Driver Performance in Highway Navigation Tasks

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An empirical study of the performance efficiency of subjects engaged in highway navigation tasks is described. The study was designed to assist in quantifying the amount of excess travel that is due to navigational failures and to assess the relative contributions of trip-planning and route-following errors. Demographically representative samples of drivers were observed driving and navigating seven-stop automobile tours in Connecticut and Wisconsin, during both day and night, under three levels of trip planning. The distances driven and the times used were compared with those necessary to accomplish the same tour using optimum routes. Analysis of the data obtained indicated that a significant proportion of the total vehicle miles traveled, and a larger proportion of the total time spent driving, may represent navigational waste. Driver demographic attributes, and time of day, had little effect on driver performance. No significant differences due to the subjects' trip-planning efforts were noted.

Past research, both in the United States (*1*, *2*) and abroad (*3*, *4*) has shown that drivers face considerable difficulties in achieving optimum (i.e., minimum distance or time, or both) routes from their origin to their destination. These travel inefficiencies have been shown to generate a considerable aggregate amount of excess travel.

A comprehensive literature search (*5*) indicated that navigational waste can arise from any of four distinct driver trip-making activities acting separately or in combination:

1. Choice of route selection criteria;
2. Route planning (i.e., application of criteria to route selection) including lack of or inadequate route planning and insufficient or inaccurate information;
3. Route following (i.e., implementation of a trip plan) including all aspects of response to, reliance on, and anticipation of highway information systems; and
4. Trip chain sequencing (i.e., ordering of multiple destinations in the absence of sequential or time constraints).

As part of a major FHWA-sponsored study of the excess travel problem and of potential remedial measures, a series of empirical studies of trip planning and route following were implemented. The present paper describes the procedures used and the results obtained for a set of experiments that address route-planning and route-following performance in "local stranger" trips.

The local stranger has been defined (*6*) as a person with overall familiarity with the general area but with no detailed knowledge of specific destinations or routes. Trips of this type are generally fairly short (i.e., less than 50 mi) and are made for non-work-related purposes. Analysis of the 1977 National Personal Travel Survey (NPTS) data (*7*) indicated that non-work-related trips of less than 50 mi amounted to approximately 48 percent of total U. S. highway travel. No data could be located that would permit disaggregating this total by familiarity with route or destination.

The overall procedure for these experiments, which were implemented in two geographically distinct areas, was as follows:

1. A set of seven destinations, typical of those used for local stranger trips, forming a tour of between 40 and 60 mi was selected;
2. The optimum route connecting these destinations was defined; and
3. Demographically representative samples of drivers were observed as they attempted to reach each of these destinations for each of three levels of trip planning; both day and night data were collected.

SITE AND TEST ROUTE SELECTION

The experiment was implemented in two separate areas:

- Western Fairfield County, Connecticut, a part of the New York metropolitan area. The start and end of the tour were located in Norwalk, Connecticut, a city of 78,000 population approximately 50 mi northeast of New York City.
- The western suburbs and the western portion of Milwaukee, Wisconsin. The start and end of the tour were located in Waukesha, Wisconsin, a city of 50,000 population, approximately 15 mi west of Milwaukee.

The character of each destination, its location, and the optimum route distance and driving time are given in Table 1. These destinations were selected to meet the following criteria:

- Different destination types and descriptors,
- Availability of alternate routes,
- Routes encompassing various highway types, and
- Different degrees of route-following complexity.

In both locations, the first destination was a gasoline service station. This first segment was used to familiarize the subjects with the vehicle used and to assess their driving style. Data for this first segment were not used in subsequent data analyses.

The optimum route for each trip segment was determined by consensus opinion. A focus group was assembled in each test location. Each of these groups consisted of five local residents who not only had an intimate knowledge of the local street and

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TABLE 1 TEST ROUTE DESCRIPTION

Segment	Destination Location	Destination Type	Optimum Distance (mi)	Optimum Time (min:sec)
Connecticut				
1	211 Post Rd, Darien	Service station	3.3	5:52
2	600 Summer St, Stamford	Restaurant	6.5	13:18
3	CT-104 at Rockrimmon Rd	Country club	8.6	15:31
4	39 Frost Pond Rd, Stamford	Residence	5.8	9:04
5	Brookside Rd, Stamford	Local government office	8.8	13:41
6	Merritt Parkway at Route 123, New Canaan	National Guard armory	4.9	7:31
7	55 Washington St, South Norwalk	Office building (origin)	3.9	7:25
Total			41.7	1:12:22
Wisconsin				
1	Grand and College Aves, Waukesha	Service station	0.7	2:01
2	National Ave and Sunnyslope Rd, New Berlin	Professional building	8.3	14:42
3	4519 W. North Ave, Milwaukee	Store	10.0	13:45
4	Moorland and Blue Mound Rds, Brookfield	Shopping center	9.7	13:07
5	Route 74 and Route V, Sussex	Nursery	11.0	19:45
6	2700 New Castle Court, Waukesha	Residence	12.2	16:49
7	142 South St, Waukesha	Office building (origin)	4.3	9:23
Total			56.2	1:29:32

highway system but were also professionally involved with trip planning and route optimization. Each focus group member first planned each trip segment individually. The group then assembled and discussed the optimum routing. A unanimous, consensus routing was achieved in nearly every case. In one or two instances, in which alternate routes with very little difference in distance or travel time were possible, the optimum route was determined by majority opinion. Distances and driving times for these optimum routes were determined by repeated test runs, under nonpeak traffic conditions, by project personnel.

SUBJECT SELECTION AND SAMPLE COMPOSITION

Subjects were recruited through newspaper advertisements, word of mouth, and previously established contacts. The subjects, who were paid, had to meet the following requirements:

- Valid, unrestricted (except for eyeglasses) driving license;
- No current, or previous, professional activities that involved driving, route planning, or any aspect of highway or traffic engineering; and
- No specific knowledge of the destinations or of the general area of the test route.

