well as auditory instructions. In this experiment, you will be driving to four destinations in Troy with the aid of the PathMaster navigation system.

This experiment will test your ability to reach the correct destination with the aid of only the navigational unit and the address or name of the destination. You will not be asked to enter destinations into the PathMaster. You will be videotaped throughout the duration of the experiment by two small cameras located near the navigation unit, and on the frame of the car. You will be asked to drive the same route twice: once using the PathMaster and a second time using oral instructions provided to you by the experimenter. Upon completion of the experiment, you will be paid $40 for your time.

****

This experiment concerns the navigation unit and is <u>not</u> a test of your driving skills. Remember, your priority is always to drive **safely.** You are expected to **obey all traffic and speed laws**. If you are not driving safely, you will be given one warning, after which the experiment can be stopped. Please tell the experimenter at any time if you feel you are unable to complete the study, you will be paid regardless. Thank you for your participation.

****

I HAVE READ AND UNDERSTAND THIS DOCUMENT.

____________________________	____________________________
Print your name	Date
____________________________	____________________________
Sign your name	Witness (experimenter)

APPENDIX Y - ROUTE KNOWLEDGE SURVEY

Post-Drive Route Knowledge Survey

	not at all				very
1) How familiar are you with driving in the city of Troy?	1	2	3	4	5
2) Previous to today, how familiar were you with the navigation system?	1	2	3	4	5

3) Have you ever driven a vehicle with another in-vehicle navigation system? Yes No

3a) If yes, what system have you used? ________________________

4) Previous to today, did you know where Maplewood Plaza was located? Yes No

5) Previous to today, did you know where Harlan Plaza was located? Yes No

6) Previous to today, did you know where Cumberland Drive was located? Yes No

7) Previous to today, did you know where Honeybaked Ham was located? Yes No

8) When do you plan on buying your next (new or used) car?

Within 5 months 6-11 months 1-2 years 3-5 years 6+ years

8a) How much do you plan on spending? $_________

9) How much would you pay for a route guidance system (like the)? $___

Additional comments (optional) ____

Using all of your driving experience (not just what you did today), please rate the difficulty of performing each of these tasks <u>while driving</u>, using the scale below.

	not difficult									very difficult
Reading the speed on the speedometer	1	2	3	4	5	6	7	8	9	10
Drinking a beverage	1	2	3	4	5	6	7	8	9	10
Reading street names	1	2	3	4	5	6	7	8	9	10
Adjusting the fan speed on the car heater or air conditioner	1	2	3	4	5	6	7	8	9	10

APPENDIX Z - USABILITY SURVEY

Subject # ___________ Name:_____________________

Post-Drive Usability and Utility Questionnaire

		Strongly disagree				Strongly agree
1)	It is safe for me to use this system while driving.	1	2	3	4	5
2)	I would likely use this system for my daily travel.	1	2	3	4	5
3)	I would use this system if I were in a hurry.	1	2	3	4	5
4)	It is safe for an inexperienced driver to use this system while driving.	1	2	3	4	5
5)	The route guidance information provided is useful.	1	2	3	4	5
6)	The PathMaster was distracting.	1	2	3	4	5
7)	I would rather use a route guidance system similar to this one than use a standard paper road map to find my way.	1	2	3	4	5
8)	I would rather use a route guidance system similar to this than use written instructions to find my way.	1	2	3	4	5
9)	The PathMaster would be helpful in locating a destination that I have never visited before.	1	2	3	4	5
10)	The PathMaster would be helpful in driving to familiar locations.	1	2	3	4	5
11)	The miles to reach next maneuver readout was useful.	1	2	3	4	5
12)	The auditory messages given were useful.	1	2	3	4	5
13)	The auditory messages were given in ample time before a turn was to be made.	1	2	3	4	5
14)	The countdown bars to a turn in guided mode were useful.	1	2	3	4	5
15)	The turn graphics in guided mode were useful.	1	2	3	4	5

APPENDIX AA - SUPPLEMENTAL SURVEY ANOVAS

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Sex	1	.361	.361	1.009	.3271
Question	2	15.515	7.758	21.695	.0001
Test	1	1.834	1.834	5.129	.0348
S-Nest (Test, Sex)	8	8.211	1.026	2.870	.0266
Residual	20	7.152	.358		

Dependent: Safety

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Sex	1	6.451	6.451	11.222	.0014
S-Nest (Test, Sex)	8	30.635	3.829	6.661	.0001
Test	1	.169	.169	.295	.5892
Question	6	49.792	8.299	14.435	.0001
Residual	60	34.494	.575		

Dependent: System Usefulness

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Sex	1	9.416	9.416	19.729	.0001
Test	1	.232	.232	.486	.4882
S-Nest (Test, Sex)	8	9.198	1.150	2.409	.0244
Question	8	11.366	1.421	2.977	.0067
Residual	64	30.545	.477		

Dependent: Feature Usefulness

Note: S-Nest is subject nested in test and sex

APPENDIX AB - ANOVA TABLES FOR SUPPLEMENTAL RESULTS

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Sex	1	295465.525	295465.525	.251	.6171
Subject (Sex, system)	6	9084615.316	1514102.553	1.284	.2657
Destination	3	81007973.653	27002657.884	22.907	.0001
Section (Destination)	10	502993528.397	50299352.840	42.671	.0001
System	1	3173929.345	3173929.345	2.693	.1023
Session	1	1799071.919	1799071.919	1.526	.2181
System * Section (Desti...	13	35775796.702	2751984.362	2.335	.0064
System * Session	1	239771.567	239771.567	.203	.6525
Residual	208	245184413.584	1178771.219		

Dependent: Straight Points

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Sex	1	150376.423	150376.423	.126	.7226
Subject (Sex, system)	6	8043833.274	1340638.879	1.126	.3482
Destination	3	13451821.386	4483940.462	3.767	.0116
Section (Destination)	10	210404557.250	21040455.725	17.674	.0001
System	1	2899187.007	2899187.007	2.435	.1201
Session	1	1958349.007	1958349.007	1.645	.2011
System * Section (Desti...	13	15681977.343	1206305.949	1.013	.4396
System * Session	1	1104956.563	1104956.563	.928	.3365
Residual	208	247613621.267	1190450.102		

Dependent: Stop Points

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Sex	1	234.164	234.164	.062	.8035
Subject (Sex, System)	6	29508.165	4918.028	1.304	.2567
Destination	3	134186.507	44728.836	11.859	.0001
Section (Destination)	10	1236178.436	123617.844	32.775	.0001
System	1	16220.450	16220.450	4.301	.0393
Session	1	7396.852	7396.852	1.961	.1629
System * Section (Desti...	13	91817.224	7062.863	1.873	.0348
System * Session	1	3280.710	3280.710	.870	.3521
Residual	208	784520.078	3771.731		

Dependent: Duration

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Sex	1	14.952	14.952	.211	.6466
Subject (Sex, System)	6	688.444	114.741	1.618	.1436
Destination	3	15778.664	5259.555	74.152	.0001
Section (Destination)	10	20654.758	2065.476	29.120	.0001
System	1	344.926	344.926	4.863	.0285
Session	1	446.896	446.896	6.301	.0128
System * Section (Desti...	13	1081.400	83.185	1.173	.3013
System * Session	1	220.489	220.489	3.109	.0793
Residual	208	14753.273	70.929		

Dependent: Overall Mean Speed

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Sex	1	8.844	8.844	.195	.6596
Subject (Sex, system)	6	643.929	107.321	2.361	.0315
Destination	3	16183.187	5394.396	118.670	.0001
Section (Destination)	10	10536.148	1053.615	23.178	.0001
System	1	157.602	157.602	3.467	.0640
Session	1	395.392	395.392	8.698	.0035
System * Section (Desti...	13	597.356	45.950	1.011	.4420
System * Session	1	113.794	113.794	2.503	.1151
Residual	208	9455.115	45.457		

Dependent: Mean Moving Speed

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Sex	1	.147	.147	.022	.8824
Subject (Sex, system)	6	65.261	10.877	1.621	.1427
Destination	3	325.198	108.399	16.154	.0001
Section (Destination)	10	1223.948	122.395	18.240	.0001
System	1	10.169	10.169	1.515	.2197
Session	1	5.460	5.460	.814	.3681
System * Section (Desti...	13	81.241	6.249	.931	.5214
System * Session	1	.267	.267	.040	.8421
Residual	208	1395.718	6.710		

