TravTek Evaluation Yoked Driver Study

Publication No. FHWA-RD-94-139

October 1995

U.S. Department of Transportation
Federal Highway Administration

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

DOT/FHWA
150088

FOREWORD

This report is one of eight reports produced as part of the evaluation of the Travtek operational field test, conducted in Orlando, Florida, during 1992-1993. Travtek, short for Travel Technology, was an advanced driver information and traffic management system that provided a combination of traveler information services and route navigation and guidance support to the driver. Twelve individual but related studies were conducted during the evaluation. Evaluation goals and objectives were represented by the following basic questions: (1) Did the TravTek system work? (2) Did drivers save time and avoid congestion? (3) Will drivers use the system? (4) How effective was voice guidance compared to moving map and turn-by-turn displays? (5) Was TravTek safe? (6) Could TravTek benefit travelers who do not have the TravTek system? (7) Will people be willing to pay for TravTek features?

Evaluation data were obtained from more than 4,000 volunteer drivers during the operation of 100 specially equipped automobiles for a l-year period. Results of the evaluation demonstrated and validated the concept of in-vehicle navigation and the provision of traveler information services to the driver. The test also provided valuable results concerning the drivers' interaction with and use of the in-vehicle displays. This project has made many important contributions supporting the goals and objectives of the Intelligent Transportation Systems Program.

L Saxton, Director
Office of Safety and Traffic
Operations Research and Development

NOTICE

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for the contents or the use thereof. This report does not constitute a standard, specification, or regulation.

The United States Government does not endorse products of manufacturers. Trade and manufacturers' names appear in this report only because they are considered essential to the object of the document.

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-RD-94-139		

4. Title and Subtitle	5. Report Date
TRAVTEK EVALUATION YOKED DRIVER STUDY	October 1995
	6. Performing Organization Code

7. Author (s)	8. Performing Organization Report No.
V. Inman, R. Sanchez, C. Porter, L. Bernstein	

9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Science Applications International Corporation 3045 Technology Pkwy Orlando, FL 32826	3B7A 11. Contract or Grant No. DTFH61-91-C-00106
12. Sponsoring Agency Name and Address Office of Safety and Traffic Operations R&D Federal Highway Administration 6300 Georgetown Pike McLean VA 22101-2296	**13. Type of Report and Period Covered** Final Report, Nov. 1991, June 1994 **14. Sponsoring Agency Code**

15. Supplementary Notes

Contracting Officer's Technical Representative: Frank Mammano, HSR-12

16. Abstract

The Yoked Driver Study was 1 of 12 investigations conducted as part of the TravTek operational test of an advanced traveler information and traffic management system (ATIS/ATMS). The TravTek system consisted of the Orlando Traffic Management Center (TMC), the TravTek vehicles, and the TravTek Information and Services Center. The TMC broadcast updated travel times for TravTek traffic links to the TravTek vehicles once each minute. The TravTek vehicles broadcast their completed link travel times back to the TMC for transmission to the other TravTek vehicles. The vehicles were equipped to provide route planning, route guidance, and a data base of local services and attractions. The primary purpose of the Yoked Driver Study was to evaluate the value of real-time traftic information, route planning, and route guidance to (a) trip efficiency, (b) navigation performance, and (c) driving performance. The study also examined willingness-to-pay, user perceptions of the system, and user recommendations.

A controlled experiment was conducted in which sets of three TravTek vehicles traveled between selected origins and destinations during peak afternoon traffic. Each of the three vehicles was configured differently: one provided route planning and route guidance that utilized real-time traffic information. A second provided the same route planning and route guidance except that it did not utilize real-time traffic information. The third required that drivers plan the trip and navigate "as they normally would." A total of 222 volunteer drivers participated in the experiment.

TravTek benefits to individual drivers included a travel time saving and a reduction in perceived workload. Real-time traffic information produced a network trip efficiency by routing many of TravTek vehicles that received it onto arterials. Although vehicles that received real-time information tended to travel farther, and to travel farther on lower class roadways, they did not have significantly longer travel times. User perception and performance data suggest that the system was easy to learn and easy to use. Participants in this study indicated that they would be willing to pay about $1000 for a system such as the one they drove.

17. Key Words	18. Distribution Statement
TravTek, ATIS, ATMS, IVHS, ITS, Real-Time Traffic Information, Route Guidance, Route Planning	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	103	

Form DOT F 1700 7 (8-72) REPRODUCTION OF COMPLETED PAGE AUTHORIZED

METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

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

AREA (APPROXIMATE)

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

MASS - WEIGHT (APPROXIMATE)

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

VOLUME (APPROXIMATE)

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

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F ❑ y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

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

AREA (APPROXIMATE)

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

MASS - WEIGHT (APPROXIMATE)

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

VOLUME (APPROXIMATE)

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

TEMPERATURE (EXACT)

[(9/5) y + 32] °C ❑ x °F

QUICK INCH-CENTIMETER LENGTH CONVERSION

INCHES	0	1	2	3	4	5	6	7	8	9	10

CENTIMETERS 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 25.40

QUICK FAHRENHEIT-CELSIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

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

TABLE OF CONTENTS

Section **Page**

OVERVIEW 1

INTRODUCTION 3

- **BACKGROUND** 4
- **PURPOSE OF TEST** 7
- **OBJECTIVES** 7
  - Issue 1: Does the Availability of Real-Time Traffic Information and Electronic Navigation Assistance Improve Trip Efficiency? 7
  - Issue 2: Does the Availability of Real-Time Traffic Information and Electronic Navigation Assistance Improve Overall Driver Performance? 8
  - Issue 3: What are Drivers Willing to Pay for TravTek Features and Functions? 9
  - Issue 4: Is the TravTek Driver Interface Usable and Useful? 10

METHODS 11

- **DURATION OF TEST** 11
- **TEST CONFIGURATION** 11
  - Navigation Plus 11
  - Navigation 14
  - Control 14
- **TEST CONDITIONS** 15
  - TravTek Traffic Network 15
  - Origin/Destination Pairs 15
  - Drivers 18
- **MATERIALS AND INSTRUMENTATION** 19
  - Pre-Tests 20
  - Observers 21
  - In-Vehicle Logs 22
  - Debriefing 22
  - Questionnaire 22
- **DETAILED TEST PROCEDURES** 23
  - Test Schedule 23
  - Assignment to Configurations 25

TABLE OF CONTENTS (Continued)

Section **Page**

Issue: What are Drivers Willing to Pay For TravTek Features and Functions? 62
Issue: Is the TravTek System Usable and Useful? 69

DISCUSSION 85

Issue 1: Does the Availability of Real-Time Traffic Information and Electronic Navigation Assistance Improve Trip Efficiency? 85
Issue 2: Does the Availability of Real-Time Traffic Information and Electronic Navigation Assistance Improve Overall Driver Performance? . . 87
Issue 3: What are Drivers Willing to Pay for TravTek Features and Functions? 88
Issue 4: Is the TravTek Driver Interface Usable and Useful? 89

CONCLUSIONS 91

REFERENCES 93

LIST OF FIGURES

Figure **Page**

1. Overview of the TravTek system. 4

2. Schematic representation of the TravTek vehicle architecture. 6

3. TravTek Guidance Display. 12

4. The TravTek Route Map displays the planned route as an overlay on the heading up map display. 13

5. O/D 1 began in a residential neighborhood south of downtown Orlando and west of Orange Blossom Trail. It ended in a residential neighborhood north of downtown Orlando. 17

6. O/D 2 began in a residential neighborhood north of downtown Orlando and ended in a residential neighborhood south of downtown and east of Orange Avenue. 17

7. O/D 3 began in a residential neighborhood south of downtown Orlando and ended in a residential neighborhood north of downtown and east of Orlando Avenue. 18

8. Trip planning time as a function of vehicle configuration. 30

9. Travel time as a function of vehicle configuration and O/D. 32

10. Travel times for yoked dyads. 33

11. Travel times for all Navigation Plus and Navigation yoked pairs that made no wrong turns and for which the Navigation Plus configuration received a different route. 34

12. Actual and predicted travel times as a function of vehicle configuration and whether the Navigation Plus member of the yoked pair planned a different route than the Navigation member. 36

13. Predicted and actual travel times for Navigation Plus vehicles that were given a different route. 37

14. Predicted and actual travel times for Navigation Plus vehicles that were given the same route as Navigation vehicles. 37

15. Travel distance for all yoked triads with complete trips. 38

LIST OF FIGURES (Continued)

Figure **Page**

16. Travel distance for all yoked pairs of Navigation Plus and Navigation drivers that completed their trips. 39

17. Travel distance for all Navigation Plus/Navigation dyads where the Navigation Plus configuration planned a different route and no driver made a wrong turn. 40

18. The locations where Navigation Plus and Navigation configuration drivers most frequently made wrong turns on O/D 1. 53

19. The time delay before drivers noted that they were off the planned route was significantly longer for the Control configuration. 55