The total sample, as well as the sample for each subexperiment, was designed to represent the age and sex distribution of the U. S. driving population weighted for actual miles driven. The actual sample distribution is given in Table 2. Figure 1 shows the cumulative age distribution of the sample as well as the cumulative distribution of total vehicle miles traveled (VMT), for non-work-related trips, by driver age for the U. S. population computed from NPTS data. According to NPTS data, women drive 37.4 percent of all non-work-related VMT; 34.8 percent of all subjects were female. Also according to NPTS data, 28.7 percent of all non-work-related driving is done at night; 34.3 percent of all data were collected at night.

TRIP-PLANNING LEVELS

All subjects were asked to perform essentially the same task: locate and drive to a sequential set of seven destinations. In addition to driver age and sex and to day or night conditions, three different levels of trip planning were used as independent variables. These levels are described hereafter. It should be noted that Level 1 required no actual planning by subjects and was designed to test route-following efficiency.

- Level 1: Subjects were given written directions to each of the seven destinations, supplemented by verbal directions to the first destination only. Subjects were instructed to follow the directions to each of the destinations as best they could.
- Level 2A: Subjects were escorted to the test car and, after familiarization with the vehicle, they were directed to Destination 1 (gasoline service station). After the gas tank was filled, the subjects were given the address of the second destination. It was left up to the subject to determine how to get to the next destination using the shortest, quickest route. On arrival at each of the destinations, subjects were given the address of the next destination.
- Level 2B: Subjects were provided with the addresses or other descriptions of all destinations while seated in the office and were asked to plan the "best" route to each of the destina-

TABLE 2 SAMPLE AGE/SEX DISTRIBUTION

Age Interval[a]	Day			Night			Total		
	M	F	All	M	F	All	M	F	All
Connecticut									
<25	6	3	9	2	2	4	8	5	14
25–34	4	2	6	3	1	4	7	3	12
35–51	8	5	13	6	2	8	14	7	17
>51	5	2	7	2	1	3	7	3	11
Total	23	12	35	13	6	19	36	18	54
Median age	35	37	35	42	35	33	39	37	38
Average age	38.4	37.8	38.2	37.5	36.5	37.2	38.1	37.4	37.9
Wisconsin									
<25	5	4	9	3	2	5	8	6	14
25–34	6	3	9	3	1	4	9	4	13
35–51	9	4	13	4	3	7	13	7	20
>51	3	2	5	2	–	2	5	2	7
Total	23	13	36	12	6	18	35	19	54
Median age	36	33	35	37	35	37	36	33	35
Average age	37.8	36.0	37.2	37.8	34.0	36.5	37.8	35.4	36.9

[a]Age intervals represent quartile points of the distribution of VMT (non-work-related) by driver age.

tions. No time limit was imposed on planning. When the subject had finished his plan, he was escorted to a car and asked to drive to the destinations according to his plan. Subjects were given verbal instructions to the first destination.

In all three levels it was made clear to the subjects that any questions directed to the observer regarding location, directions, or routing would not be answered. The subjects were free, at any time, to stop to ask for directions from others. In all three levels, a detailed map and street guide were available to the subject at all times.

EXPERIMENTAL PROCEDURES

On arrival at the test location each subject was told that he would be participating in highway driving research involving over-the-road exercises. Approximate duration of participation was 3 hr for Level 1 and 6 hr for Levels 2A and 2B.

Each subject was required to read and sign a participation consent form and to submit his driver's license for examination of expiration date, restrictions, and validity. Each subject was then read instructions appropriate to the particular experiment level to which he was assigned.

General

Subjects were scheduled for morning, afternoon, or evening sessions to balance day and night conditions. Assignment of subjects to sessions was blocked to include one subject per age and sex category per session per experiment. Observer assignment to subjects was counterbalanced as well as possible so that each observer would have an equal number of subjects categorized by experiment level, session, sex, and age. Data analysis showed no significant effect due to observer assignment.

Equipment

Two vehicles were used at each test site. Midsized, American-made cars were leased for the duration of data collection. All vehicles were equipped with cruise control, power steering, power brakes, air conditioning, and AM/FM radio. Each automobile was outfitted with a work station that included record-

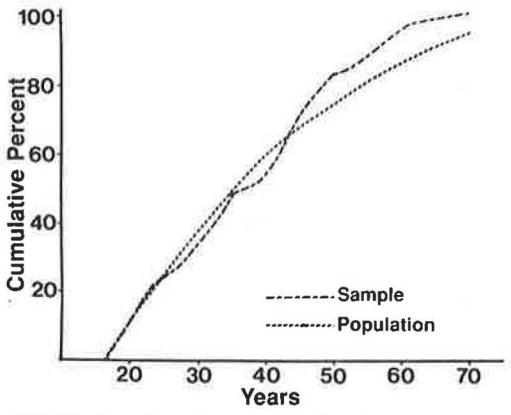

FIGURE 1 Sample distribution by age.

ing distance measuring equipment (DME), clipboard, digital stopwatch, digital wristwatch with stopwatch mode, and portable light.

The following maps were made available to the subjects for assistance in both trip planning and route following:

- Connecticut: "Stamford," distributed by the Connecticut Motor Club, 2276 Whitney Avenue, Hamden, Connecticut (copyright 1983), and
- Wisconsin: "Milwaukee County and Waukesha County Map and Street Guide," published by Milwaukee Map Service, Inc., 4519 W. North Avenue, Milwaukee, Wisconsin (copyright 1982).

Data Collection

Data were collected in Connecticut in October and November 1984 and in Wisconsin in November and December 1984. Data collection consisted of recording, using the DME and the stopwatch, the distance from the origin and the elapsed time since the beginning of the segment for each of the following items:

- Passing of any decision point,
- Turn,
- Deviation from planned route, and
- Arrival at destination.