Dependent: SD Moving Speed

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Sex	1	47.501	47.501	3.921	.0490
Subject (Sex, system)	6	219.618	36.603	3.022	.0075
Destination	3	461.176	153.725	12.691	.0001
Section (Destination)	10	5833.382	583.338	48.158	.0001
System	1	19.921	19.921	1.645	.2011
Session	1	2.847	2.847	.235	.6283
System * Section (Desti...	13	211.119	16.240	1.341	.1915
System * Session	1	.013	.013	.001	.9735
Residual	208	2519.498	12.113		

Dependent: Mean Throttle

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Sex	1	44.582	44.582	6.807	.0097
Subject (Sex, system)	6	115.633	19.272	2.943	.0089
Destination	3	58.932	19.644	2.999	.0316
Section (Destination)	10	499.668	49.967	7.629	.0001
System	1	26.784	26.784	4.090	.0444
Session	1	.640	.640	.098	.7550
System * Section (Desti...	13	117.860	9.066	1.384	.1689
System * Session	1	15.534	15.534	2.372	.1251
Residual	208	1362.288	6.549		

Dependent: SD Throttle

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Sex	1	6749.134	6749.134	2.497	.1163
Subject (Sex, system)	4	22470.890	5617.722	2.078	.0868
Destination	3	56255.145	18751.715	6.937	.0002
Section (Destination)	10	141821.249	14182.125	5.247	.0001
system	1	1225758.767	1225758.767	453.458	.0001
Session	1	13.077	13.077	.005	.9446
system * Section (Desti...	13	90197.607	6938.277	2.567	.0033
system * Session	1	281.764	281.764	.104	.7473
Residual	142	383845.103	2703.135		

Dependent: Mean Range Beta

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Sex	1	754.314	754.314	.927	.3372
Subject (Sex, system)	4	2383.075	595.769	.732	.5712
Destination	3	24502.444	8167.481	10.042	.0001
Section (Destination)	10	42741.562	4274.156	5.255	.0001
system	1	61649.330	61649.330	75.797	.0001
Session	1	246.320	246.320	.303	.5830
system * Section (Desti...	13	41932.753	3225.596	3.966	.0001
system * Session	1	9.025	9.025	.011	.9163
Residual	142	115495.041	813.345		

Dependent: SD Range Beta

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Sex	1	.516	.516	1.214	.2719
Subject (Sex, system)	6	9.353	1.559	3.668	.0017
Destination	3	12.789	4.263	10.030	.0001
Section (Destination)	10	10.258	1.026	2.414	.0098
System	1	12.804	12.804	30.125	.0001
Session	1	.122	.122	.288	.5922
System * Section (Desti...	13	22.392	1.722	4.052	.0001
System * Session	1	.649	.649	1.526	.2181
Residual	208	88.409	.425		

Dependent: Mean Lateral Pos

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Sex	1	.105	.105	1.291	.2573
Subject (Sex, system)	6	.428	.071	.875	.5141
Destination	3	1.141	.380	4.670	.0035
Section (Destination)	10	4.382	.438	5.380	.0001
System	1	19.923	19.923	244.641	.0001
Session	1	.027	.027	.332	.5650
System * Section (Desti...	13	4.805	.370	4.539	.0001
System * Session	1	.005	.005	.065	.7985
Residual	204	16.614	.081		

Dependent: SD Lateral Position

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Sex	1	640.206	640.206	3.679	.0565
Subject (Sex, system)	6	630.851	105.142	.604	.7268
Destination	3	24766.086	8255.362	47.446	.0001
Section (Destination)	10	61708.891	6170.889	35.466	.0001
System	1	763.323	763.323	4.387	.0374
Session	1	14.384	14.384	.083	.7740
System * Section (Desti...	13	2256.453	173.573	.998	.4548
System * Session	1	240.794	240.794	1.384	.2408
Residual	208	36190.641	173.993		

Dependent: Mean Wheel Angle

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Sex	1	35.568	35.568	.187	.6661
Subject (Sex, system)	6	802.194	133.699	.702	.6485
Destination	3	40421.705	13473.902	70.719	.0001
Section (Destination)	10	62358.236	6235.824	32.729	.0001
System	1	307.907	307.907	1.616	.2051
Session	1	34.902	34.902	.183	.6691
System * Section (Desti...	13	2187.956	168.304	.883	.5715
System * Session	1	10.842	10.842	.057	.8117
Residual	208	39629.834	190.528		

Dependent: SD Wheel Angle

APPENDIX AC - SUBJECT COMMENTS

Sex	Age	Time	session #	Dest #	Ali-Scout Mode	Location	Comment/Error
F	22	day	1	1	switch from autonomous to guided	I-75 north at first beacon	"I don't know what that means." (referring to chime)
F	22	day	1	1	guided	exit off of I-75 on exit ramp	"Shouldn't it say 'get off at the exit' or something?" (referring to 'turn right' command)
F	22	day	1	1	guided	south on Crooks Rd.	"This thing in the corner, is that how far I am from it?" (referring to miles to destination)
F	22	day	1	2	guided	east on Long Lake Rd.	"Now does this also know where construction is or where it is really congested and take you around that?"
F	22	day	1	2	guided	Rochester Rd., waiting to turn left onto Wattles Rd.	"Okay, right there when it said take the left hand lane and I saw the thing pointing so I knew I would probably turn left here, but could it have been up there and I jumped the gun by getting over too soon?" (referring to turn command)
F	22	day	1	2	autonomous	east on Wattles near destination	"What was that little compass flash on there?" (referring to destination area graphic)
M	22	rush	1	4	guided	west on Wattles Rd.	"What do these numbers mean down here again?" (referring to miles to destination)
M	53	night	1	1	autonomous	parking lot of starting point	"That's 2 meters?" (referring to miles to destination)
M	53	night	1	1	autonomous	merge onto I-75 north	"So when the arrow is pointed up, that means just go straight ahead?" (referring to crow-fly arrow)
M	53	night	1	1	guided	south on Crooks Rd.	"So it doesn't do a line integral on distance, it actually just takes the crow fly distance? It should do a line integral, that's one of my remarks, because it should match what the odometer does on the car."
M	53	night	1	1	autonomous	South on Crooks Rd.	"Now, is this autonomous?"
M	53	night	1	2	autonomous	north on Crooks Rd.	"How do you know its autonomous again?"
M	53	night	1	2	autonomous	north on Crooks Rd. at Long Lake	Missed right turn onto Long Lake
M	53	night	1	2	autonomous	north on Crooks Rd. after Long Lake	"Oh, was I supposed to follow that arrow?" (after missing right turn)
M	53	night	1	2	autonomous	south on Crooks to turn around and take turn again	"Well actually I can see why they use crow fly distance now, because once you make a bad turn it's all screwed up. If I were doing line integral here, I would be adding all kinds of distance."

M	53	night	1	4	guided	south on Rochester Rd.	"That's not the international symbol for miles, that's the international symbol for meters" (referring to miles to destination)
M	53	night	1	4	switch from guided to autonomous	southwest on Rochester Rd. split	"Oh, what did that mean? An arrow going everywhere...it doesn't say autonomous." (referring to destination area graphic)
F	22	day	2	2	guided	before turn onto Rochester Rd. from Long Lake	"I like the 'right turn ahead' message better...'get in the right hand lane' doesn't mean a whole lot to me sometimes."
M	22	rush hour	1	1	guided	before left turn off exit ramp onto Crooks Rd.	"When it had arrows like that, does that mean for awhile just keep going on the same route?" (referring to follow current path graphic)
M	22	rush hour	1	1	autonomous	parking lot SOC Credit Union	"How come when you are a quarter of a mile away it doesn't tell you anything?"
M	22	rush hour	1	2	guided	west on Long Lake Rd.	"I thought it kind of told you if there was a traffic jam ahead or an accident."
M	24	night	1	1	guided	exit ramp off I-75	"This is cool."
M	19	day	1	1	guided	I-75 north	"So, when I get within a quarter mile its not going to give me exact directions, right?"
M	19	day	1	1	guided	I-75 north	"So, in other words, it wants me to exit?" (referring to 'turn right' command)
M	19	day	1	2	autonomous	Crooks Rd. at Long Lake	Missed right turn onto Long Lake
F	50	night	1	1	switch from guided to autonomous	south on Crooks Rd.	"Does that mean I passed it?" (referring to chime)
F	50	night	1	4	guided	west on Wattles	"Is this the position of our car here?" (referring to lane position graphic)
F	50	night	1	4	autonomous	parking lot of Maplewood	"This is pretty good. It gets you there."
M	22	rush hour	2	1	guided	exit ramp off I-75, near intersection with Crooks Rd.	"This thing is pretty smart, it knows that there are two left turn lanes and everything." (referring to 'take one of the two left hand lanes' command)
M	22	rush hour	2	1	guided	On exit ramp at Crooks Rd.	"How does that voice get there. Can you program voices, different sound bits?"
M	19	day	2	1	autonomous	entrance ramp to I-75	"It's still in autonomous mode? Why is it still in autonomous mode?"
M	19	day	2	2	autonomous	Crooks Rd. north at Long Lake Rd.	"Isn't that a beacon that we just passed? Why didn't it do anything?"
F	45	day	1	2	guided	Long Lake Rd. east at before Rochester Rd.	"Should I turn here or at the main road?"
F	45	day	1	2	autonomous	Harlan plaza parking lot	"What is this top right, this A? And then the circle?" (referring to the destination area graphic)
F	45	day	1	3	autonomous		Turned right out of Harlan plaza instead of left