20. Total time elapsed between going off route and returning to a planned route. 56

21. Questionnaire items related to driving performance were rated on a six point Likert scale. 59

22. An example of a willingness-to-pay scale in the questionnaire. 63

23. Estimated market penetration for the TravTek system “such as the one you drove.”. 67

24. Estimated market penetration for the TravTek system purchased as “options on a new car.” 67

25. Estimated market penetration for the TravTek system purchased as “an add-on to any car.”. 68

26. Estimated market penetration for the TravTek system as added cost on a weekly rental rate. 68

27. An example of the training checklist used to rate driver proficiency in entering a destination. 73

28. An example of the TravTek “keyboard” interface. 83

LIST OF TABLES

Table **Page**

1. Does the availability of real-time traffic information and electronic navigation assistance improve tripefficiency? 7
2. Does the availability of real-time traffic information and electronic navigation assistance improve overall driver performance?. 8
3. What are drivers willing to pay for TravTek features and functions?. 10
4. Is the TravTek system usable and useful?. 10
5. Number of drivers that completed O/D's as a function of vehicle configuration. 31
6. Analysis of variance summary table for travel time of all triads. 31
7. Analysis of variance source table for travel time of yoked Navigation Plus and Navigation drivers. 33
8. Analysis of variance source table for travel distance of all yoked triads that completed their trips. 39
9. Overall congestion rating summaries 41
10. Mean congestion ratings recorded by observers as a function of vehicle configuration. 42
11. Overall congestion level by vehicle configuration. 43
12. Mean distance traveled by vehicle configuration and road class. 43
13. Mean distance traveled by vehicle configuration and road class for yoked triads. 44
14. Mean congestion level by vehicle configuration for 22 yoked dyads. 44
15. Mean distance traveled by vehicle configuration and road class for 22 yokeddyads. 45
16. Close-call or near-miss statistics as a function of vehicle configuration. . 46
17. Incidence of trips on which at least one abrupt turn was recorded. 47

LIST OF TABLES (Continued)

Table **Page**

18. The incidences of trips with one or more abrupt turns when the Navigation Plus vehicle selected an alternative route. 47

19. The frequency of trips with abrupt maneuvers. 48

20. Frequency of trips with abrupt maneuvers by Navigation Plus and Navigation pairs for trips when the Navigation Plus configuration took an alternative route. 48

21. Number of drivers who made wrong turns as a function of vehicle configuration (yoked triads). 49

22. Number of drivers who made wrong turns as a function of vehicle configuration (yoked dyads). 49

23. Number of drivers in each wrong turn classification for dyads where the Navigation Plus driver received an alternative route.. 49

24. Number of drivers who made wrong turns as a function of O/D (yoked triads). 50

25. Percentage of drivers in yoked triads who made at least one wrong turn. .50

26. Number of drivers who made wrong turns as a function of O/D (yoked dyads). 51

27. Description of maneuvers that resulted in a driver’ s first wrong turn. . . .51

28. Wrong turn classification for Navigation Plus and Navigation triads as a function of vehicle configuration. 52

29. How drivers got back onto a planned route. .54

30. Mean workload ratings for yoked triads as a function of vehicle configuration, type of workload, and trip segment (category). 58

31. Items from the Yoked Driver Study and Orlando Test Network Study questionnaire that were selected to represent driver opinion of the TravTek system’ seffect of on driver performance. 60

32. Correlation matrix of 14 questionnaire items that concerned driving performance. 61

33. Factor structure for the four factor solution with quartimax rotation. 62

34. Summary of responses to the willingness-to-pay questions. 64

LIST OF TABLES (Continued)

Table **Page**

35. Proportion of participants who said they would pay nothing. 66

36. Frequency of judgments as to whether the TravTek system would be useful forat home driving. 69

37. Mean ratings for questionnaire items used to assess TravTek's utility as a routing and navigation aid. 71

38. The percentage of drivers who answered system information questions correctly each time they were asked. 72

39. Mean number of training runs to attain proficiency at entering a destination by gender and age group. 73

40. Average number of errors (sample size in parentheses) in performing each of five system manipulation tasks.. 74

41. Overall, what impressions do you have about TravTek now that you've had a chance to test drive the future? 76

42. What was your favorite feature? 77

43. What was your least favorite feature? 79

44. While driving with TravTek, were there any situations where TravTek was especially helpful?. 80

45. While driving with TravTek, were there any situations where TravTek was not helpful? 82

46. Did the training you were given prepare you for driving with TravTek? . . 83

47. Can you think of anything that could be improved about TravTek to make it better?. 84

OVERVIEW

TravTek was a joint public and private sector operational field test of an advanced traveler information and traffic management system (ATIS/ATMS). Public sector participants were the City of Orlando, the Federal Highway Administration, and the Florida Department of Transportation. The American Automobile Association, and General Motors were the private sector participants.

The TravTek system was composed of three primary components: the TravTek vehicles, the TravTek Information and Service Center (TISC), and the Traffic Management Center (TMC). Once each minute, the TMC broadcast updated travel times for TravTek traffic links to the TravTek vehicles. The TravTek vehicles broadcast their link travel times back to the TMC for transmission to the other TravTek vehicles. The vehicles were equipped with software and computers that provided route planning, route guidance, and a data base of local services and attractions.

The Yoked Driver Study was 1 of 12 evaluation studies conducted as part of the operational test. The primary purpose of this study was to evaluate the contributions of real-time traffic information, route planning, and route guidance to trip efficiency and driver performance.

A yoked methodology was used. That methodology called for three TravTek vehicles to depart at 2-min intervals from the same origin for the same destination during peak afternoon traffic. Sending the vehicles on the same trip at the same time of day was intended to ensure that they would be subject to the same network environment. Each of the three vehicles was configured differently. One was in the Navigation Plus configuration. To plan efficient routes, the Navigation Plus configuration utilized real-time traffic information for 1,488 traffic links. A second vehicle was in the Navigation configuration. This configuration used the same route planning software as the Navigation Plus configuration, but did not use real-time traffic information. The third vehicle was in the Control configuration. The drivers of Control configuration vehicles planned and navigated as "they normally would." That is, in the Control configuration drivers used a paper map or a transcribed list of instructions.

A total of 222 drivers participated in the Yoked Driver Study. Of these drivers, 108 contributed to complete Yoked triads, where a triad consisted of one Navigation Plus, one Navigation, and one Control configuration vehicle. On days when three drivers were not available for testing, Yoked dyads with Navigation Plus and Navigation configuration vehicles were run.

The Navigation Plus and Navigation configurations each resulted in a large trip planning time savings compared to the Control configuration. The Navigation Plus and Navigation configurations also yielded significant en route travel-time saving, but this saving was not observed on all origin destination pairs.

The availability of real-time information to the Navigation Plus vehicles often resulted in the Navigation Plus vehicles planning different routes than those planned by the Navigation vehicles. On average, when taking a different route, the Navigation Plus vehicles traveled a greater distance than the Navigation vehicles, and traveled farther on lower class roadways. Despite this, they did not experience significantly longer travel times. Two conclusions are suggested by the real-time traffic information findings: (1) if travel time information for arterials had been better, a travel time saving might have been observed; and (2) by avoiding adding to the delay on the Interstate, Navigation Plus vehicles contributed a network travel time saving.

Near accident and abrupt maneuver performance measures indicate that driver performance in the Navigation Plus and Navigation configurations was at least as good as that in the Control condition. Drivers' reported significantly reduced workload when using the TravTek system compared to the Control condition, Furthermore, in questionnaire responses, drivers indicated that TravTek helped them drive more safely and helped them find their way.

Questionnaire responses suggest that participants would be willing to pay about $1000 for a system such as the one they drove. Participants also indicated a willingness to pay about $28/week additional for a rental car with a system such as the one they drove. Participants rated route guidance as the most valuable TravTek feature, followed by navigation assistance (a moving map with present position), and real-time traffic information.

Evidence is also presented that suggests the TravTek system was easy to learn and easy to use.

TravTek's Voice Guidance was most frequently named as participants' "favorite" TravTek feature. The sound quality of the voice guide was most frequently identified as the least liked TravTek feature and the one that most needed improvement.

INTRODUCTION

TravTek was a joint public and private sector operational field test of an advanced traveler information and traffic management system (ATIS/ATMS).[1, 2] Public sector participants were the City of Orlando, the Federal Highway Administration, and the Florida Department of Transportation. The American Automobile Association, and General Motors were the private sector participants.

The TravTek Evaluation consisted of a series of behavioral, engineering, and modeling studies designed to evaluate the TravTek system from multiple perspectives. The Yoked Driver Study was a behavioral and systems study to evaluate the value of

- Real-time traffic information.
- TravTek's route planning and route guidance functions.

The study examined value with respect to:

- Trip efficiency.
- Navigation performance.
- Driving performance.

Driver perceptions of the TravTek system, ease of learning, and willingness-to-pay for TravTek functions were also examined.