Also noted were each time the subject referred to the instructions or map and the length of time of referral, each time the subject stopped the car to read or refer to the instructions or the map or to ask directions, weather conditions, road conditions, and driving habits of subject.

Data Reduction

All data collected were reduced by the individual observers, checked by the experiment supervisor, and entered into elec-

TABLE 3 SUMMARY STATISTICS FOR SEGMENTS 2–7 COMBINED, PARAMETER: DISTANCE (mi)

	Experiments in Connecticut				Experiments in Wisconsin			
	1	2-A	2-B	2AB	1	2-A	2-B	2AB
Day								
Average	43.45	46.42	45.67	46.09	61.06	75.09	72.03	73.56
Standard deviation	5.25	4.49	8.56	6.45	8.47	10.08	15.68	12.99
Maximum	53.21	53.23	60.55	60.55	81.16	98.67	113.90	113.90
Minimum	38.24	39.57	37.70	37.70	55.44	57.86	57.26	57.26
Median	42.03	46.20	42.44	45.16	57.36	74.14	69.23	73.24
Difference from optimum (%)	13.01	20.75	18.80	19.87	9.85	35.09	29.60	32.34
No. of observations	12	11	9	20	12	12	12	24
Night								
Average	44.68	46.55	46.11	46.39	61.47	74.92	65.04	69.98
Standard deviation	4.76	9.24	0.42	7.16	6.40	13.98	5.47	11.36
Maximum	49.45	64.10	46.52	64.10	70.63	101.31	72.48	101.31
Minimum	38.86	39.11	45.67	39.11	55.99	60.48	57.12	57.12
Median	45.75	42.17	46.14	45.67	58.75	73.17	64.56	68.13
Difference from optimum (%)	16.21	21.09	19.94	20.67	10.59	34.79	17.00	25.90
No. of observations	5	7	4	11	6	6	6	12
Male								
Average	44.89	44.23	44.38	44.51	58.13	71.08	71.25	71.16
Standard deviation	4.91	4.31	6.68	5.31	3.60	6.95	15.56	11.78
Maximum	53.21	52.66	60.55	60.55	68.17	82.63	113.90	113.90
Minimum	38.24	39.11	37.70	37.70	55.91	57.86	57.12	57.12
Median	44.61	44.66	45.57	44.75	56.80	73.12	64.79	72.06
Difference from optimum (%)	16.77	15.04	16.73	15.76	4.58	27.88	28.18	28.03
No. of observations	12	12	9	21	11	12	12	24
Female								
Average	41.21	50.97	47.91	49.75	66.02	82.94	66.60	74.77
Standard deviation	4.63	8.09	8.28	7.85	9.99	14.15	7.79	13.83
Maximum	49.45	64.10	59.28	64.10	81.16	101.31	76.22	101.31
Minimum	38.71	42.32	39.42	39.42	55.44	66.81	57.26	57.26
Median	39.32	51.54	46.47	48.18	65.62	78.73	68.02	72.93
Difference from optimum (%)	7.18	32.58	24.61	29.39	18.77	49.22	19.83	34.52
No. of observations	5	6	4	10	7	6	6	12
All								
Average	43.81	46.48	45.81	46.20	61.20	75.03	69.70	72.37
Standard deviation	4.99	6.48	7.00	6.60	7.65	11.10	13.40	12.42
Maximum	53.21	64.10	60.55	64.10	31.16	101.31	113.90	113.90
Minimum	38.24	39.11	37.70	37.70	55.44	57.86	57.12	57.12
Median	43.26	44.96	45.67	45.57	57.36	73.29	66.17	72.36
Difference from optimum (%)	13.95	20.88	19.15	20.16	10.10	34.99	25.40	30.19
No. of observations	17	18	13	31	18	18	18	36

Note: Optimum distance = 38.45 mi in Connecticut and 55.58 mi in Wisconsin.

TABLE 4 SUMMARY STATISTICS FOR SEGMENTS 2–7 COMBINED, PARAMETER: TIME (hr:min:sec)