M	21	day	1	1	autonomous	entrance ramp to I-75	"Is this thing going to say stuff?"
M	21	day	1	1	guided	north on I-75	"Whose voice is that?"
M	21	day	1	1	guided	exit ramp at Crooks Rd.	"How does it know there are two?" (referring to 'take one of the two left hand lanes' command)
M	21	day	1	1	guided	exit ramp at Crooks Rd.	"Now that's a given, when it says get in the left hand lane" (referring to the 'left turn' instruction)
M	21	day	1	2	autonomous	Crooks Rd. north at Long Lake	"The Ali-Scout's not talking to me here"
M	21	day	1	2	guided	south on Rochester Rd.	"What is this? What does this mean?" (referring to follow current path graphic)
M	21	day	1	2	autonomous	east on Wattles Rd.	"I don't see an A" (referring to the destination zone graphic)
F	19	rush hour	1	1	guided	north I-75	"Does it tell you when to exit and everything?"
F	19	rush hour	1	2	autonomous	north on Crooks before intersection with Long Lake	"Will it tell me, or do I follow the arrow 'til it gets into..?"
F	19	rush hour	1	2	guided	south on Rochester Rd. at Wattles Rd.	"What if there is an accident somewhere? Would it pick that up and tell you to go another way?"
F	50	night	2	2	guided	south on Rochester Rd. at Wattles	"I had a question with these little cars here." (referring to the lane position graphic)
M	20	day	1	2	autonomous	north on Crooks at Long Lake	Missed right turn on Long Lake
M	20	day	1	2	guided	south on Rochester Rd.	"When you first use this, you almost expect it to tell you where to go all the time."
F	21	night	1	1	switch from autonomous to guided	north on I-75	"Oh, that scared me. What is this? Now I know they told me what this means, but I forget." (referring to chime and then follow current path graphic)
F	21	night	1	1	guided	north on I-75	"Oh, that means get off at this exit?" (referring to the 'turn right' command)
F	21	night	1	1	guided	exit ramp at Crooks Rd.	"Oh, I have to turn don't I?"
F	21	night	1	1	switch from guided to autonomous	south on Crooks Rd.	"That means I'm in the area?" (referring to chime)
F	21	night	1	2	autonomous	north on Crooks Rd. at Long Lake	Missed right turn on Long Lake
F	21	night	1	2	guided	south on Rochester Rd. at Wattles	"Do I want to turn? I do, don't I? See, it kind of told me a little late, because I saw this arrow, but it didn't tell me to turn." (referring to 'take the left hand lane' followed by the 'turn left' command)

F	21	night	1	2	autonomous	east on Wattles	"Oh wait, I don't know where I am. Well, it's going to be on the right." (referring to destination)
F	21	night	1	3	autonomous	east on Wattles at John R	"Okay, I think that I want to turn here."
F	21	night	1	3	autonomous	north on John R	"No, that's Mt.Vernon. I think I wanted to go there though."
M	41	day	1	1	guided	north on I-75	"It's a male voice. You can't get female voices?"
M	41	day	1	1	guided	exit ramp off I-75 at Crooks Rd.	"It knows that there's more that one left hand lane here? That's cool." (referring to 'take one of the left hand lanes' command)
M	41	day	1	1	guided	exit ramp off I-75 at Crooks Rd.	"What's the little cars down here?" (referring to lane position graphics)
M	41	day	1	1	guided	exit ramp off I-75 at Crooks Rd.	"When do you get the countdown on the mileage thing?"
M	41	day	1	1	guided	south on Crooks Rd. at Long Lake	"I guess this wouldn't be much different than being lost and using a map. I keep anticipating something, waiting for it to do something."
M	41	day	1	1	autonomous	south on Crooks Rd. after SOC	"I thought we got a countdown bar or something." (referring to destination after he passed it)
M	41	day	1	1	autonomous	parked on side street	"So it doesn't really tell you anything when you've reached your destination?"
M	41	day	1	2	autonomous	north on Crooks Rd.	"I can anticipate this a little bit. It's pointing that way, I'm obviously going to want to turn that way."
M	41	day	1	2	autonomous	Crooks and Long Lake	"Can I do this? Is this right?" (referring to right turn on Long Lake)
M	41	day	1	2	switch from autonomous to guided	east on Long Lake	"What does the chime mean?"
M	41	day	1	2	guided	Long Lake and Rochester Rd.	"The countdown bars are just for turns?"
M	41	day	1	2	guided	Long Lake and Rochester Rd.	"At the light right?" (referring to 'turn right' command)
M	41	day	1	2	guided	Rochester Rd. and Wattles	"Ahhhhhh..." (didn't know whether to turn left at light or into shopping plaza)
M	21	rush hour	1	1	autonomous	parked after missing SOC	"Is this miles right here?" (referring to miles to destination)
M	21	rush hour	1	2	autonomous	north on Crooks at Long Lake	"Oh, so I should have made a right here, huh? Because I saw it getting further away."
M	21	rush hour	1	2	autonomous	north on Crooks at Long Lake	Missed right turn on Long Lake
M	21	rush hour	1	4	guided	south on Rochester Rd. at split	"There?" (referring to 'turn right' command)

M	21	rush hour	1	4	guided	south on Rochester Rd. at split	Missed right turn onto Rochester Rd. split
M	21	night	1	2	autonomous	north on Crooks Rd. at Long Lake	" Where's my little bar graph? I should be turning shouldn't I? I think I should turn. I'm going to turn."
M	21	night	1	2	guided	south on Rochester Rd. at Wattles	"Do I want to turn left here? Yeah, I think so. It didn't tell me to though." (following 'take the left hand lane' command)
M	21	night	1	3	guided	south on Rochester Rd. before Big Beaver	"Is this it right here? But it's not telling me to turn."
M	19	day	1	1	autonomous	exit ramp of I-75 (Ali-Scout not working)	"Does this A in the upper right hand corner stand for autonomous?"
M	19	day	1	2	autonomous	north on Crooks at Long Lake	"It's a pretty good thing if you get lost. But I wouldn't, like, depend on it especially in this autonomous mode."
M	19	day	1	2	guided	east on Long Lake	"This mode is cool and all (referring to guided mode), but the other one really sucks. Even when you're right there I was having trouble."
M	19	day	1	2	guided	east on Long Lake, before Rochester Rd.	"It would never tell you to turn on a sub-road would it?"
M	19	day	1	2	guided	south on Rochester Rd. at Wattles Rd.	"Am I supposed to get in the left hand lane? Because it's giving me this... because I saw this and this only comes up when you're making a turn, right?" (referring to turn graphic)
M	19	day	1	2	autonomous	east on Wattles	"Are these expensive?"
M	19	day	1	3	autonomous	east on Wattles at John R	"Okay, I think I should make a left here."
F	45	day	2	2	autonomous	north on Crooks before Long Lake	"I'm going to go straight, right? I'm going to go by the screen, but it didn't say anything?"
M	72	rush	1	1	autonomous	north on I-75	"Now, that's indicating that I should get over in the next lane? Is that what it is trying to tell me?" (referring to autonomous arrow)
M	72	rush	1	1	autonomous	north on I-75	"Okay, now I have to make a turn, right?"
M	72	rush	1	1	autonomous	south on Crooks	"Okay, do I have to start looking now, or something?"
M	72	rush	1	2	autonomous	north on John R	"I don't hear any voices, does that mean I've passed it?"
M	65	night	1	2	guided	east on Long Lake	"Is this thing in metric to confuse people?" (referring to miles to destination)
M	65	night	1	2	guided	south on Rochester Rd. at Wattles	"Not enough warning." (referring to the 'turn left' command) "If its going to tell you to turn left, it should tell you a little ways before you turn left."