There were multiple objectives for the TravTek system. From a driver's perspective, goals included navigation assistance, congestion avoidance, reduction in trip times, and access to information about the local area. From a safety perspective, either an enhancement in safety, or, minimally, no increase in risk was expected. From a traffic systems perspective, goals included decreased congestion, increased in fuel economy, and an increased safety. The purpose of the Yoked Driver Study was twofold: (1) to evaluate the ability of the TravTek system to meet its objectives, and (2) to provide guidance as to which alternative implementations might best fulfill the objectives.

The Yoked Driver Study focused on the value of real-time traffic information to the TravTek system. The performance of visitors to the Orlando area in navigating between Orlando origins and destinations was observed under three conditions:

- TravTek route planning and route guidance supplemented with real-time travel information.
- TravTek route planning and route guidance without the benefit of real-time travel information.
- Route planning and route guidance without the aid of the TravTek system.

BACKGROUND

The TravTek system architecture was composed of three primary components: the TravTek vehicles, the TravTek Information and Service Center (TISC), and the Traffic Management Center (TMC). These three components are described briefly here, with the focus on aspects that are important to the objectives of the Yoked Driver Study. The reader may refer to Rillings and Lewis for additional details about the TravTek system.[2] Figure 1 provides a graphical overview of the TravTek system architecture. In the figure, data links are indicated by arrows. It can be seen that the vehicle both received and transmitted data. Data transmitted by the vehicle included travel times across TravTek network roadway segments.

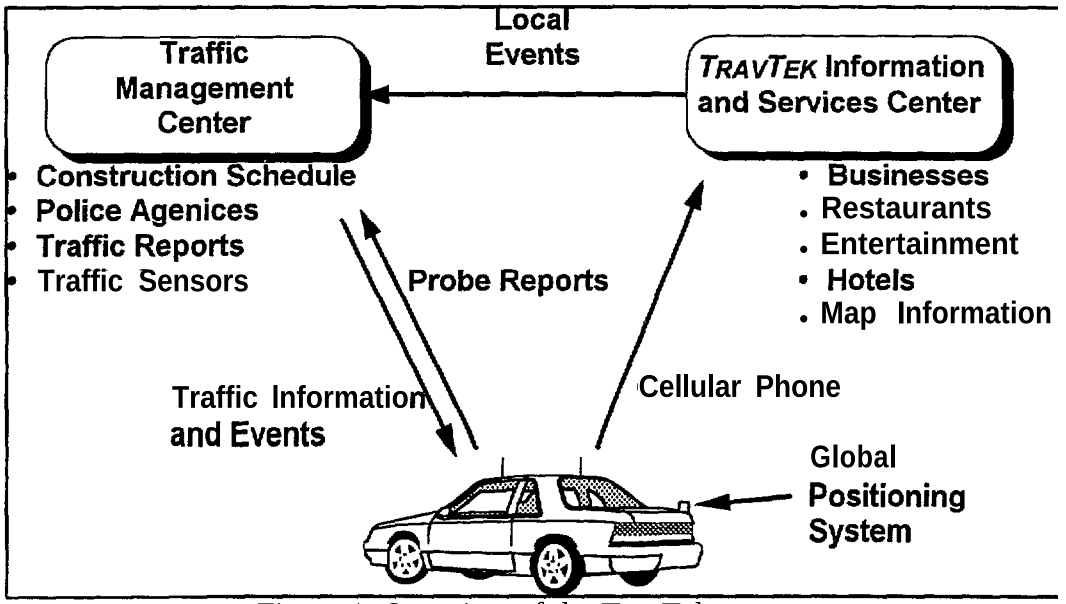

Figure 1. Overview of the TravTek system.

TravTek made a wealth of information available to drivers. This information included: route planning, turn-by-turn route guidance, real-time traffic reports, and real-time re-routing advisories. Some of the features of the TravTek system were:

- **Navigation** — A variable-scale color map was displayed on a 127 mm (5 in) video display. The video display, an option on the Oldsmobile Toronado, was positioned high on the dashboard and to the driver's right. The navigation system used a combination of dead-reckoning, map-matching, and Global Positioning System information to indicate the vehicle's position on the map. The vehicle's position was indicated by an icon that was horizontally-centered three-fourths of the distance from the top of the screen. When the vehicle was in DRIVE the map was displayed in a heading-up format.

- **Route** Selection — An in-vehicle routing computer provided the minimum-time route from the vehicle's current position to a selected destination. The minimum-time criterion was subjected to constraints such as turn penalties, preference for higher level roadways, and avoidance of short-cuts through residential areas.

- **Route Guidance** — When a route had been computed, a sequence of guidance displays provided maneuver-by-maneuver driving instruction. The visual guidance display could be augmented by synthesized voice that provided the next turn direction, distance to the turn, and the name of the street on which to turn. The driver could switch between the maneuver-by-maneuver *Guidance Display* and a Route *Map*. The Route Map showed the planned route as a magenta line traced over the map display (described above). Buttons on the steering wheel hub were used to swap between the Guidance Display and the Route Map and to turn the voice guidance function off or on. An illustration of the Guidance Display is provided in figure 3 on page 12. An illustration of the Route Map is provided in figure 4 on page 13.

- **Real-time Traffic Information** — Real-time traffic information was broadcast to TravTek vehicles once every minute. To limit the quantity of information broadcast, only exceptions to normal traffic flows were reported. The real-time information could be used in route planning. Also, if conditions changed while the vehicle was en route, a new, faster, route could be offered to the driver. Conditions available to the system via broadcasts from the TMC included:

  — Historical travel times as a function of time of day and day of week.

  — Roadway sensor data (e.g., loop detectors).

  — Police reports.

  — City reports of maintenance and road closures.

  — Probe reports from other TravTek vehicles of travel times across TravTek traffic links (roadway segments).[1]

  When the real-time information function was active and a route was planned, the routing computer made a continual search for a significantly faster route. If a faster route was found, it was offered to the driver for acceptance or rejection. Traffic congestion and incidents were represented on both the Guidance Display and Route Map screens. Synthesized voice announcement of traffic information was toggled on or off by a TRAFFIC REPORT button on the steering wheel hub.

1To prevent confounding of the experimental design, probe reports from Yoked Study vehicles were not broadcast by the TMC.

- **Help Desk Telephone Assistance —** When the vehicle was in PARK, a *HELP* function was available by pressing a touch sensitive key on the video display. One feature of the HELP function was free cellular telephone calls to the TISC.

The TISC was operated by the American Automobile Association. Help desk operators had access to a TravTek simulator that replicated the TravTek functions in the vehicles. This enabled the help desk operators to replicate problems encountered by drivers, or to plan routes just as they are planned in the vehicle. Participants in this study's Control condition (drivers using TravTek vehicles but not using TravTek functions) were permitted to call the help desk for assistance in finding their destination.

Figure 2 provides an overview of the TravTek in-vehicle architecture. Compass, wheel sensor, and Global Positioning System data were used by the navigation computer to position the vehicle relative to a map data base. A second computer, the routing computer, used a different data base to plan routes and to provide navigation assistance. The routing computer also maintained a data log that is described in the Methods section. The driver could interact with the system via touch sensitive buttons on the video display, steering wheel buttons, and buttons on the video display bezel.

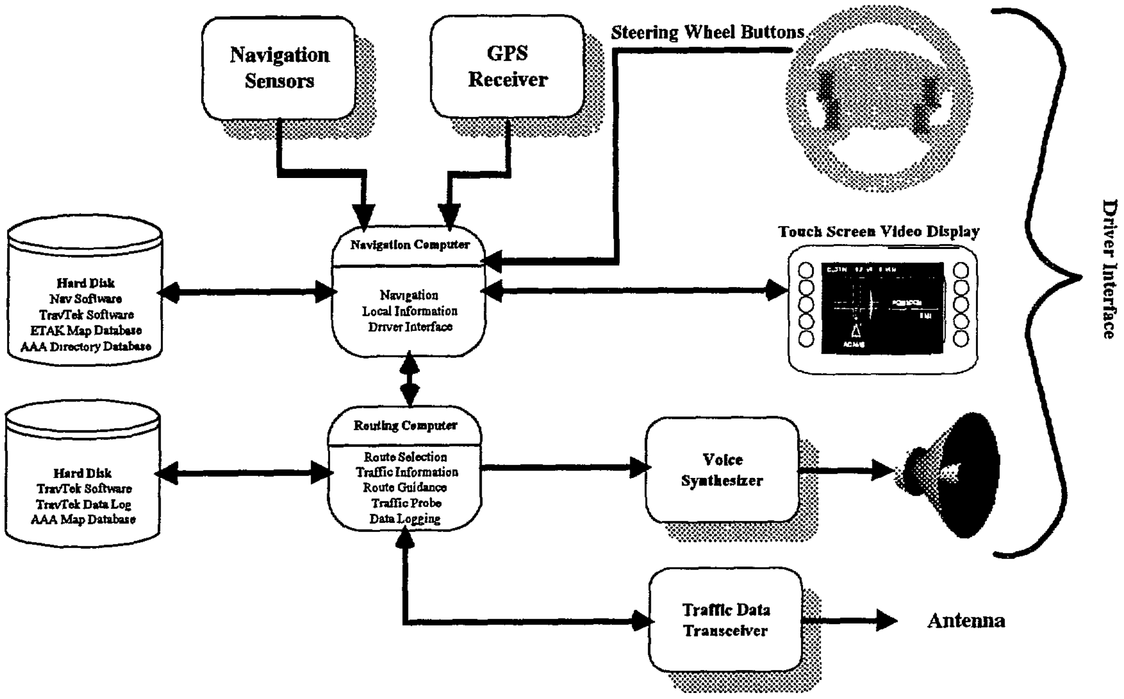

Figure 2. Schematic representation of the TravTek vehicle architecture.