	Experiments in Connecticut				Experiments in Wisconsin			
	1	2-A	2-B	2AB	1	2-A	2-B	2AB
Day								
Average	1:26:05	1:53:23	1:47:05	1:50:23	1:50:49	2:36:20	2:28:50	2:32:35
Standard deviation	0:12:25	0:22:39	0:27:52	0:24:50	0:19:23	0:34:52	0:45:12	0:39:40
Maximum	1:51:49	2:32:58	2:55:22	2:55:22	2:44:09	3:36:25	4:30:14	4:30:14
Minimum	1:16:09	1:10:15	1:14:08	1:10:15	1:34:33	1:47:14	1:42:25	1:42:25
Median	1:19:31	1:50:55	1:39:00	1:45:46	1:44:02	2:34:11	2:21:30	2:25:03
Difference from optimum (%)	29.47	70.51	61.05	66.01	26.64	78.64	70.07	74.35
No. of observations	11	11	10	21	12	12	12	24
Night								
Average	1:40:58	1:53:38	1:54:07	1:53:50	2:05:51	2:22:46	2:23:01	2:22:54
Standard deviation	0:14:24	0:26:29	0:12:18	0:20:55	0:25:51	0:34:43	0:57:59	0:45:34
Maximum	1:55:09	2:35:26	2:03:10	2:35:26	2:41:34	3:26:59	4:15:21	4:15:21
Minimum	1:19:47	1:28:22	1:32:35	1:28:22	1:40:56	1:46:27	1:35:57	1:35:57
Median	1:39:34	1:48:11	1:58:25	1:53:20	1:55:50	2:17:36	2:05:25	2:13:27
Difference from optimum (%)	51.85	70.90	71.61	71.19	43.80	63.15	63.43	63.29
No. of observations	5	7	5	12	6	6	6	12
Male								
Average	1:33:21	1:47:38	1:40:29	1:44:23	1:48:04	2:20:56	2:23:18	2:22:07
Standard deviation	0:16:01	0:23:28	0:13:13	0:19:24	0:16:31	0:30:24	0:46:42	0:38:34
Maximum	1:55:09	2:32:58	2:00:12	2:32:58	2:33:59	3:34:00	4:30:14	4:30:14
Minimum	1:17:08	1:10:15	1:14:08	1:10:15	1:34:33	1:46:27	1:35:57	1:35:57
Median	1:31:17	1:44:27	1:39:00	1:41:16	1:44:22	2:23:38	2:13:44	2:17:50
Difference from optimum (%)	40.39	61.87	51.13	56.99	23.49	61.05	63.75	62.40
No. of observations	11	12	10	22	11	12	12	24
Female								
Average	1:24:59	2:05:10	2:07:19	2:06:09	2:08:02	2:53:34	2:34:04	2:43:49
Standard deviation	0:09:01	0:20:18	0:30:45	0:24:12	0:25:38	0:33:47	0:54:42	0:44:32
Maximum	1:39:34	2:35:26	2:55:22	2:55:22	2:44:09	3:36:25	4:15:21	4:15:21
Minimum	1:16:09	1:45:46	1:30:13	1:30:13	1:39:06	2:13:13	1:42:50	1:42:50
Median	1:23:15	1:56:51	2:03:10	2:00:18	2:02:35	2:51:29	2:24:25	2:35:47
Difference from optimum (%)	27.81	88.24	91.46	89.70	46.30	98.33	76.06	87.20
No. of observations	5	6	5	11	7	6	6	12
All								
Average	1:30:44	1:53:29	1:49:26	1:51:38	1:55:50	2:31:49	2:26:54	2:29:21
Standard deviation	0:14:27	0:23:27	0:23:32	0:23:12	0:22:12	0:34:25	0:48:09	0:41:20
Maximum	1:55:09	2:35:26	2:55:22	2:55:22	2:44:09	3:36:25	4:30:14	4:30:14
Minimum	1:16:09	1:10:15	1:14:08	1:10:15	1:34:33	1:46:27	1:35:57	1:35:57
Median	1:24:52	1:49:18	1:41:44	1:48:10	1:47:54	2:26:10	2:17:27	2:21:56
Difference from optimum (%)	36.46	70.66	64.57	67.89	32.36	73.47	67.86	70.67
No. of observations	16	18	15	33	18	18	18	36

Note: Optimum time = 1:06:30 for Connecticut and 1:27:31 for Wisconsin.

tronic data processing (EDP) storage. Distributional parameters of the data set, stratified by variables of interest, were then computed.

DATA ANALYSIS

Tables 3–5 give summary aggregate statistics for the three measures of effectiveness. These data were analyzed, using both single- and multi-variate analyses. The results of these analyses are described in terms of the independent variable considered.

Levels of Trip Planning

The three levels of trip planning were

- Level 1: No trip planning by subjects. Each subject was given a plan for the optimum route.
- Level 2A: Minimum trip planning. Subjects were given the next destination immediately preceding the start of each segment.
- Level 2B: Comfortable trip planning. Subjects were given all destinations while seated in the office and asked to plan the entire trip without any time constraints.

The results, aggregated by trip-planning level, are given in Table 6. A series of pairwise comparisons, using the *t*-test, was made for all possible combinations of the three levels with the results (at the 0.95 confidence level) given in Table 6. It can be seen that, on the basis of these tests, there appears to be no significant difference between trip-planning Levels 2A and 2B. There were significant differences in both time and average speed between Level 1 and Level 2A in Connecticut. In Wisconsin, significant differences between Levels 1 and 2A and 2B in both distance and time can be noted.

In view of the apparent lack of a significant difference between Levels 2A and 2B, a closer examination of these data

TABLE 5 SUMMARY STATISTICS FOR SEGMENTS 2–7 COMBINED, PARAMETER: AVERAGE SPEED (mph)

	Experiments in Connecticut				Experiments in Wisconsin			
	1	2-A	2-B	2AB	1	2-A	2-B	2AB
Day								
Average	30.4	25.2	26.8	25.9	33.3	29.6	29.8	29.7
Standard deviation	2.8	4.1	4.6	4.3	2.6	4.6	4.0	4.2
Maximum	35.0	33.8	36.6	36.6	37.4	39.7	35.5	39.7
Minimum	26.8	20.7	20.3	20.3	29.4	21.5	21.5	21.5
Median	30.0	24.9	26.2	25.5	33.0	28.3	30.4	29.1
Difference from optimum (%)	−12.40	−27.28	−22.64	−25.19	−12.64	−22.42	−21.83	−22.13
No. of observations	11	11	9	20	12	12	12	24
Night								
Average	26.8	24.9	24.9	24.9	29.8	32.2	29.8	31.0
Standard deviation	2.6	2.6	3.3	2.7	2.9	6.1	8.1	6.9
Maximum	29.8	26.9	29.7	29.7	33.6	42.0	41.1	42.0
Minimum	23.8	20.7	22.6	20.7	26.2	24.7	17.0	17.0
Median	25.7	25.3	23.6	24.2	30.5	30.5	28.7	29.7
Difference from optimum (%)	−22.87	−28.33	−28.31	−28.32	−21.81	−15.43	−21.90	−18.66
No. of observations	5	7	4	11	6	6	6	12
Male								
Average	29.3	25.3	27.6	26.3	32.6	31.3	30.9	31.1
Standard deviation	3.8	3.7	4.1	4.0	2.7	6.1	5.2	5.6
Maximum	35.0	33.8	36.6	36.6	35.9	42.0	41.1	42.0
Minimum	23.8	20.7	23.6	20.7	26.6	21.5	21.5	21.5
Median	29.2	25.9	26.2	26.1	32.9	30.3	31.0	30.4
Difference from optimum (%)	−15.49	−27.02	−20.47	−24.21	−14.40	−17.95	−18.96	−18.46
No. of observations	11	12	9	21	11	12	12	24
Female								
Average	29.1	24.6	23.2	24.0	31.4	28.8	27.6	28.2
Standard deviation	1.4	3.4	2.5	3.0	3.8	1.6	5.6	4.0
Maximum	30.5	30.2	26.2	30.2	37.4	31.0	33.4	33.4
Minimum	27.3	20.7	20.3	20.3	26.2	27.4	17.0	17.0
Median	29.8	23.9	23.1	23.2	30.9	28.5	28.3	28.3
Difference from optimum (%)	−16.09	−29.02	−33.20	−30.69	−17.72	−24.36	−27.64	−26.00
No. of observations	5	6	4	10	7	6	6	12
All								
Average	29.3	25.1	26.2	25.6	32.1	30.5	29.8	30.1
Standard deviation	3.2	3.5	4.2	3.8	3.1	5.1	5.4	5.2
Maximum	35.0	33.8	33.6	36.6	37.4	42.0	41.1	42.0
Minimum	23.8	20.7	20.3	20.3	26.2	21.5	17.0	17.0
Median	29.5	25.3	25.3	25.3	32.1	29.5	29.6	29.5
Difference from optimum (%)	−15.68	−27.69	−24.39	−26.30	−15.69	−20.09	−21.85	−20.97
No. of observations	16	18	13	31	18	18	18	36