F	46	day	1	2	autonomous	north on Crooks at Long Lake	Missed right on Long Lake
F	46	day	1	2	guided	south on Rochester at Wattles	Missed left on Wattles
M	22	night	1	1	autonomous	parking lot of SOC	"That came up on you really quick, that autonomous mode. If there had been any traffic I don't know if I would have been able to get over."
M	22	night	1	2	autonomous	north on Crooks at Long Lake	Missed right on Long Lake
M	22	night	1	2	guided	south on Rochester at Wattles	Missed left on Wattles
M	72	rush	2	2	autonomous	north on Crooks at Long Lake	"No, I've got three miles to go still" (referring to right turn on Long Lake)
M	72	rush	2	2	autonomous	north on Crooks at Long Lake	Missed right turn on Long Lake
M	72	rush	2	3	autonomous	east on Wattles at John R	"Now, am I supposed to turn here, or does it say?"
M	41	day	2	4	guided	west on Wattles at Rochester	"So those bars represent like tenth of miles or something in particular?" (referring to countdown bars)
F	20	rush	1	1	autonomous	pulled off past SOC	"Why can't they tell you to go right, or wherever, where your destination is?"
F	20	rush	1	2	autonomous	north on Crooks at Long Lake	Missed right on Long Lake
F	20	rush	1	3	autonomous	out of Harlan plaza parking lot	"Go backwards? Okay, I'm going to go left."
M	22	night	2	1	guided	north I-75 at exit ramp	"You know, that's one thing I don't like about this thing. Why can't it say exit?" (referring to 'turn right' command)
M	22	night	2	2	guided	south on Rochester at Wattles	"Oh, I'm screwing up. Oh no, I guess not."
M	22	night	2	2	guided	south on Rochester at Wattles	"That's what I remember, I don't like about it. Even though it shows you this picture, it says take the left hand lane. But when it says that to me, I don't think of the turn lane, I think of the left hand lane." (referring to the turn graphic)
M	22	night	2	2	guided	east on Wattles	"Why did this thing just go into autonomous mode? I'm not a quarter of a mile."
M	21	day	2	2	autonomous	north on Crooks at Long Lake	"Oh, no" (realizing that he has to turn right on Long Lake)
M	21	day	2	4	guided	South on Rochester Rd.	"Now, if I go past, will the Ali-Scout say 'hey'"
M	65	night	1	1	autonomous	parking lot of SOC	"Why didn't it say 'turn right' into the destination"

M	65	night	1	2	autonomous	north on Crooks Rd. before Long Lake	"Yeah, but I'm going this way. Why is that thing going that way?" "Is this telling me anything ...that I should turn right?"
M	65	night	1	2	guided	south on Rochester Rd.	"What does the m stand for?" (referring to miles to destination)
F	52	rush	1	1	autonomous	parked on street after SOC	"What was that big burst?" (referring to destination zone graphic)
F	52	rush	1	2	autonomous	north on Crooks at Long Lake	Missed right onto Long Lake
M	44	night	1	1	switch from guided to autonomous	south on Crooks Rd.	"That means I passed it, or I didn't find it?" (referring to chime)
M	44	night	1	1	autonomous	SOC parking lot	"Is there any reason why they can't tell you right up to where you are going?"
M	44	night	1	2	autonomous	north on Crooks at Long Lake	Missed right on Long Lake
M	44	night	1	3	autonomous	leaving the parking lot of Harlan plaza	"I've got no idea where I'm going"
M	44	night	1	4	guided	west on Wattles at Rochester Rd.	"It said left hand lane, not left turn lane. It should have said left turn lane." (referring to 'take the left hand lane' command)
F	72	day	1	1	guided	north on I-75	"Three different arrows, does that mean I turn?" (referring to follow current path graphic)
F	72	day	1	2	guided	south on Rochester at Wattles	"You're a little late." (referring to 'turn left' command)
F	72	day	1	3	autonomous	east on Wattles at John R	"Now I'm confused."
F	77	day	1	1	guided	north on I-75	"That three means three ways?" (referring to follow current path graphic)
F	77	day	1	2	autonomous	north on Crooks at Long Lake	Missed right on Long Lake
F	77	day	1	2	switch from guided to autonomous mode	east on Wattles	"Does that mean you're there?" (referring to chime)
F	77	day	1	3	autonomous	east on Wattles at John R	"Is that right?" (referring to left turn)
F	52	rush	2	2	autonomous	north on Crooks at Long Lake	"Am I supposed to make a right?"
F	51	night	1	1	guided	south on Crooks Rd. after exit ramp	"What do the two little cars mean that were down here back at the light?" (referring to lane position graphic)
F	51	night	1	1	autonomous	north on Crooks at Long Lake	"This is now in autonomous with the A?"

F	51	night	1	3	autonomous	east on Wattles at John R	"I'm going to take a shot that it comes out on this street and not that one." (referring to left turn onto John R)
F	51	night	1	4	switch from autonomous to guided	west on Wattles Rd.	"Is that bing for when it goes on?" (referring to chime)
M	54	rush	2	1	autonomous	pulling into SOC	"What I really like about this thing are the miles. When you've overshot it, it's going to tell you that you're three tenths of a mile past or whatever."
M	54	rush	2	3	autonomous	east on Wattles at John R	"Do I want to make a left turn, is that what I want to do?"
M	54	rush	2	4	guided	west on Wattles at Rochester Rd.	"What is the symbol of the little automobile on the bottom?" (referring to lane position graphic)
F	72	day	2	1	guided	south on Crooks Rd.	"It doesn't go into an arrow bit here?" (referring to autonomous mode)
M	69	rush	1	2	guided	south on Rochester at Wattles	"Lucky there was no traffic coming." (referring to the lateness of the 'turn left' command)
M	69	rush	1	3	autonomous	parking lot of Harlan plaza	"What do I do here?" (unsure of where to turn out of parking lot)
M	44	night	2	2	autonomous	north on Crooks at Long Lake	Missed right on Long Lake
M	44	night	2	3	autonomous	east on Wattles at John R	Missed left turn onto John R Rd.
M	51	rush	1	1	switch from autonomous to guided	north on I-75	"What does that buzzer mean?" (referring to chime)
M	51	rush	1	2	autonomous	north on Crooks at Long Lake	"Now I can follow the arrow, or do I have to wait for it tell me something?"
M	51	rush	1	2	guided	east on Long Lake	"Does that mean three lanes?" (referring to follow current path graphic)
M	51	rush	1	4	guided	south on Rochester Rd./ Stevenson Hwy.	"Here? Rochester Rd. or Maple Rd.?" (unsure where to turn right)
M	51	rush	1	4	guided	south on Rochester Rd./ Stevenson Hwy. at split	missed right on Rochester Rd. where it splits off from Stevenson Hwy.
F	41	night	1	1	autonomous	south on Crooks Rd. before at SOC	"Oh, I'm not supposed to be turning, right?"
F	41	night	1	2	autonomous	north on Crooks at Long Lake	Missed right turn onto Long Lake Rd.
F	41	night	1	2	guided	south on Rochester at Wattles	Subject pulled into shopping plaza, before turn at Wattles Rd.
M	77	day	1	1	autonomous	entrance ramp to north on I-75	"Is this telling me to make a right?"