PURPOSE OF TEST

Yoked Driver Study addresses four primary issues:

1. Does the availability of real-time traffic information and electronic navigation assistance improve trip efficiency?
2. Does the availability of real-time traffic information and electronic navigation assistance improve overall driver performance?
3. What are drivers willing to pay for TravTek features and functions?
4. Is the TravTek system usable and useful?

The following section describes the Yoked Driver Study objectives that address each of these broad issues and provides an overview of the approach. The Methods section provides a detailed description of the approach.

OBJECTIVES

In this section, Yoked Driver Study objectives are described for each of the four primary issues.

Issue 1: Does the Availability of Real-Time Traffic Information and Electronic Navigation Assistance Improve Trip Efficiency?

Research objectives associated with Issue 1 are summarized in table 1.

Table 1. Does the availability of real-time traffic information and electronic navigation assistance improve trip efficiency?

Objective	Hypothesis	Measure Of Effectiveness	Measure Of Performance	Data Source
Assess the trip efficiency benefit of TravTek's real-time traffic information.	TravTek's real-time traffic information function results in increased trip efficiency when contrasted with TravTek without real-time information or to trips with neither navigation assistance nor real-time information.	• Trip efficiency	• Trip planning time • Time en route • Distance en route • Time at less than 75 percent of the posted speed limit for more than 90 seconds • Congestion levels encountered (judged by visual assessment)	• Observer • In-vehicle log

For the purposes of this study, a more efficient trip is defined as a trip that:

- Decreases trip planning time.
- Decreases time en route.

- Decreases distance driven.
- Avoids congestion.

Together, trip planning time and time en route travel time are referred to as travel time. Distance driven includes both distance on the planned route and distance due to navigational errors. Congestion is defined both in terms of speed relative to the posted speed, and in terms of observer ratings using Transportation Research Board standards.(3) Most of the data used to address this issue were recorded by observers who rode with participants during test runs. However, data recorded from the vehicle data bus are also used in examining the congestion hypothesis.

Issue 2. Does the Availability of Real-Time Traffic Information and Electronic Navigation Assistance Improve Overall Driver Performance?

Driver performance variables not directly related to navigation are explored under Issue 2. Whereas the TravTek system was intended to aid drivers navigate to destinations and avoid congestion, its use might affect other aspects of the driving task. The impact of using TravTek might improve driving performance to the extent that it relieves drivers from excess attention to navigation. However, if the TravTek system distracts drivers or requires more attention than would otherwise be required, TravTek might detract from driver performance. The objective here was to assess the effects of TravTek on driver performance, subjective workload, and driver perception of performance.

Research objectives associated with determination of the effect of TravTek on driver performance with are summarized in table 2.

Table 2. Does the availability of real-time traffic information and electronic navigation assistance improve overall driver performance?

Objective	Hypothesis	Measure of Effectiveness	Measure of Performance	Data Source
Assess the effects of TravTek on: • Driver performance • Workload . Perceived performance	. Driver performance varies as a function of vehicle configuration. . Driver workload varies as a function of vehicle configuration.	* Driving performance or quality . Driver workload	* Maneuver abruptness • Number of accidents . Number of near accidents • Number of wrong turns . Subjective workload	* Observer
	. Drivers perceive the TravTek system to be safe.	• Driver confidence	. Subjective measures	. Questionnaire

In this study driving performance was assessed using measures that could be observed and recorded by an observer sitting in the passenger's seat. These measures included abrupt maneuvers, close calls (near accidents), turn preparation, and turn signal use. The

TravTek *Evaluation Task C_3 Camera Car Study* final report provides results for additional driver performance measures that include longitudinal and lateral acceleration; steering wheel reversals; and eye glance frequency and dwell times.[4]

Driver performance measures are not independent of navigation performance. For instance, maneuver abruptness was defined as: (a) getting into the proper lane for a turn too early or too late, (b) applying the turn signal too early or too late, and (c) turning more radically (i.e., faster, crossing more lanes) than usual. All of the abruptness measures were relative to the way the individual normally drove. Abruptness ratings required the assumption on the part of the observer that the abruptness was the result of navigational uncertainty.

If a system such as TravTek makes driving easier or harder, the result may or may not be reflected in observable changes in performance. Changes might only be observable during rare emergency situations or when the driver becomes fatigued. In an attempt to assess effects of TravTek on driver performance that might not be readily observable, subjective workload measures were obtained. Subjective workload measures are obtained by asking drivers to rate their level of effort in performing the driving task. In this context, effort refers to mental effort, not physical effort. Subjective measures of workload are used to reflect differences in effort before the point at which performance is reliably degraded.[5] Thus, subjective workload measures may be sensitive to task differences that performance measures are not.

Whereas TravTek may plan more efficient trips than drivers might plan for themselves, that efficiency may not be realized if the drivers cannot follow the planned route. We examine the effect of vehicle configuration on the number of wrong turns drivers make, on the kinds of navigational errors they make, and how they recover from wrong turns. The length of time off route and the time required by the driver before the deviation from the planned route is noticed are also examined.

Accidents and near accidents are examined to assess the effect of the TravTek system on safety. In addition, drivers' subjective assessments of the effect of the TravTek system on their driving performance are also examined.

Issue 3: What are Drivers Willing to Pay for TravTek Features and Functions?

No matter how many TravTek benefits are identified, if people do not purchase and use TravTek like systems, those benefits will not be realized. The amount study participants estimated that they are willing to pay for the TravTek system in (a) a new car, (b) in any other car (e.g., current or used car), or (c) in a rental car is assessed. In addition to assessing willingness-to-pay or the TravTek system, willingness-to-pay for the navigation, route guidance, and real-time information features is assessed.

Research objectives associated with determination of the willingness-to-pay are summarized in table 3.

Table 3. What are drivers willing to pay for TravTek features and functions?

Objective	Hypothesis	Measure of Effectiveness	Measure of Performance	Data Source
• **Assess** drivers willingness-to-pay for TravTek features and functions.	• Willingness-to-pay will vary as a function of features and functions.	• Willingness-to-Pay	Subjective Judgment	Questionnaire

Issue 4: Is the TravTek Driver Interface Usable and Useful?

In part, the usability of TravTek can be inferred from the findings under the first three issues. Under Issue 4, additional data that reflect on the usability of TravTek are examined.

One usability issue is ease of learning. Data are presented on how quickly Yoked Study participants became proficient in entering destinations. A second usability issue, the ease of comprehending various other TravTek functions, is also explored.

Although not necessarily related to usability, it is under this issue that we discuss what study participants had to say in semi-structured debriefings. In the debriefings, participants were free to comment on whatever aspects of TravTek they desired, but many of the user comments reflected usability issues.

Research objectives associated with usability are summarized in Table 4.

Table 4. Is the TravTek system usable and useful?

Objective	Hypothesis	Measure of Effectiveness	Measure of Performance	Data Source
Assess learnability and usability of the TravTek system	• TravTek is easy to learn. • TravTek is easy to use	• Learnability • Usability	• Errors in learning • Trials to correct responding • Debriefing comments	• Observer • Debriefing
Assess utility of the TravTek system	• TravTek is useful	• Utility for navigating to a destination	• Driver ratings of usefulness	• Questionnaire

METHODS

The title of this study derives from the experimental methodology for performing "yoked" trials. In a yoked trial, two or more experimental units are run at the same time and in the same environment. This procedure helps to reduce variability between conditions that may result from changes in the environment over time. In the Yoked Driver study the experimental units were three TravTek vehicles. The experimental manipulation was to vary vehicle configuration:

- One TravTek vehicle was configured to use real-time traffic information for route planning. This was the Navigation Plus vehicle.
- A second TravTek vehicle planned its route without the benefit of real-time information. This was the Navigation vehicle.
- A third TravTek vehicle did not use the TravTek system for route planning. This was the Control vehicle.

To ensure that all three vehicles were faced with the same driving environment, they were tested at tbe same time and their drivers were asked to travel from the same origin to the same destination.

DURATION OF TEST

Formal data collection for the Yoked Driver Study was conducted between November 17, 1992, and March 18, 1993. Pilot testing was conducted between March and November of 1992.

TEST CONFIGURATION

Three vehicle configurations were used:

- Navigation Plus.
- Navigation.
- Control.