Note: Optimum speed = 34.7 mph for Connecticut and 38.1 mph for Wisconsin.

was made. Comparative data for each individual route segment and for defined subgroups of the subject population (day/night, male/female) were analyzed using a number of parametric and nonparametric statistical tests. The results are given in Table 7 for Connecticut data and in Table 8 for Wisconsin data. Significant results, at the 0.95 level of significance, of the following statistical tests are shown:

- *t*-test (*t*)
- Median test (MD)
- Mann-Whitney test (MW)
- *F*-test (*F*)

Only scattered indications of significant differences can be noted and these do not form any clear pattern. In most cases (54 out of 90) the significant differences noted were in the *F*-test. Because of outliers in small samples, variances were high. In only one instance, Connecticut-Night-Distance, did any test of central tendency on aggregate data show a significant difference. This result is, however, based on an extremely small sample. Further doubt is cast on the practical significance of this result by the fact that most of this difference could be attributed to one urban segment with operating fixed illumination.

In view of this apparent lack of significant differences, the merged data for Levels 2A and 2B were added to subsequent comparisons.

Ambient Illumination

Approximately one-third of all subjects, in both Connecticut and Wisconsin, drove the test route after dark. Results of pairwise comparisons are given in Table 9. Significant results are, again, scarce and scattered. On an aggregate basis, only Experiment 1 showed any significant differences in central tendency. In both Connecticut and Wisconsin, average speeds, at night, were significantly lower.

TABLE 6 TRIP-PLANNING LEVELS

Level	Measure of Effectiveness: Distance (mi) N	Mean	S.D.	Time (hr:min:sec) N	Mean	S.D.	Avg Speed N	Mean	S.D.
Connecticut									
1	17	43.81	4.99	16	1:30:44	0:14:27	16	29.3	3.2
2A	18	46.48	6.48	18	1:53:29	0:23:27	18	25.1	3.5
2B	13	45.81	7.00	15	1:49:26	0:23:32	13	26.2	4.2
Wisconsin									
1	18	61.20	7.65	18	1:55:50	0:22:12	18	32.1	3.1
2A	18	75.03	11.10	18	2:31:49	0:34:25	18	30.5	5.1
2B	18	69.70	13.40	18	2:26:54	0:48:09	18	29.8	5.4

Note: Statistical significance of the parameters is as follows.

	Parameter: Distance	Time	Speed
Connecticut			
1 versus 2A	NS	S	S
1 versus 2B	NS	S	S
2A versus 2B	NS	NS	NS
Wisconsin			
1 versus 2A	S	S	NS
1 versus 2B	S	S	NS
2A versus 2B	NS	NS	NS

TABLE 7 TRIP-PLANNING LEVELS 2A AND 2B, CONNECTICUT

Subgroup	Segment	Parameter: Distance *t*	MD	MW	*F*	Time *t*	MD	MW	*F*	Speed *t*	MD	MW	*F*
Day	2	–	–	–	–	–	–	–	–	–	–	–	–
	3	–	–	–	–	–	–	–	–	–	–	–	–
	4	–	–	–	–	–	–	–	–	–	–	–	S
	5	–	–	–	–	–	–	–	–	–	–	–	–
	6	–	–	–	S	–	–	–	S	–	–	–	–
	7	–	–	–	S	–	–	S	S	–	–	–	–
	2–7	–	–	–	S	–	–	–	–	–	–	–	–
Night	2	–	–	–	–	–	–	–	–	–	–	–	S
	3	–	–	–	S	–	–	–	S	–	–	–	–
	4	–	–	–	–	–	–	–	–	–	–	–	S
	5	–	–	–	–	–	–	S	–	–	–	–	–
	6	–	–	–	–	–	–	–	–	–	–	–	–
	7	–	–	S	S	S	–	S	–	–	–	–	–
	2–7	–	–	S	S	–	–	–	–	–	–	–	–
Male	2	–	S	–	–	–	–	–	–	–	–	–	–
	3	–	–	–	–	–	–	–	–	–	–	–	–
	4	–	–	–	S	–	–	S	–	–	–	–	S
	5	–	–	–	S	–	–	–	–	–	–	–	–
	6	–	–	–	–	–	–	–	–	–	–	–	S
	7	–	–	–	S	–	–	–	S	–	–	–	–
	2–7	–	–	–	–	–	–	–	–	–	–	–	–
Female	2	–	–	–	S	–	–	–	–	–	–	–	–
	3	–	–	–	–	–	–	–	S	–	–	–	–
	4	–	–	–	S	–	–	–	–	–	–	–	–
	5	–	–	–	–	–	S	S	–	S	S	–	–
	6	–	–	–	S	–	–	–	–	–	–	–	–
	7	–	–	S	S	–	–	–	S	–	–	–	–
	2–7	–	–	–	–	–	–	–	–	–	–	–	–
All	2	–	–	–	–	–	–	–	–	–	–	–	–
	3	–	–	–	–	–	–	–	–	–	–	–	–
	4	–	–	–	S	–	–	–	–	–	–	–	–
	5	–	–	–	–	–	–	–	–	–	–	–	–
	6	–	–	–	–	–	–	–	–	–	–	–	–
	7	–	–	–	–	–	–	–	–	–	–	–	–
	2–7	–	–	–	–	–	–	–	–	–	–	–	–