M	77	day	1	1	autonomous	north on I-75	"Does this mean make a right turn, this R?" (referring to A in the upper left corner of Ali-Scout screen)
M	77	day	1	2	autonomous	north on Crooks at Long Lake	"I'm going to make a right? I don't know if that's correct."
M	77	day	1	2	guided	south on Rochester Rd. at Wattles	"Uh oh, that's kind of late, wasn't it" (referring to 'turn left' command)
F	20	rush	1	1	guided	north on I-75	"That means, its telling me to go straight, right?" (referring to follow current path graphic)
F	20	rush	1	2	autonomous	north on Crooks at Long Lake	"So if that's there it's not going to tell me to turn, but I probably should? Oh no. Okay, I'm going to do it."
F	20	rush	1	3	autonomous	Harlan plaza parking lot	"Now if it's pointing backwards what do I do? (referring to autonomous arrow)
F	20	rush	1	3	autonomous	Harlan plaza parking lot	Turned right out of parking lot instead of left
M	65	night	2	1	guided	exit ramp of I-75 at Crooks Rd.	"See how far away we were from the intersection when that said turn left? If that light were green and I thought I was going through that intersection it doesn't give you enough warning."
F	77	day	2	2	autonomous	north on Crooks at Long Lake	"Is that right? (referring to the right turn she is about to make onto Long Lake)
M	51	rush	2	1	switch from autonomous to guided	north on I-75	"What was that beep for?" (referring to chime)
M	51	rush	2	2	guided	south on Rochester at Wattles	"This is it right here, isn't it? Harlan plaza? Guess not." (referring to plaza at Rochester and Wattles)
F	51	night	2	1	guided	north on I-75 before exit	"Does this always have four lanes down here, no matter how many lanes there are in the road?" (referring to lane position graphic)
M	77	day	1	1	switch from guided to autonomous mode	south on Crooks Rd.	"What does that mean?" (referring to chime)
M	77	day	1	1	autonomous	south on Crooks Rd.	"It's not going to tell me anything?"
M	77	day	1	2	autonomous	north on Crooks at Long Lake	Missed right turn onto Long Lake Rd.
F	20	rush	2	2	autonomous	north on Crooks at Long Lake	Missed right turn onto Long Lake Rd.
F	20	rush	2	4	switch from autonomous to guided	west on Wattles	"Does that thing mean guided mode?" (referring to chime)
M	69	night	2	1	autonomous	south on Crooks, past SOC	"Well the miles never went to zero. I was waiting for the miles to go to zero before I turned into the destination."
M	69	night	2	2	autonomous	north on Crooks	"Well, I've got to turn right someplace"

M	69	night	2	2	autonomous	north on Crooks at Long Lake	"Is this going to tell me to turn right?"
M	69	night	2	2	guided	south on Rochester at Wattles	"They should have that say, just turn left at the next light or something." (referring to 'take the left hand lane' command)
M	69	night	2	2	guided	east on Wattles	"Oh, that signals the warning, you're close?"
M	69	night	2	3	autonomous	east on Wattles at John R	"How come it doesn't go across 90 degrees?" (referring to autonomous arrow at turn onto John R)
M	22	rush	1	2	guided	south on Rochester at Wattles	"I don't know if I'm supposed to turn here, but..."
F	41	night	2	2	guided	south on Rochester at Wattles	Turned left into shopping plaza rather than turning left onto Wattles Rd.
F	76	rush	1	1	autonomous	north on I-75	"Now, it's telling me to go to the left?" (referring to autonomous arrow
F	76	rush	1	1	autonomous	north on I-75	"So, I can be anywhere."
F	76	rush	1	2	autonomous	north on Crooks at Long Lake	"So do I make a right up here at the light? Do I understand?"
F	76	rush	1	4	autonomous	south on Rochester Rd. split off	"You know, you get used to that monitor (Ali-Scout interface). I didn't like the idea of that when I started, but it's not too bad."
M	58	night	1	1	autonomous	driving into SOC credit union	"OK, this thing decreases the miles as you get near to it?"
M	58	night	1	2	autonomous	north on Crooks	"I see that there is a monitor(referring to beacon) up at the corner, so it should click in by the time we get up there?"
M	58	night	1	2	autonomous	north on Crooks at Long Lake	Missed right turn on Long Lake
M	58	night	1	3	autonomous	north on John R past Cumberland Dr.	"I was watching the Ali-Scout 'cause I didn't know where the street was and it didn't even get close, down to the hundredths."
M	58	night	1	4	guided	west on Wattles at Rochester Rd.	"I thought the bars were only there when you were at the end." (referring to countdown bars at turn)
M	77	day	2	2	autonomous	north on Crooks at Long Lake	Missed right turn onto Long Lake
M	77	day	2	2	autonomous	east on Long Lake	"That wasn't good information. I'd say that's a weakness." (referring to the autonomous arrow at Long Lake)
M	21	night	2	2	autonomous	north on Crooks at Long Lake	"It didn't say turn. I thought it would, but that's okay."
M	21	night	2	2	guided	south on Rochester at Wattles	"Nice warning! It said turn left right when the lights there. They didn't give you any warning at all."

M	21	night	2	2	guided	south on Rochester at Wattles	Missed left turn at Wattles Rd.
M	21	night	2	3	autonomous	east on Wattles at John R	"Hmm, I thought I turned here." (referring to left turn onto John R Rd.)
M	69	rush	2	2	guided	east on Long Lake at Rochester	"What's that little square here?" (referring to countdown bars to turn)
F	66	night	1	1	guided	north on I-75	"Does that tell me that I have three lanes?" (referring to "follow current path" graphic)
F	66	night	1	2	guided	east on Long Lake	"Do you think that people will be paying more attention to this than to their driving?"
F	66	night	1	4	autonomous	west on Wattles	Tried to turn left into a plaza after making the right turn onto Wattles because the Ali-Scout's autonomous mode was pointing in that direction.
M	77	day	2	2	autonomous	north on Crooks at Long Lake	Missed right turn onto Long Lake
M	48	day	1	1	switch from autonomous to guided	north on I-75	"That tone was from the computer, right?" (referring to chime
M	48	day	1	1	guided	north on I-75	"That must mean take this exit?" (referring to Ali-Scout's command to 'turn right')
M	51	night	2	2	autonomous	north on Crooks at Long Lake	"This thing reads in meters, right?" (referring to the miles to destination readout)
F	75	day	1	1	guided	north on I-75	"I have to keep remembering to look at it"
F	75	day	1	1	guided	north on I-75	"At the exit, huh." (referring to the 'turn right' command)
F	75	day	1	1	guided	exit ramp off I-75	"I forget to watch that thing, it's a good thing that there's noise." (referring to chime)
F	75	day	1	1	autonomous	south on Crooks	"What am I supposed to do now?" (referring to autonomous mode)
F	75	day	1	2	switch from autonomous to guided	east on Long Lake	"What was that bell for?" (referring to chime)
F	75	day	1	2	guided	east on Long Lake	"What is this? This shows the minutes or miles?" (referring to the miles to destination readout)
F	75	day	1	4	guided	south on Rochester at split	"Should I get ready for a turn?" (referring to the 'take the right hand lane' command)
F	44	rush	1	1	autonomous	north on I-75	"So this is telling me that it's that way?" (referring to autonomous arrow)
F	44	rush	1	2	autonomous	north on Crooks at Long Lake	"Is it going to talk to me before I make any turns? What if I turn here, would that be right or wrong?"
F	44	rush	1	2	autonomous	east on Wattles at John R	"This isn't right, is it? I want to get out of this lane" (referring to left turn)

F	44	rush	1	2	autonomous	east on Wattles at John R	Missed left turn onto John R Rd.
M	48	day	2	4	guided	south on Rochester at split	"It'd be nice if those commands came a little bit earlier." (referring to 'turn right' command)
F	53	rush	1	1	autonomous	north on I-75	"Do those letters mean something?" (referring to A in upper right corner of Ali-Scout)
F	53	rush	1	2	autonomous	north on Crooks at Long Lake	"Does it want me to turn? I guess I'll turn."
M	77	day	1	1	autonomous	parking lot of SOC	"When it got near this place, that big star came on, but I didn't notice, did it point right? It didn't seem like I had much warning." (referring to destination zone graphic)
M	77	day	1	2	autonomous	north on Crooks	"I'm supposed to follow that arrow?"
M	77	day	1	3	autonomous	Harlan Plaza parking lot	Missed left turn out of parking lot
F	65	rush	1	1	switch from autonomous to guided	north on I-75	"Okay now that means we don't get off here, we keep going straight." (referring to chime)
F	65	rush	1	2	autonomous	north on Crooks at Long Lake	"This is going to tell me to make a right turn, but not here, it will tell me?"
F	65	rush	1	2	autonomous	south on Crooks	"When does it go back into the mode where it tells you?"
F	65	rush	1	2	autonomous	north on Crooks Rd. at Long Lake	"Now, it's going to take us three minutes, instead of 1 minute?" (referring to the miles to destination readout)
F	65	rush	1	2	guided	east on Long Lake	"I like it best when its talking."
F	65	rush	1	3	autonomous	east on Wattles at John R	"Would this be at a right angle if it wanted you to turn here?" (referring to autonomous arrow)
F	45	day	1	2	autonomous	north on Crooks at Long Lake	"Now, does that mean I'm supposed to turn right?"
F	44	rush	2	1	guided	south on Crooks	"How do you know when it goes off?" (referring to autonomous mode)
F	44	rush	2	2	autonomous	north on Crooks at Long Lake	"It should be telling me now right?"
F	66	night	2	1	guided	north on I-75	"They give you a lot of good time before they tell you to do the things that you do."
F	66	night	2	4	autonomous right before guided	west on Wattles right after John R	Subject wanted to turn into a shopping plaza and was directed not to by the experimenter
F	66	night	2	4	guided	west on Wattles	"I would never buy this for my car. I would rather look at a map and go from there."