The sections that follow describe the three vehicle configurations.

Navigation Plus

The Navigation Plus configuration consisted of a TravTek vehicle with all TravTek system capabilities enabled. **This** was the only vehicle configuration that used real-time traffic information. Travel-time estimates for TravTek traffic links were updated once per minute. The in-vehicle system used the updates to select a route that minimized travel time. Once a route was planned, the driver might be offered a new, faster, route if traffic conditions resulted in the projected travel time for an alternative route that was significantly shorter.

While en route, traffic conditions were presented to Navigation Plus drivers. There were three methods of displaying traffic conditions:

- Synthesized voice messages.
- A caution on the Guidance Display.
- Congestion symbols overlaid on the Route Map display.

Drivers with the Navigation Plus and Navigation configurations were required to use the Guidance Display. As the TravTek system's default method or displaying route guidance, the Guidance Display was presented whenever the vehicle was on a planned route.

Figure 3 provides an example of the Guidance Display. The Guidance Display presented the TravTek vehicle's present position in a heading-up format with the vehicle represented by an arrowhead shaped icon. Below the vehicle icon was the name of the current street. At the top of the display, distance and estimated time to the destination were presented. The next maneuver along the route and the relationship of present position to that maneuver were represented by a geometric outline that approximated the shape of the intersection. An arrow within the intersection outline depicted the direction of the maneuver. Tic marks above the vehicle icon represented distance to the maneuver point. On limited access roadways, each tic mark represented two-tenths miles, otherwise each tic mark represented one-tenth mile. Tic marks were displayed when the vehicle was with 0.9 miles of the maneuver point, or 0.9 miles on limited access roadways. Distance to the next maneuver was also shown in text below the next street name. The name of the road at the next maneuver was presented to the right of the arrow that indicted the direction of the turn. If the next maneuver required two turns is rapid succession, then text underneath the next street name indicated the direction of the second turn, for example "then left," or "then right."

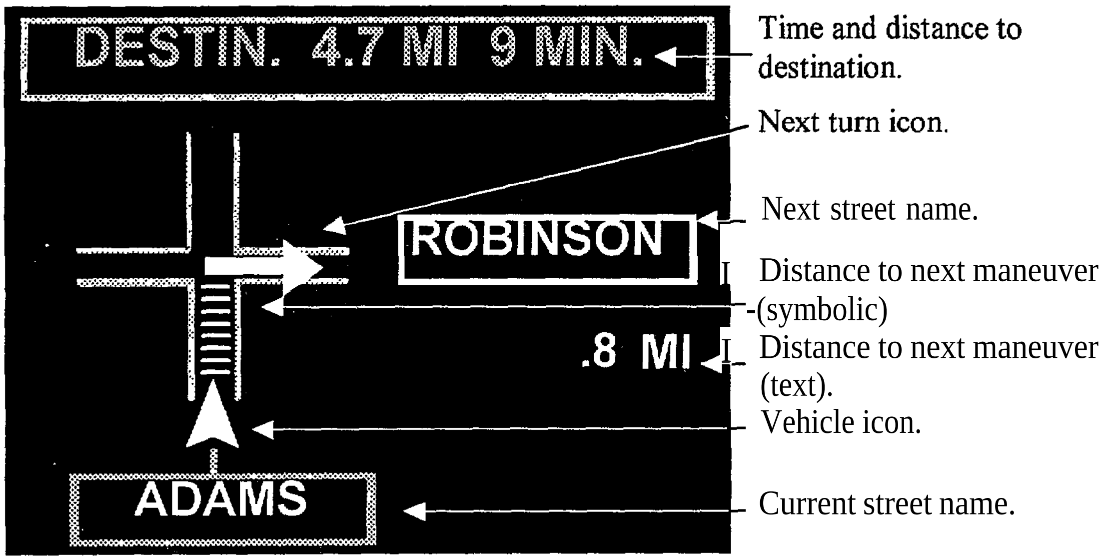

Figure 3. TravTek Guidance Display.

In this study, the Route Map display was only displayed the TravTek system detected that the vehicle was off the planned route. The Route Map display is illustrated in figure 4. The text banner at the bottom of the illustrated display was shown whenever the vehicle deviated from the planned route. Whereas the design of the Yoked Driver Study did not require use of the Route Map, participants were trained in its use. The Route Map was a moving map display that, in its default setting, displayed 0.81 km of the area ahead of the vehicle. The vehicle was represented by an arrowhead icon that was centered horizontally three-quarters of the distance from the top of the display. The planned route was represented by a magenta line. Unlike the Guidance Display, the name of the street for which the next maneuver was planned was not always displayed. Display of street names was dependent on a complex set of criteria that were influenced by zoom level and road classification. Zoom level could only be changed when the vehicle was stopped. Zoom was controlled from two soft keys that were presented on the route map display when the vehicle was stopped. Zoom levels available were 1/8, 1/4, 1/2, 1, 2, 5, 10, 20, 40 miles (0.21, 0.40, 0.81, 1.61, 3.22, 8.05, 16.1, 32.2, 64.4 km).

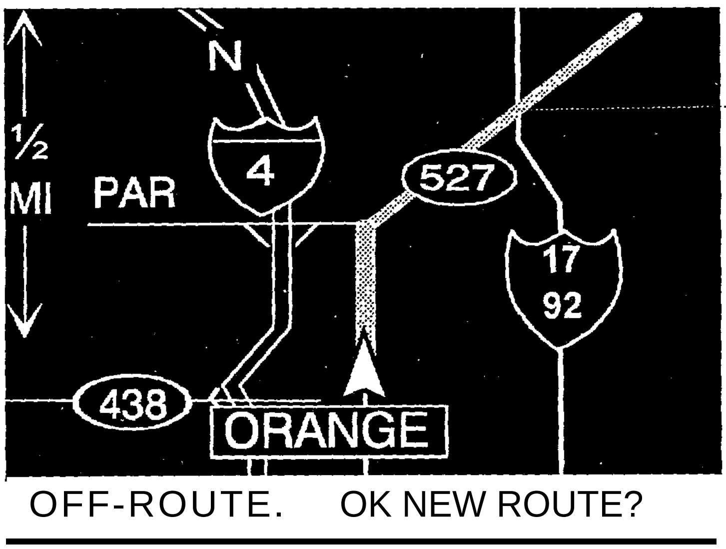

Figure 4. The TravTek Route Map displays the planned route as an overlay on the heading up map display.

Some drivers, in both the Navigation Plus and Navigation configurations, used the route map after making a wrong turn (deviating from the planned route) by driving towards the magenta line on the route map.

Navigation Plus and Navigation configuration drivers always drove with the Voice Guide on, The Voice Guide provided much of the same information that was available on the Guidance Display, that is:

- Directions to drive on to the route either at beginning of trip or after deviating from planned route.
- Announcement of next maneuver in 9 tenths miles (1.45 km) [or 1.9 miles (3.06 km) on limited access roadways].

- Announcement of next maneuver in 1tenths mile (0.16 km) [or 2 tenths mile (0.32 km) on limited access roadways].
- Turn direction and street name.
- Off-route warning.
- Proximity to destination announcement.

In addition, in the Navigation Plus configuration, drivers received synthesized voice TRAFFIC REPORT information for the planned route. Only below-nominal traffic conditions were reported, e.g., moderate or heavy congestion, construction, and lane closures.

Navigation

The Navigation configuration was the same as the Navigation Plus configuration except that functions related to real-time traffic information were not enabled. The Navigation configuration was characterized by the following attributes:

- Route planning was based on nominal travel times (based on the speed limit).
- Travel times did not take into account time-of-day or day-of-week variations.
- TRAFFIC REPORT information was not available.
- Traffic information was not displayed on the route map.
- Traffic information alert symbols and messages were not presented on the Guidance Display or Route Map.

From the user's perspective, route planning was the same as for the Navigation Plus configuration. That is, the route planning differences between Navigation and Navigation Plus were not apparent to the driver. When no traffic information was broadcast by the Traffic Management Center, as was the case when all TravTek traffic links were uncongested, the routes planned by the Navigation and Navigation Plus configurations were the same.

Control

In the Control configuration, drivers did not have access to TravTek planning or navigation functions. To plan a trip, drivers had the options of using an American Automobile Association paper map (supplied at the beginning of the experiment) or using the cellular phone to request assistance from the TISC operator. If drivers elected to use the Help Desk, the operator asked where they were, and where they wanted to go. The operator provided scripted turn-by-turn instructions. The operator's turn-by-turn instructions were the same as those generated by TravTek's Navigation configuration software. Pen, clipboard and paper were provided so that the driver could write down the instructions, or make notes from the paper map. The Help Desk approach approximated the case in which a driver would call a friend to ask for directions. Regardless of whether Control configuration drivers used a paper map or called the help desk, they were required to describe their entire route to the research assistant before they left the origin. This requirement was to enable to research assistant to detect when drivers had deviated from their planned routes.