TABLE 8 TRIP-PLANNING LEVELS 2A AND 2B, WISCONSIN

		Parameter											
		Distance				Time				Speed			
Subgroup	Segment	*t*	MD	MW	*F*	*t*	MD	MW	*F*	*t*	MD	MW	*F*
Day	2	–	–	–	S	–	–	–	S	–	S	S	S
	3	–	S	–	–	S	–	–	S	–	–	–	–
	4	–	–	–	S	–	–	–	–	–	–	–	–
	5	–	–	–	S	–	–	–	S	–	–	–	–
	6	–	–	–	–	–	–	–	–	–	–	–	–
	7	–	–	–	–	–	–	S	S	S	S	–	–
	2–7	–	–	–	–	–	–	–	–	–	–	–	–
Night	2	S	S	–	S	–	–	–	S	–	–	–	–
	3	–	–	–	–	–	–	–	–	–	–	–	–
	4	–	–	–	S	–	–	–	–	–	–	–	–
	5	–	S	–	S	–	–	–	–	–	–	–	–
	6	–	–	–	–	–	–	–	–	–	–	–	–
	7	–	–	–	–	–	–	–	S	–	–	–	S
	2–7	–	–	–	S	–	–	–	–	–	–	–	–
Male	2	–	–	–	S	–	–	–	S	–	–	–	S
	3	–	–	–	–	–	–	–	S	–	–	–	–
	4	–	–	–	S	–	–	–	–	–	–	–	–
	5	–	–	–	S	–	–	–	S	–	–	–	–
	6	–	–	–	–	–	–	–	–	–	–	–	–
	7	–	–	–	–	–	–	S	S	–	S	–	–
	2–7	–	–	–	S	–	–	–	–	–	–	–	–
Female	2	S	S	–	–	S	S	–	–	–	S	S	S
	3	–	–	–	S	–	–	–	–	–	–	–	–
	4	–	–	–	–	–	–	–	–	–	–	–	–
	5	–	–	–	–	–	–	–	–	–	–	–	–
	6	–	S	–	–	–	S	–	–	–	–	–	–
	7	S	S	–	–	–	–	–	S	–	–	–	–
	2–7	–	–	–	–	–	–	–	–	–	–	–	S
All	2	–	–	–	–	–	–	–	–	–	S	S	S
	3	–	–	–	–	–	–	–	–	–	–	–	–
	4	–	–	–	–	–	–	–	–	–	–	–	–
	5	–	–	–	–	–	–	–	–	–	–	–	–
	6	–	–	–	–	–	–	–	–	–	–	–	–
	7	–	–	–	–	–	–	–	–	S	S	S	–
	2–7	–	–	–	–	–	–	–	–	–	–	–	–

TABLE 9 DAY-NIGHT COMPARISONS

		Experiment															
		1				2A				2B				2A and 2B			
Parameter	Segment	*t*	MD	MW	*F*	*t*	MD	MW	*F*	*t*	MD	MW	*F*	*t*	MD	MW	*F*
Wisconsin																	
Distance	2	–	–	–	S	–	–	–	–	S	–	–	S	–	–	–	–
	3	–	–	S	S	–	–	–	–	–	–	–	–	–	–	–	S
	4	–	–	–	S	–	–	–	–	–	–	–	S	–	–	–	S
	5	–	–	–	–	–	–	–	–	–	–	–	S	–	–	–	–
	6	–	–	–	S	–	–	–	–	–	–	–	–	–	–	–	–
	7	–	–	S	–	–	–	–	–	–	–	–	–	–	–	–	–
	2–7	–	–	–	–	–	–	–	–	–	–	–	S	–	–	–	–
Time	2	–	–	–	–	–	–	–	–	–	–	–	S	–	–	–	S
	3	–	–	–	S	–	–	–	S	–	–	–	–	–	–	–	–
	4	–	–	S	S	–	–	–	S	–	–	–	–	–	–	–	–
	5	–	–	–	–	–	–	–	–	–	–	–	S	–	–	–	–
	6	–	–	S	S	–	–	–	–	–	–	–	–	–	–	–	–
	7	–	–	S	–	–	–	–	–	–	–	–	S	–	–	–	S
	2–7	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Speed	2	–	–	–	–	–	–	–	S	–	–	–	S	–	–	–	S
	3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	4	–	–	–	–	–	–	–	S	–	–	–	–	–	–	S	–
	5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	6	S	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	7	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	2–7	S	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Connecticut																	
Distance	2	–	–	–	S	–	–	–	–	–	–	–	–	–	–	–	–
	3	–	–	S	–	–	–	–	–	–	–	–	–	–	–	–	–
	4	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	S
	5	–	–	–	–	–	–	–	S	–	–	–	–	–	–	–	S
	6	–	–	–	S	–	–	–	–	–	–	–	S	–	–	–	S
	7	–	–	–	–	–	–	–	S	–	–	–	–	–	–	–	–
	2–7	–	–	–	–	–	–	–	–	–	–	–	S	–	–	–	–
Time	2	–	–	–	S	–	–	–	–	–	–	–	–	–	–	–	–
	3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	4	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	S
	5	–	–	–	–	–	–	–	–	–	S	–	–	–	–	–	S
	6	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	7	–	–	–	–	–	–	–	S	–	–	–	–	–	–	–	–
	2–7	–	–	S	–	–	–	–	–	–	–	–	–	–	–	–	–
Speed	2	–	–	–	–	–	–	–	–	–	–	–	S	–	–	–	–
	3	–	–	–	–	–	–	–	–	–	–	–	–	–	S	–	–
	4	S	–	–	–	S	S	–	–	–	–	–	–	–	–	–	S
	5	–	–	–	–	–	–	S	–	–	–	–	–	–	–	–	–
	6	–	–	–	–	–	–	–	–	–	–	–	–	S	S	S	–
	7	–	–	–	–	–	–	S	–	S	S	–	–	–	–	–	–
	2–7	S	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