F	75	day	2	1	switch between autonomous and guided	north on I-75	"I keep forgetting to look at that. I'm supposed to keep going, huh?"
F	75	day	2	1	guided	north on I-75	"I'll be exiting then here, at Crooks?" (referring to 'turn right' command)
F	75	day	2	1	switch from guided to autonomous	south on Crooks	"What is that?" (referring to chime)
F	75	day	2	2	guided	south on Rochester	"Will it tell me if I should be in the right or left lane?"
F	75	day	2	4	guided	south on Rochester at the split	"Should I turn here?"
M	77	day	2	1	autonomous	north on I-75	"Shouldn't that arrow be pointing straighter?"
M	77	day	2	2	guided	south on Rochester at Wattles	"They didn't give you much warning then, did they?" "They said get in the left lane, but they didn't say left turn lane. Then all of a sudden it says turn left."
F	72	night	1	1	switch from autonomous to guided	north on I-75	"What's that mean?" (referring to chime)
F	72	night	1	1	guided	north on I-75	"Less than a minute to go before we get off?" (referring to miles to destination readout)
F	72	night	1	1	switch from guided to autonomous	south on Crooks	"Now, what was that boing?" (referring to chime)
F	72	night	1	2	autonomous	north on Crooks Rd. at Long Lake	"Turn right here?" "Well, the arrows pointing that way, so I guess that's all right."
F	72	night	1	2	guided	east on Long Lake	"Well there's three arrows now." (referring to follow current path graphic)
F	72	night	1	3	autonomous	east on Wattles at John R	"Well, its not really left is it? Just sort of. I don't like that. Well, its getting more so." (referring to autonomous arrow)
F	72	night	1	4	guided	west on Wattles	"Maplewood plaza, 2 minutes" (referring to miles to destination readout)
F	72	night	1	4	guided	west on Wattles at Rochester	"turn?" (following the "take the left hand lane" command)
M	68	rush	1	2	autonomous	north on Crooks at Long Lake	Missed right turn onto Long Lake
M	68	rush	1	2	guided	east on Long Lake	Turned early into subdivision rather than at the light between Long Lake and Rochester Rd.
M	68	rush	1	3	autonomous	north on John R after Wattles	Subject tried to turn into parking lot of old bank - was told to continue
M	46	rush	1	1	autonomous	north on I-75	"Those three arrows, would that designate like three lanes that are available?" (referring to follow current path graphic)

M	46	rush	1	2	autonomous	north on Crooks at Long Lake	Subject missed right at Long Lake "I don't understand my arrows."
M	46	rush	1	2	autonomous	east on Long Lake - before passing Crooks	"Now this tells me I'm three miles away from it?" (referring to miles to destination readout)
M	46	rush	1	2	guided	south on Rochester at Wattles	"Wait a minute, it said the left hand lane... Yeah, it means turn left"
F	72	night	2	1	switch from autonomous to guided	north on I-75	"Does that indicate that we get off at Crooks?" (referring to chime)
F	72	night	2	2	autonomous	north on Crooks at Long Lake	"Do I turn here? I don't remember from last time."
F	72	night	2	2	guided	south on Rochester at Wattles	"Left turn?" (referring to 'take the left hand lane' command)
F	72	night	2	4	guided	south on Rochester at split	"Now?!" (referring to the turn right command)
M	46	rush	2	2	guided	south at Rochester at Wattles	"Hum, it said take the left hand lane, but it doesn't say turn left. But the arrow is pointing that way."
F	23	day	1	2	guided	south on Rochester at Wattles	Missed left turn onto Wattles
F	23	day	1	3	autonomous	east on Wattles at John R	"Where does it want me to go? Well I'm turning. Nope, I don't think that is right."
F	21	day	1	2	autonomous	north on Crooks at Long Lake	Missed right turn onto Long Lake
F	21	day	1	3	autonomous	parking lot of Harlan Plaza	"Hmmm, I guess I go left"
F	19	night	1	2	autonomous	north on Crooks at Long Lake	Missed right turn onto Long Lake
F	19	night	1	2	guided	east on Long Lake at Rochester Rd.	"Uh, right here? Uh, I don't know?"
F	19	night	1	2	guided	east on Long Lake at Rochester Rd.	Turned before the light, into parking lot. Was redirected onto the route
F	19	night	1	2	guided	south on Rochester at Wattles	"Oh, do I get in the left hand turn lane?"
F	21	day	2	2	autonomous	north on Crooks at Long Lake	"Am I supposed to turn?"
F	21	day	2	2	autonomous	north on Crooks at Long Lake	Missed right turn onto Long Lake
F	70	rush	1	2	autonomous	north on Crooks at Long Lake	Missed right turn onto Long Lake

F	70	rush	1	1	autonomous	entrance ramp to I-75	"I'm a little bit leery about the Ali-Scout."
F	70	rush	1	1	autonomous	north on I-75	"I don't hear anything yet.."
F	70	rush	1	1	guided	south on Crooks	"Pretty soon I can expect to hear something?"
F	70	rush	1	1	autonomous	south on Crooks	"And it's not telling me anything here?"
F	70	rush	1	2	guided	south on Rochester at Wattles	"In the farthest lane?" (referring to 'take the left hand lane' command)
F	70	rush	1	2	autonomous	east on Wattles	"Does that mean make a left turn?" (referring to autonomous arrow)
F	70	rush	1	3	autonomous	east on Wattles at John R	"I'm going more by the arrows."
F	65	night	1	2	autonomous	north on Crooks at Long Lake	"I don't like this direction. Three miles to the right?"
F	65	night	1	3	autonomous	east on Wattles at John R	"Looks like a left turn already? I hope that this is correct"
F	65	night	1	4	switch from autonomous to guided	west on Wattles	"What?...I don't like that bell." (referring to chime)
F	65	night	2	1	switch from autonomous to guided	north on I-75	"That means that we're going to exit, or ... What is that bong?" (referring to chime)
F	65	night	2	2	autonomous	north on Crooks at Long Lake	"Now he's (the Ali-Scout) not saying anything but this looks right to me. (referring to the right turn onto Long Lake)
F	65	night	2	2	guided	south on Rochester at Wattles	"This is the left hand lane isn't it, or does he (Ali-Scout) want me to take the turn lane?"
M	49	after noon	1	2	autonomous	north on Crooks at Long Lake	Missed right turn onto Long Lake
F	70	rush hour	2	1	switch from autonomous to guided	north on I-75	"This is where I get puzzled."
F	70	rush hour	2	2	autonomous	north on Crooks at Long Lake	Missed the right turn onto Long Lake
F	70	rush hour	2	2	guided	east on Long Lake before Rochester Rd.	"Now this won't say anything? I'm supposed to know?"
M	68	night	1	1	autonomous	north on I-75	"That arrow changes as you change.. as you turn" (referring to autonomous arrow)
M	68	night	1	1	autonomous	north on I-75	"Will it tell me the exit or not?"
M	68	night	1	1	guided	exit ramp off I-75	"We must be exiting on Crooks Rd., aren't we?"
M	68	night	1	1	switch from autonomous to guided	south on Crooks Rd.	"Are we here?" (referring to chime)
M	68	night	1	2	autonomous	north on Crooks at Long Lake	"I will go according to the arrow, so I will take the first right here."