TEST CONDITIONS

TravTek Traffic Network

Real-time traffic information was available for 1,488 TravTek traffic links in the Orlando area. For the area in which the Yoked Driver Study was conducted, real-time information was available for all limited access roadways. Real-time information was also available for many of the arterials and some of the local feeder roadways. The origin/destination pairs, described next, were selected to maximize the probability of selecting routes that traversed network links for which traffic information was available. To maximize the probability that traffic information would be useful in planning routes, the experiment was conducted during the peak evening travel. The Traffic Management Center and the TravTek broadcasting system were operational at all times during data collection.

Origin/Destination Pairs

Three origin to destination pairs (O/D's) were selected for the evaluation. These same O/D's were used in two other TravTek evaluation studies: the Orlando Test Network Study, and the Camera Car Study.[6, 4] Use of the same O/D's for multiple studies enables comparisons of more conditions than would otherwise be the case. For instance, whereas the Yoked Driver Study was always conducted during the afternoon traffic peak, the Orlando Test Network Study was conducted during non-peak hours, but with otherwise similar research methods. Thus comparisons between the Yoked Driver Study and Orlando Test Network Study may shed some understanding of the effects of TravTek navigation functions on navigation performance with differing levels of traffic congestion (levels of service).

Pre-defined O/D's were necessary to enable a fair assessment of the effects of vehicle configuration with relatively few trials. More than one O/D was used to minimize the possibility of obtaining results that are unique to an O/D pair. To minimize variability in dependent measures, such as travel time, attributable to differences in O/D's rather than vehicle configuration, the three O/D's were roughly equated for the following factors:

- Average travel time during off-peak hours.
- Distance between origin and destination.
- Number of left and right turns.
- Distance on limited access roadways.
- Number of traffic sensors in proximity to the route.
- Number of traffic control signals.

- Average number of required stops.
- Level of service.
- Number of lanes.
- Direction of flow (i.e., one-way, two-way)

With so many factors to equate, no set of three real-world O/D's could exactly match on all criteria. Equation of O/D's was complicated by the fact that only the origin and destination are supplied to the drivers; many different paths could have be taken between an origin and a destination. Instructions to the drivers recommended selection of a route that minimized travel time. For the conditions in which TravTek system was used (Navigation and Navigation Plus), the instructions directed drivers to select "FASTEST" from the TravTek route planning menu.' In the Navigation configuration, vehicles always planned the same route, and O/D matching was based primarily on that route. Routes selected in the Navigation Plus and Control configurations could be different. To the extent feasible, alternative route availability was equated across the three O/D's. In particular, at least two major north-south arterials were always available as alternatives to Interstate 4. There were alternative on-ramps and off-ramps to those used by TravTek's Navigation configuration. Both the Navigation Plus software and Control drivers made use of those alternatives.

Drivers in any test configuration may have unintentionally deviated from the planned route. Temporary road conditions such as street flooding or construction may have also resulted in alternative routes being taken. Thus selection of O/D pairs could be only roughly equated. Figures 5, 6, and 7 show the general location of the three O/D's, These O/D's are hereafter referred to as O/D 1, O/D 2, and O/D 3 respectively. The Navigation configuration routes for the O/D's are indicated by shading. Note that all three Navigation configuration routes include a segment of Interstate 4 through central Orlando. Also note that there were three major arterials (U.S. 17, U.S. 92, Orange Blossom Trail; State Route 527, Orange Avenue; and U.S. 17, U.S. 92, Orlando Avenue), that Navigation Plus and Control drivers could use to avoid part or all of the freeway. Another occasional alternative route for O/D 1 was to enter Interstate 4 at International Drive and exit Interstate 4 at Orange Blossom Trail (where the Navigation configuration entered the Interstate).

---

2 Drivers were instructed not to use the "Avoid Tolls" and "Avoid Interstates" options.

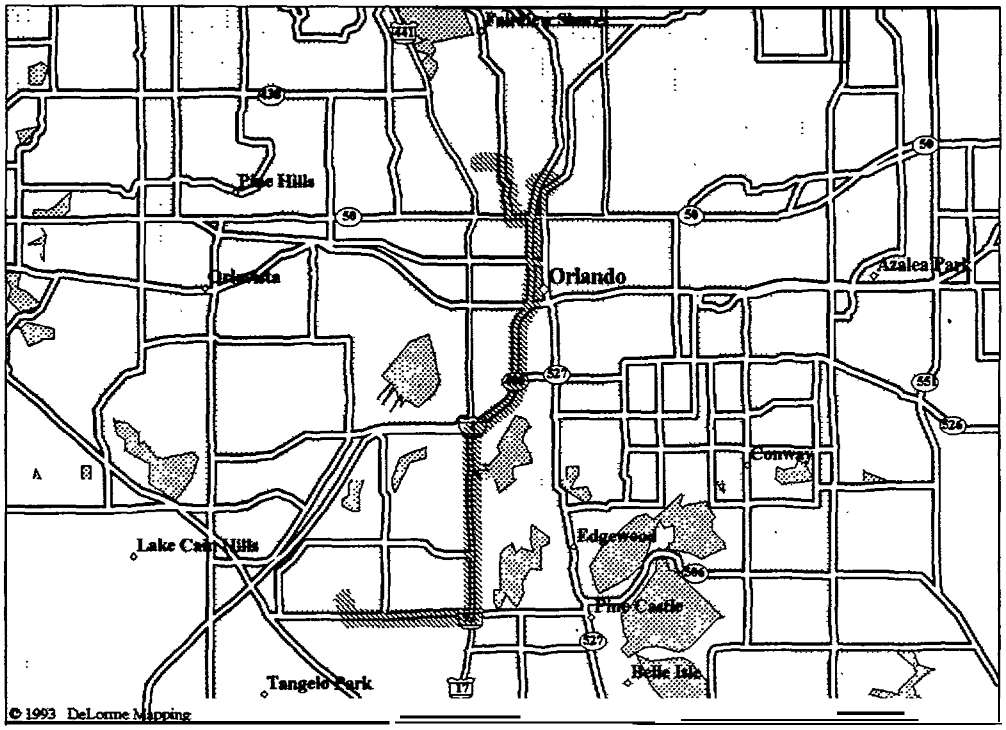

Figure 5. O/D 1 began in a residential neighborhood south of downtown Orlando and west of Orange Blossom Trail. It ended in a residential neighborhood north of downtown Orlando.

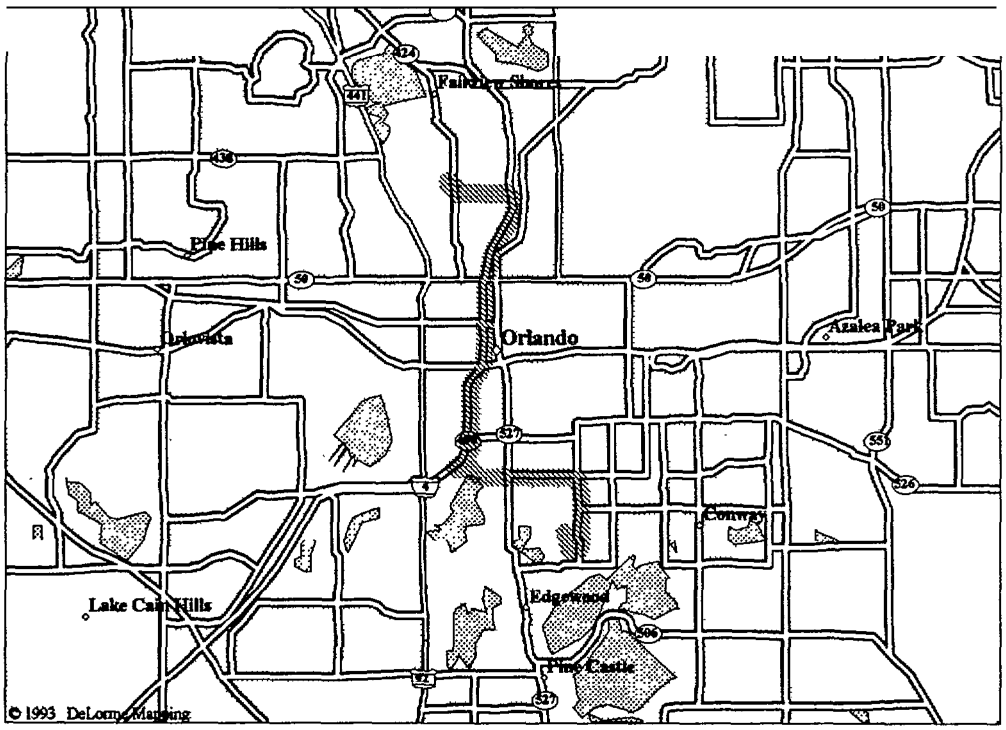

Figure 6. O/D 2 began in a residential neighborhood north of downtown Orlando and ended in a residential neighborhood south of downtown and east of Orange Avenue.