Sex of Subjects

As previously stated, the distribution of the sample followed that of total VMT. Approximately one-third of the subjects were female. Results of pairwise comparisons are given in Table 10. Significant differences can be noted for Experiment 2 in Connecticut and for Experiment 1 in Wisconsin in which men generally performed better.

Other Variables

The possible effects of a number of other independent variables on subject performance were investigated. Single- and multivariate regression and correlation methods, as well as graphic (box plots, scatter diagrams) techniques, were employed using the SYSTAT statistical package. The variables considered included

- Age,
- Years of driving experience,
- Education,
- Miles driven per year, and
- Driving style.

Only scattered instances of statistically significant correlations for individual experiments, for one or more of these variables, were noted. No general pattern was apparent.

DISCUSSION OF RESULTS

The data collected demonstrate that considerable and significant excess driving occurs as a result of navigational failures in both trip planning and route following. Table 11 and Figure 2 summarize this excess in terms of both time and distance. It should be noted that excess time always exceeds excess distance. In addition to the extra time necessary to travel the excess distance, an additional time penalty is exacted as a result of directional uncertainty.

The overall results of these experiments are given in the following table in terms of the percentage of excess over optimum for each of two trip-planning levels and for each of three parameters.

	Trip Planning Level	
Parameter	*1*	*2*
Distance	12.3	26.5
Time	34.1	69.6
Speed	−17.6	−25.4

TABLE 10 MALE-FEMALE COMPARISONS

		Experiment															
		1				2A				2B				2A and 2B			
Parameter	Segment	*t*	MD	MW	*F*	*t*	MD	MW	*F*	*t*	MD	MW	*F*	*t*	MD	MW	*F*
Connecticut																	
Distance	2	–	–	–	S	–	–	S	–	–	–	–	–	S	–	–	–
	3	–	–	–	–	–	–	–	–	–	–	–	S	–	–	–	–
	4	–	–	–	S	–	–	S	S	–	–	–	S	–	–	–	–
	5	–	–	–	S	–	–	–	–	–	–	–	–	–	–	–	–
	6	–	–	–	S	–	–	–	–	–	–	–	S	–	–	–	S
	7	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	2–7	–	–	–	–	S	–	S	–	–	–	–	–	S	–	S	–
Time	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	S	–
	3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	4	–	–	–	S	S	–	S	–	–	–	–	–	–	–	–	–
	5	–	–	–	–	–	–	–	–	S	S	–	S	–	–	–	–
	6	–	–	–	–	–	–	–	–	–	–	–	–	S	–	–	S
	7	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	S
	2–7	–	–	–	–	–	–	S	–	S	–	–	–	S	S	S	–
Speed	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	4	–	–	–	S	–	–	–	–	–	–	–	S	–	–	–	S
	5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	6	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	7	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	2–7	–	–	–	S	–	–	–	–	–	–	–	–	–	–	–	–
Wisconsin																	
Distance	2	–	–	–	–	–	–	–	–	–	–	–	S	–	–	–	–
	3	–	S	S	–	–	–	S	S	–	–	–	–	–	–	S	S
	4	–	–	–	S	S	–	S	–	–	–	–	–	–	–	–	–
	5	–	–	–	S	–	–	–	–	–	–	–	–	–	–	–	–
	6	–	–	–	S	–	–	–	–	–	–	–	–	–	–	–	–
	7	–	–	–	–	–	–	–	–	–	–	–	S	–	–	–	S
	2–7	–	S	S	–	S	–	S	–	–	–	–	–	–	–	–	–
Time	2	–	–	–	–	–	–	–	–	–	–	–	S	–	–	–	–
	3	–	–	S	–	S	–	S	–	–	–	–	S	–	–	–	–
	4	–	–	S	–	S	–	S	–	–	–	–	–	–	–	S	S
	5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	6	–	–	S	S	–	–	–	–	–	–	–	–	–	–	–	–
	7	–	–	–	–	–	–	S	–	–	–	S	S	–	–	S	S
	2–7	–	–	S	–	–	–	S	–	–	–	–	–	–	–	–	–
Speed	2	–	–	–	S	–	–	–	S	–	–	–	–	–	–	–	S
	3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	4	–	–	–	–	–	–	–	–	–	–	–	–	–	S	–	–
	5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	6	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	7	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	2–7	–	–	–	S	–	–	–	–	–	–	–	–	–	–	–	–