M	68	night	1	2	autonomous	east on Wattles	"I must be getting close, huh? Because the thing has changed."
F	27	night	1	1	guided	south on Crooks	"Uh, is it in here? Ooooooh, I can't remember,"
F	27	night	1	2	autonomous	north on Crooks at Long Lake	"Okay, I need to go right it says. Okay, this I think means turn right, oooh."
F	27	night	1	2	guided	east on Long Lake	"Can I make a suggestion? Can you make it more polite to say please and thank you?"
F	27	night	1	2	guided	south on Rochester at Wattles	"Okay, get in the left lane, I'm in the left lane... they must mean the very left lane. Okay."
F	27	night	1	2	autonomous	at Harlan Plaza	"This is very... I like this. How soon can I put one of these in my car?"
F	27	night	2	2	autonomous	east on Wattles	"Why is this lighted up like a little star?" (referring to destination zone graphic)
F	19	night	2	2	autonomous	north on Crooks at Long Lake	"It didn't tell me to turn?"
F	19	night	2	2	autonomous	parking lot of Harlan Plaza	"This looks cool. I would seriously put this in my car if I could."

APPENDIX AD - DESCRIPTION OF THE DATA SET FROM THE SUPPLEMENTAL EXPERIMENT

Straight driving points

The primary analysis occurred when subjects were driving straight (steering wheel angles were small). These data were examined to give a sense of how much data was collected and where it was obtained. In the ANOVA of the number of straight driving points, neither of the driver-related factors (sex nor subject nested by sex and system) were not found to be significant. Figure 112 shows the differences between subjects by interface and sex.

The difference due to system (an average of 2282 points/section for Ali-Scout subjects and 2032 points/section for PathMaster subjects) was also not significant, simplifying the analysis. PathMaster subjects had fewer straight driving points because they drove faster during the straight portions of sections.

As expected, route-related factors, both destination (p=0.0001) and section within destination (p=0.0001), were found to be significant. The small number of data points for destination 3 (over 800) is due to the short distance of both sections. Figure 113 shows the mean number of straight driving points for system by section nested by destination. The Ali-Scout and PathMaster subjects seem to follow the same pattern over sections. Readers interested in a more detailed description of the sections should see Appendix L.

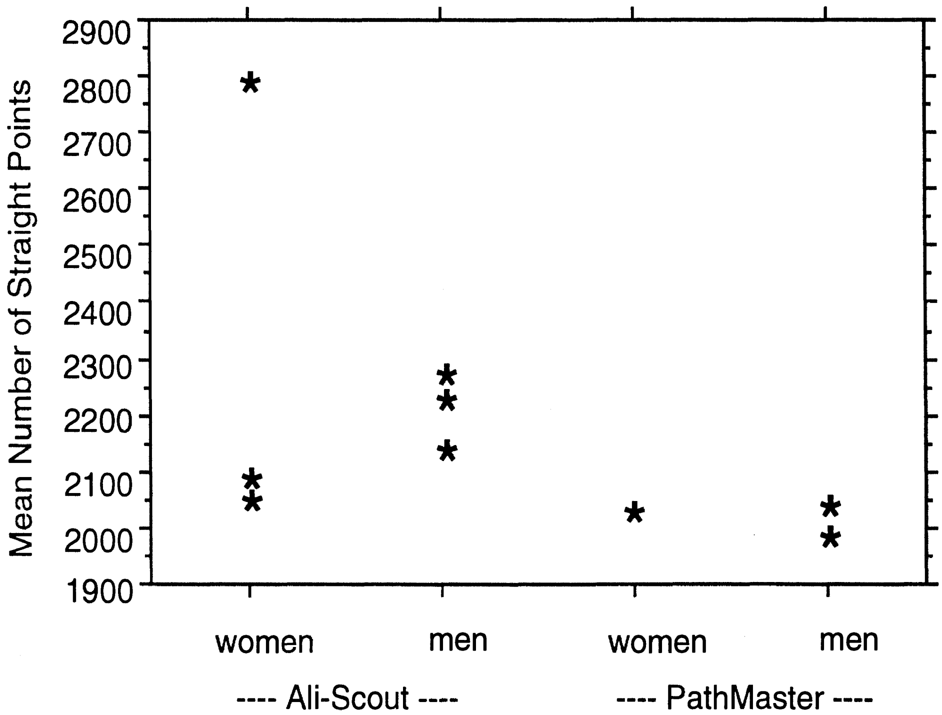


Figure 112. Mean number of straight points for all subjects.

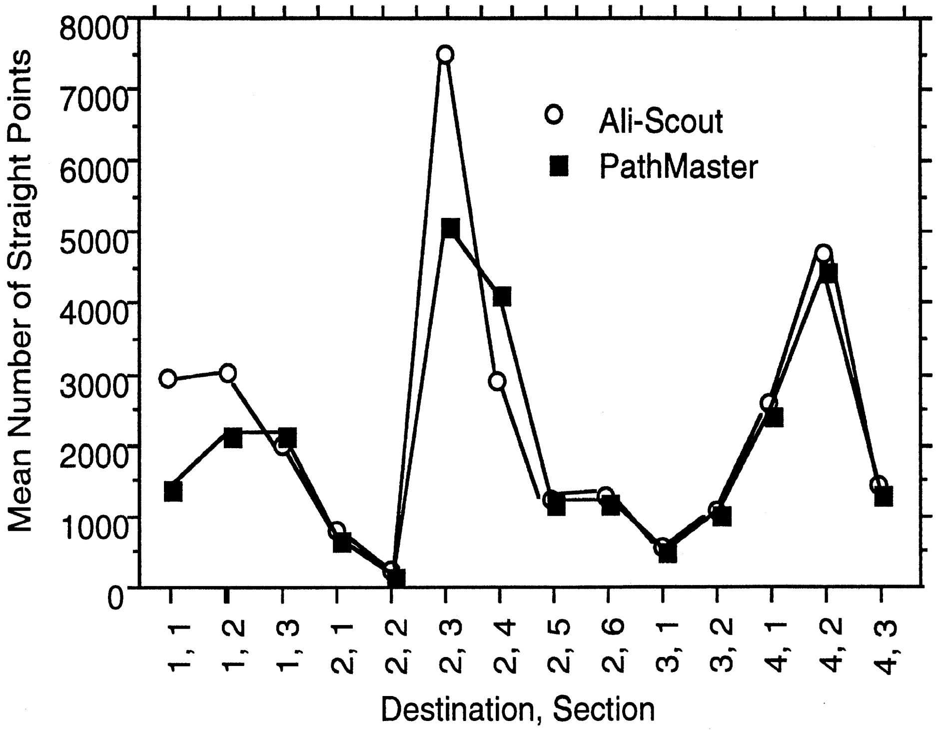


Figure 113. Mean number of straight points for system by section.

Although neither trial number nor system by trial number were found to be significant, for completeness Figure 114 shows the interaction. Readers should recall the baseline data represents two different groups following the same route under experimenter guidance. Nonetheless, the Ali-Scout subjects had more (but not significantly more) straight points, indicating slower speeds during experimentation.

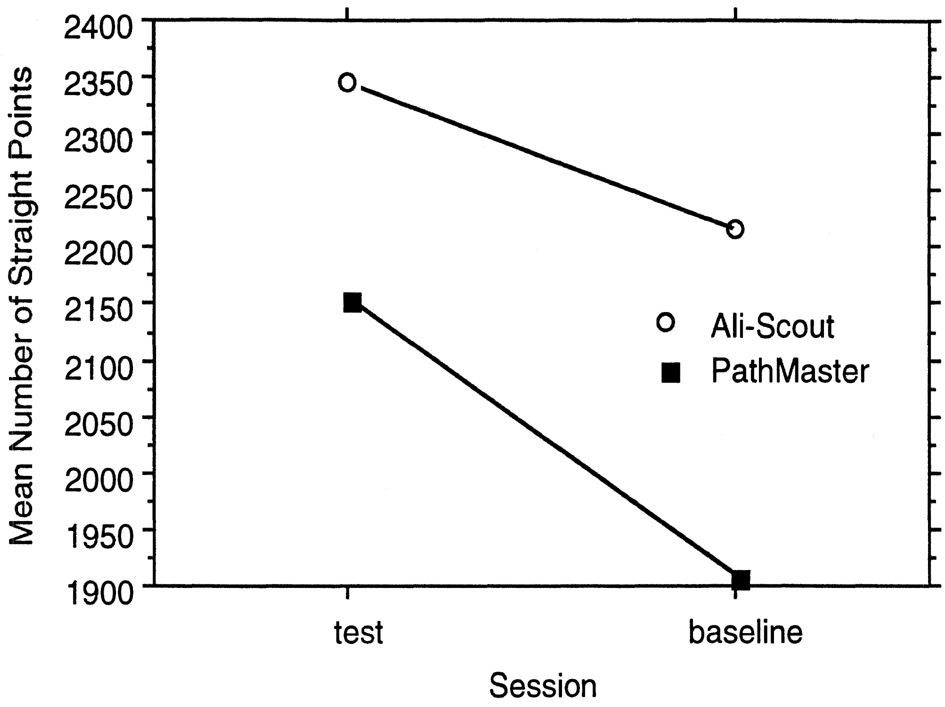


Figure 114. Mean number of straight points for system by trial number.