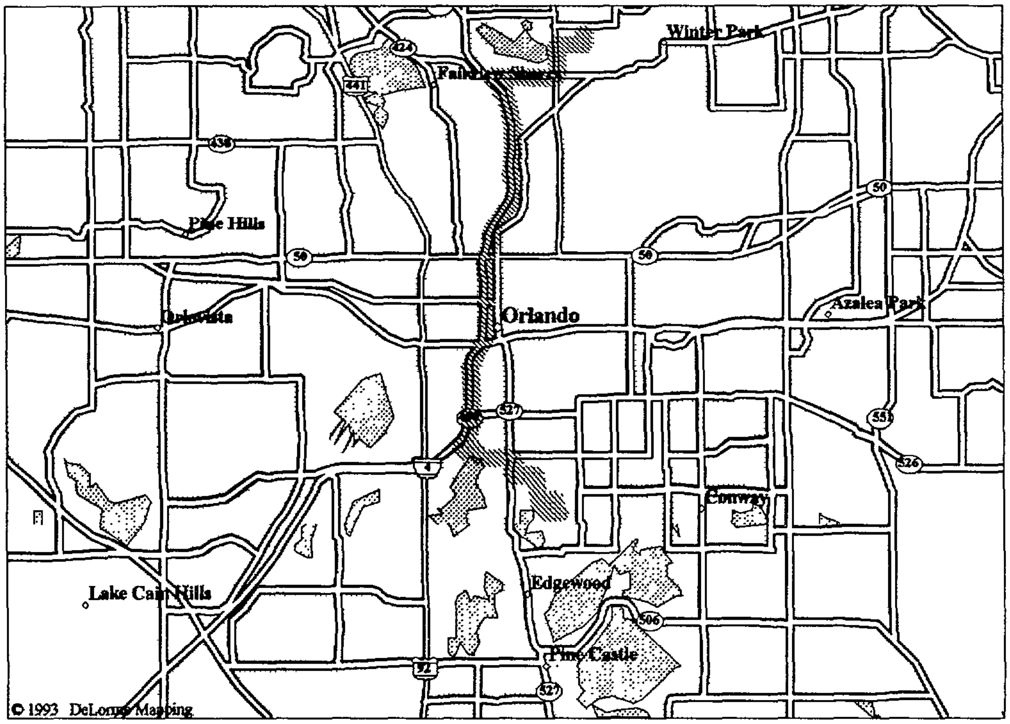

Figure 7. O/D 3 began in a residential neighborhood south of downtown Orlando and ended in a residential neighborhood north of downtown and east of Orlando Avenue.

Drivers

Drivers were recruited at a major Orlando tourist attraction. A TravTek exhibit was setup in a pavilion at the attraction. The exhibit included a working TravTek in-vehicle system simulator embedded in a free-standing Oldsmobile Toronado dashboard. The system was demonstrated and guests were offered an opportunity to "test drive the future." Exhibit guests who expressed an interest were briefed on the nature and requirements of the experiment, and, if they remained interested, were signed up to return for the test drive. Although volunteers were compensated $25 for their participation, compensation was not emphasized during recruitment. Participation in the study required approximately 5 h, and most of the volunteers were vacationers. It is probably safe to assume that the primary motivation for volunteering was the opportunity to drive a prototype vehicle and participate in transportation research. Most of the volunteers participated the day after they were recruited. Recruitment was conducted Sunday through Thursday and testing was conducted Monday through Thursday.

Approximately 222 individuals participated as drivers in the study. Sample sizes for various tests in this report differ slightly because of occasional lapses by research assistants in recording data elements. Rather than exclude all participants with missing data, we have tried to include all usable data. The majority of recruits were visitors to the Orlando area. Familiarity with the Orlando area was assessed as part of the testing procedure, but was not a criterion for participation.

Three tests were used to assess familiarity with Orlando. The first asked the participants to rate "your awareness of Orange County roadways" on a 1 to 6 scale. The anchors for this rating were: (1) "never been to Orlando," and (6) "know as well as a cab driver." Among 191 valid responses, 50 percent (110) participants rated themselves a 1 on the scale. Ninety-three percent (178) rated themselves 3 or less. Three of the 191 respondents rated themselves 6.

A second assessment of how familiar the drivers were with Orlando asked them to name the nearest major cross streets to 8 area landmarks (e.g., Church Street Station, Universal Studios, The Citrus Bowl). Eighty-seven percent of the participants failed to correctly identify any of the intersections. Only two participants were able to identify all eight intersections.

A third assessment asked how long the participant had lived in Orlando. Eighty-seven percent said they had never lived in Orlando.

Because all test origins and destinations were in residential neighborhoods, it was unlikely that general familiarity with the Orlando area would greatly affect performance of the few local residents that participated.

Whereas the yoked procedure controlled for variations in the traffic environment, there was no similar control for differences between drivers in driving style. However, drivers were randomly assigned to the three vehicle configurations with the constraint that the configurations be roughly equated for driver age and gender. Therefore effects due to differences between drivers would be expected to be equally distributed across the three configurations.

MATERIALS AND INSTRUMENTATION

The following sections describe key elements of data collection:

- Pre-tests given to participants before they drove.
- Observer (research assistant) training and the observer logbook.
- The in-vehicle electronic data log.
- The debriefing protocol.
- The TravTek questionnaire.

Pre-Tests

Pre-testing consisted of a visual screening, auditory screening, and the map skill screening battery. Dependent measures generated by these tests were:

- Snellen visual acuity.
  - Left eye.
  - Right eye.
  - Both eyes.
- Pelli-Robson contrast sensitivity.
  - Left eye.
  - Right eye.
  - Both eyes.
- An auditory street name recognition.
- Map skill assessment scores.

The Snellen test is a standard for measurement of fovea1 visual acuity. The Snellen test uses high-contrast letters of varying visual angles. Participants whose Snellen acuity was worse than 20/40 were excluded from driving.

The Pelli-Robson test assesses contrast dependent acuity.(7) Contrast sensitivity varies as a function of age. The contrast sensitivity assessment was included, in part, to provide a means of explaining potential differences in performance or preference as a function of age.

The auditory test required identification of street names recorded from the TravTek vehicle. The subject's task was to listen, through headphones, to a street name and then select that name from a written list of five alternatives. There were 10 recorded street names. This auditory assessment was selected to provide a practical means assessing speech sensitivity specifically for TravTek's synthesized voice. Subjects adjusted the volume according to their own preference.

The map skills screening consisted of two tests from the Kit of Factor-Referenced Cognitive Tests and a self-assessment question.(') The following tests from the Kit of Factor-Referenced tests are administered to participants prior to in-vehicle data collection:

- Building Memory.
- Card Rotation Test.

The Building Memory and Card Rotation tests were selected because (a) they appear related to map skill, (b) they are easily administered and scored, and (c) there is a large body of literature relating performance on these tests to other cognitive and performance measures.

Participants were asked to rate “how good is your sense of direction” on a seven point scale. Kozlowski and Bryant report that the answer to this question is highly correlated with spatial orientation and path finding ability.[9]

Observers

Undergraduate students from the University of Central Florida were employed as research assistants to observe drivers in this study. The observers rode in the front seat and performed the following functions:

- Pre-drive orientation.
- On-road training.
- On-road evaluation of learning.
- Data collection.
- Debriefing.

The pre-drive orientation included an orientation to the Toronado controls and displays, and hands on TravTek route planning instructions.

On-road training included: programming of five destinations; making a wrong turn and pressing OK NEW ROUTE to plan a new route to the destination; and correcting vehicle position with HOP LEFT and HOP RIGHT buttons.

Three tasks were used to evaluate learning of the TravTek system: (1) quizzing drivers’ for understanding of the system; (2) rating drivers’ proficiency in entering destinations; and (3) scoring performance of various TravTek drive functions.

During testing, that is after training, the observers recorded the information about the following:

- Odometer reading at the origin.
- Trip planning start time.
- Trip planning finish time.
- Begin moving trip time.
- Current street name.
- Congestion (Level of service).
- Use of turn signal.
- Turn preparation.
- Turn abruptness.
- Drivers’ subjective workload ratings.

- Near accidents.
- Driver comments.
- Wrong turns.

Further description of what the observers recorded is provided in the *Detailed Test Procedures* and *Results* sections.

In-Vehicle Logs

One of two TravTek onboard computers was used to record performance data. This in-vehicle log recorded events with time and date stamps for all driver interaction with the TravTek interface. Thus every button press, whether on the steering wheel hub or on the TravTek touch screen, was recorded. Much data was recorded in this log and the current description is not intended to be exhaustive. Other in-vehicle log data included:

- All messages received from the Traffic Management Center.
- The identity and travel time for every TravTek traffic link that was traversed.
- Latitudes and longitudes from both the Global Positioning System and the dead reckoning/map matching system (every 15 s).
- Vehicle speed once per second.

Debriefing

Upon completion of the test O/D drivers were debriefed. This debriefing was conducted while returning to the point of embarkation. The purpose of the debriefing was to elicit open ended driver reactions to the TravTek system. A semi-structured interview technique was used to elicit the responses. Probe questions used by the observers are described in the Results section along with a summary of the more frequent driver responses .