TABLE 11 NAVIGATIONAL WASTE

	Experiment 1					Experiments 2A and 2B				
	Day	Night	Male	Female	Total	Day	Night	Male	Female	Total
Connecticut										
Subjects total	12	6	12	6	18	24	12	23	13	36
Subjects completing	12	5	12	5	17	21	10	20	11	31
Excess distance										
Mean	13.0	16.2	16.8	7.2	13.9	19.9	20.7	15.8	29.4	20.2
<2 %	2	2	3	1	4	2	0	1	1	2
2–7 %	2	2	3	1	4	5	1	4	2	6
7–15 %	1	0	1	0	1	2	2	4	0	4
>15 %	7	1	5	3	8	12	7	11	8	19
Excess time										
Mean	29.5	51.8	40.4	27.8	36.5	66.0	71.2	57.0	89.7	67.9
<2 %	0	0	0	0	0	0	0	0	0	0
2–7 %	0	0	0	0	0	1	0	1	0	1
7–15 %	0	1	1	0	1	1	0	1	0	1
>15 %	11	4	10	5	15	20	11	19	12	31
Wisconsin										
Subjects total	11	7	12	6	18	24	12	24	12	36
Subjects completing	11	7	12	6	18	24	12	24	12	36
Excess distance										
Mean	9.9	10.6	4.6	18.8	10.1	32.3	25.9	28.0	34.5	30.2
<2 %	4	1	3	2	5	0	0	0	0	0
2–7 %	5	1	5	1	6	2	2	3	1	4
7–15 %	1	2	2	1	3	6	0	3	3	6
>15 %	1	3	2	2	4	16	10	18	8	26
Excess time										
Mean	26.6	43.8	23.5	46.3	32.4	74.4	63.3	62.4	87.2	70.7
<2 %	0	0	0	0	0	0	0	0	0	0
2–7 %	0	0	0	0	0	0	0	0	0	0
7–15 %	3	1	4	0	4	1	0	0	1	1
>15 %	8	6	8	6	14	23	12	24	11	35

For the type of travel to unfamiliar destinations represented by the test routes, the following results appear indicated on the basis of the data obtained.

- Navigational failures are responsible for approximately 20 percent of all miles driven and approximately 40 percent of all time spent driving.

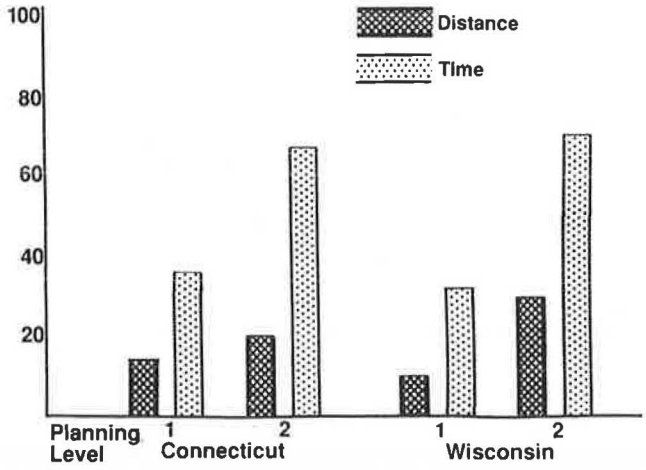

FIGURE 2 Percentage excess distance and time.

- The contributions to these totals of, respectively, trip-planning deficiencies and route-following deficiencies are approximately equal.
- The magnitude of navigational waste due to trip-planning failures appears to be independent of the type of planning done.
- Male drivers appear to perform slightly better than female drivers although this advantage is not consistent across locations or trip-planning levels.
- Driver's education, age, driving experience, or geographic location appears to have no significant effect on the amount of navigational waste.

ACKNOWLEDGMENTS

The research reported herein was conducted under a contract entitled "Economic Assessment of Potential Solutions for Improving Motorist Route Following" with the FHWA, U. S. Department of Transportation. Truman Mast of FHWA served as the Contracting Officer's Technical Representative. The results and views expressed in this paper are those of the author and do not necessarily reflect the views of FHWA. The contributions of Dunlap and Associates, East, Inc., of Norwalk, Connecticut, which served as a subcontractor in the areas of experimental design and data collection, and of Robert Dewar

of Calgary, Alberta, and Slade Hulbert of San Ramon, California, who served as project consultants, are gratefully acknowledged.

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Publication of this paper sponsored by Committee on User Information Systems.

Driver Attitudes Concerning Aspects of Highway Navigation

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A comprehensive questionnaire dealing with various aspects of highway navigation was developed, pretested, and administered to a demographically representative sample of the U. S. driving population. The sample was drawn from a group of paid subjects engaged in highway navigation experiments. The analysis of 125 completed and usable questionnaires is presented. In addition to background information on demographics and on driving experience, topics addressed included route selection, behavior under directional uncertainty, distance-time-costs trade-offs, and attitudes toward proposed remedial measures. The data obtained indicate that drivers are, generally, fairly well satisfied with their ability to perform route-planning or route-following tasks effectively and believe that the major constraints on their effectiveness arise from the unavailability of adequate and accurate route and traffic information. This satisfaction is, however, not supported by data on the extent of excess travel due to navigational waste. Furthermore, answers to a number of questions indicated an insufficient appreciation of the complexities of determining optimum routes and of the extent and seriousness of the problem of navigational waste.

The purpose of all motor vehicle travel, except for the extremely small proportion classified as pleasure driving, is to proceed from an origin to a destination. The aggregate of all such travel represents the total miles driven in the United States—an aggregate total that approached 1.8 trillion miles in 1985 (*1*).

All driving accrues costs that are incurred by the vehicle operator or owner, or both; by other vehicle occupants; by public agencies responsible for the construction, maintenance, and operation of the highway system; by owners of property abutting the travel route; and by society as a whole.

With increasing constraints on the availability of resources, increasing awareness of the importance of environmental conservation, and increasing awareness of the enormous societal costs of highway accidents, it has become imperative to reduce these costs to the maximum extent possible. One approach to achieving this objective is to minimize total travel without a change in the aggregate origin-destination matrix by implementing measures that will increase the probability that all trips will be made on optimum routes. This approach is designed to minimize or eliminate unproductive or excess travel. Excessive travel implies a failure in route selection or route following, or both.

A survey of existing literature on the subject (*2*) indicated that efficiency of route selection and route following may be affected by such driver demographic attributes as age, sex,

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