Stopped points

With respect to the mean number of stop data points, both sex and subject nested by sex and system were not found to be significant. However, Figure 115 is included to understand the distribution of Ali-Scout and PathMaster subjects by sex. Notice that for males the number of data points varies between 650 and over 1250, a 1:2 ratio, though in time, this corresponds to about a 20-second difference.

Although navigation system was not found to be significant, the means for both the Ali-Scout and PathMaster subjects were 999 points/section and 773 points/section, respectively. This indicates that Ali-Scout subjects were required to slow down (speeds below 3.5 mi/hr), or stop more frequently. This may be due to differences in traffic density over the two navigation systems or subject differences (in terms of how aggressively they drove).

As expected, both destination (p=0.0116) and section within destination (p=0.0001) were significant. In addition, Figure 116 shows the mean number of stop points for system by section nested by destination. The two sets of users seem to follow a similar pattern across sections. Sections 2 and 3 of destination 2 both have back-ups due to high traffic density during rush hour.

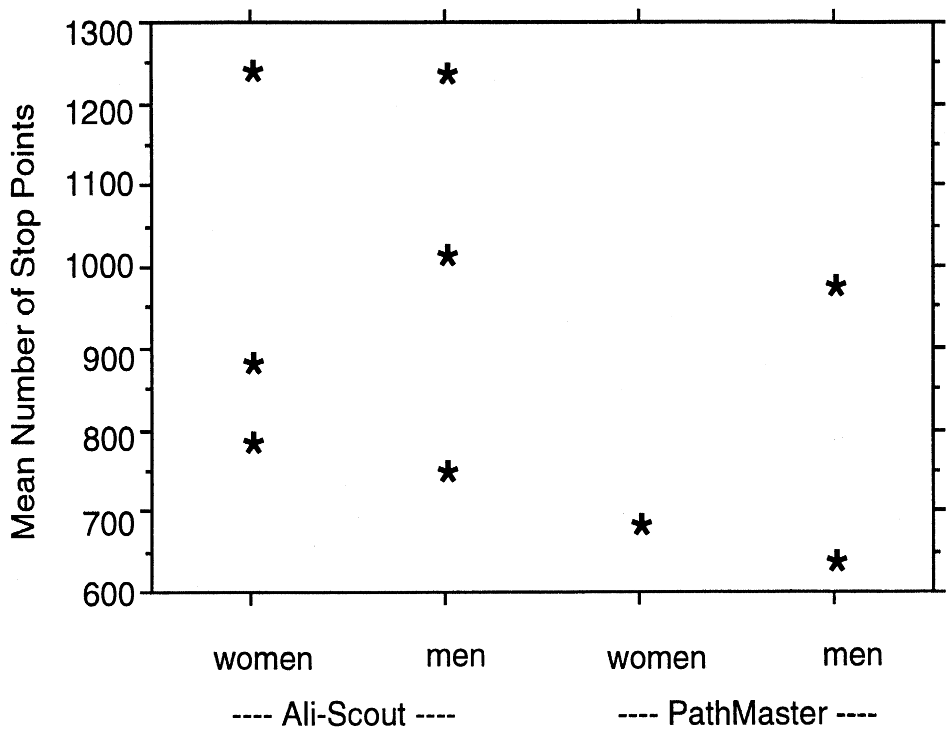


Figure 115. Mean number of stop points for subjects by sex and system

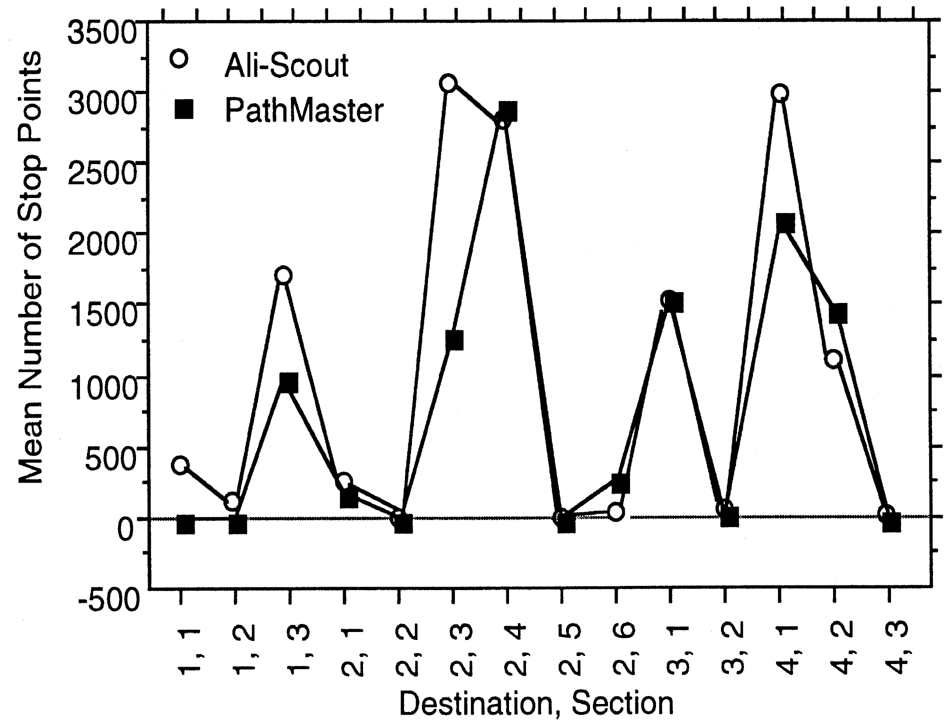


Figure 116. Mean number of stop points by system and section.

Neither trial nor the system*trial interactions were significant. For reference purposes, Figure 117 shows this interaction. Interestingly, the largest differences were in the baseline trial, which should have been identical as they both involved experimenter guidance.

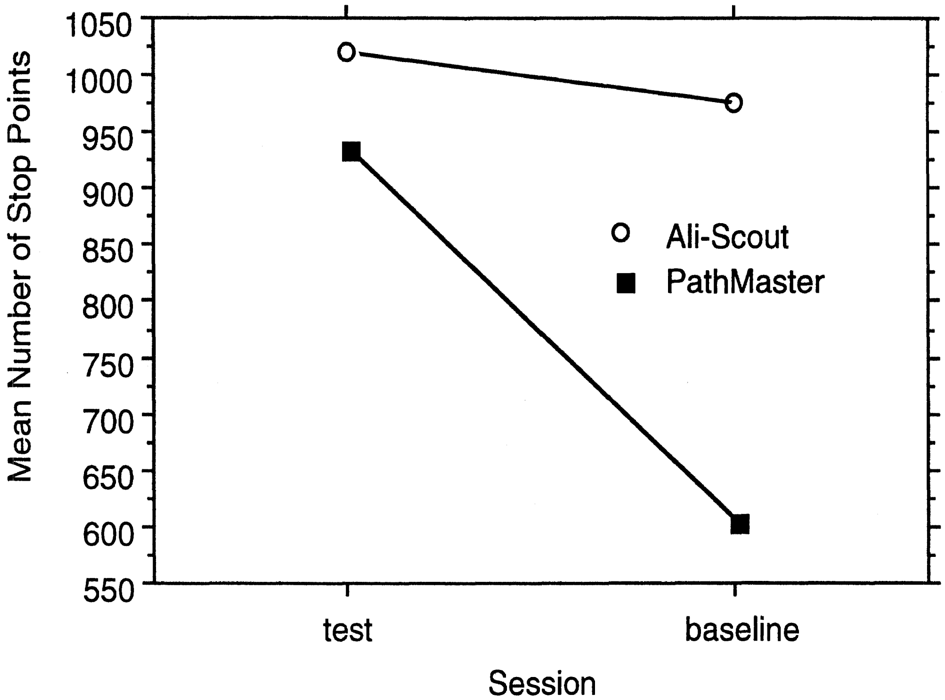


Figure 117. Mean number of stop points by system and trial number.