Questionnaire

A questionnaire was administered to the drivers after they completed their test drive. To complete the questionnaire, many participants returned to the room where they had been briefed on the TravTek system. Others took the questionnaire with them and returned it in a postage paid envelope. Completed questionnaires were received from 194 Yoked Driver Study participants. A common core set of questionnaire items were used across five TravTek Evaluation studies: the Rental User Study, the Local User Study, the Yoked Driver Study, the Orlando Test Network Study, and the Camera Car Study. Because the testing procedures as well as questionnaires were very similar, questionnaire result presented in this report combine responses from both the Yoked Driver Study and the Orlando Test Network Study.

DETAILED TEST PROCEDURES

The following sections provide a more detailed description of test procedures.

Test Schedule

The test O/D's were driven during the afternoon traffic peak. Typically the test O/D's were begun about 5:30 PM. Testing was conducted Monday through Thursday. Testing was not done on Friday because evening traffic flows on that day vary considerably from the other week days. Drivers' participation began about 3 : 15 PM with a classroom briefing on the TravTek system, test procedures, and safety considerations. The briefing took about 15 min. Subsequent to the briefing, participants took the Building Memory and Card Rotation tests. These tests were followed by the hearing and vision evaluations. After a brief break, participants were transported to the TravTek vehicles where they were given a vehicle orientation. Besides orientation to the TravTek system, the orientation included use of the windshield wipers, headlights, windows, remote mirror controls and electric seat controls.

At approximately 4:30 PM, participants began the on-road training. This training accomplished three goals:

- It allowed the participants to program five destinations with the TravTek system.
- It allowed the researchers to observe all participants plan a trip without benefit of the TravTek system.
- It moved the vehicle from the embarkation point to the origin of the test O/D.

The trip from the embarkation point to the test origin was segmented into six training O/D' s. Route planning for these six O/D's followed the same procedure used for the test O/D. This procedure was to give the driver a card that contained the street names at a destination intersection. The card specified the navigation mode to be used. For training, the modes were:

- Route Map with Voice Guide.
- Route Map without Voice Guide.
- Guidance Display with Voice Guide.
- Guidance Display without Voice Guide.
- Voice Guide without visual display.
- Control (Plan and navigate "the way you normally would without TravTek").

On one training O/D the observer instructed the driver to turn off the planned route. This intentional wrong turn was used as an opportunity to demonstrate what the TravTek system does when the driver makes a wrong turn, and to demonstrate the OK NEW ROUTE feature. When a TravTek vehicle deviated from a TravTek planned route, a voice message announced "You may be off the planned route, if so, press OK NEW ROUTE for a new route." A banner message on the video display also indicated that the vehicle might be off the planned route (see figure 4). The OK NEW ROUTE button was located on the steering wheel hub. Subsequent to an off route indication, pressing OK NEW ROUTE would result in a new route plan that took into account the vehicle's current position.[3]

Also while on a training O/D, the observer demonstrated the function of the HOP LEFT and HOP RIGHT buttons on the steering wheel hub. On relatively rare occasions the TravTek dead reckoning and map matching would locate the vehicle incorrectly. If the TravTek system erroneously showed the vehicle to be on a street that paralleled the one it was on, the hop buttons could be used to reposition the vehicle icon on the Route Map.

During the training O/D's the observers quizzed the drivers on information about the TravTek system. In addition, drivers were asked the to exercise certain TravTek functions, such as turning the Voice Guide on or off, adjusting the Voice Guide volume, and switching between the Route Map and Guidance Display. The questions that were asked and a description of the functions that were exercised is deferred to the Results section.

For the test O/D, the sequence of events was as follows:

- The observer configured the TravTek system to be in the assigned configuration (Navigation Plus, Navigation, or Control).
- The driver was given a card with a destination on it (the names of two intersecting streets).
- The driver planned a route by either:
    - Entering the destination in the TravTek system (Navigation Plus and Navigation).
    - Calling the Help Desk (Control).
    - Using a paper map (Control).[4]

When all yoked drivers had completed trip planning, drivers were instructed to begin their trips at 2-min intervals.

At the origin, the observers recorded:

- The time when the driver was handed the destination card.

---

3 Planning took into account that the vehicle might be moving and planned a route with sufficient lead such that when the route was presented to the driver any required turns would still be ahead.

4 If a paper map was used, the driver was required to give the observer a turn-by-turn description of the intended route. The time required to provide this description to the observer was not included in trip planning time.

- The time that either (a) the TravTek system completed route planning, or (b) the time that the driver said route planning was done (Control configuration).
- The odometer reading.
- The time that the vehicle was put in gear.

En route the observer recorded:

- Subjective workload ratings:
  - Upon beginning the trip.
  - Upon leaving the residential neighborhood.
  - At seven pre-designated latitudes.
  - Upon reaching the destination.
- Each street taken and the time that street was entered.
- All wrong turns.
- Use of turn signals.
- When the driver began preparing to turn.
- Near accidents.
- Abrupt maneuvers.
- Driver comments.

At the destination the observer recorded the time and the odometer reading.

Assignment to Configurations

All drivers were trained to use the TravTek system, and all drivers drove a training O/D in the control condition. However, each driver served in only one test condition. Before they arrived for training, the drivers were randomly assigned to Navigation Plus, Navigation, and Control configurations. The only restriction on random assignment was an attempt to balance age group (25 to 34, 35 to 54, and 55 and older) and gender across the three experimental conditions. Age and gender were noted at the time the participants volunteered.

Six vehicles and six observers were available each test day. Thus it was feasible to conduct two yoked tests in 1 day. However, it often happened that fewer than six participants volunteered or appeared for testing. The following rules were applied to the assignment of drivers to O/D's and configurations:

- If there were more than three drivers, two different O/D's were used.
- For any O/D, if there were three drivers, one driver was assigned to each of the three vehicle configurations (Navigation Plus, Navigation, and Control).
- For any O/D, if there were two drivers, one driver was assigned to the Navigation Plus configuration and one was assigned to Navigation configuration.
- If there was only one driver for an O/D, that driver was assigned to the Navigation Plus configuration.

Because the primary interest of this study was the value of real-time traffic information compared to TravTek without real-time information, the control condition was sacrificed whenever a third driver was not available. When only one driver was available for an O/D, there was nothing to be gained from an experimental perspective. However, the test was conducted because it afforded additional observational experience with real-time information.

Yoked Procedure

The yoked procedure was used to ensure that all three configurations were exposed to the same network environment. Thus three vehicles were tested on the same O/D at the same time of day. However, because the TravTek system is in large part a navigation system, precautions were taken to prevent drivers from following another vehicle in the study. Drivers were instructed not to intentionally follow other TravTek vehicles if they encountered them. However the primary precaution was to dispatch the vehicles from the origin at precise 2-min intervals. The order in which the three configurations departed was balanced across days. Because the vehicles were to leave at 2-min intervals, it was necessary that (a) all drivers complete training O/D's before the test began, and (b) all drivers complete trip planning before the first vehicle left the origin.

RESEARCH DESIGN

Data sources were:

- TravTek in-vehicle log.
- TMC log.
- TISC log.
- Post-experiment debriefs.
- Research assistant (observer) records.
- Training records.
- Pre-Tests and Driver Profiles.

The primary dependent variables were:

- Travel time, including trip planning time and en route time.
- Trip distance.
- Congestion, or level of service.
- Number of accidents.
- Number of close calls (near accidents).
- Maneuver abruptness.
- Subjective Driver Workload.
- Perceived driving performance benefits.
- The amount participants would be willing to pay for a system such as the one they drove.
- The amount participants would be willing to pay for TravTek functions as options on a new car.
- The amount participants would be willing to pay for TravTek functions as add-ons to an existing car.
- The amount participants would be willing to pay for TravTek functions in a rental car.
- Number of trials required to learn.
- Subjective ratings of usability and utility.

For navigation and driving performance measures the primary independent variable was vehicle configuration:

- Navigation Plus.
- Navigation.
- Control.

For questionnaire items and pre-tests results, the following were sometimes treated as independent variables:

- Age group.
- Gender.
- Income.

All independent variables were assessed as between group variables.

RESULTS

In the introduction, four issues were defined:

1. Does the availability of real-time traffic information and electronic navigation assistance improve trip efficiency?
2. Does the availability of real-time traffic information and electronic navigation assistance improve overall driver performance?
3. What are drivers willing to pay for TravTek features and functions?
4. Is the TravTek system usable and useful?

These issues are examined sequentially. However some measures of performance associated with a later issue may have implications for interpretation of measures of performance examined earlier. For instance, for the trip efficiency issue, travel time is the central measure of performance. Yet driver performance, in particular wrong turns, can be expected to influence travel time. Trip efficiency results are presented for travel time with issue one, whereas wrong turn data are presented with issue two. Because measures of performance for one issue may be important to the interpretation of other issues, some measures of performance are discussed with more than one issue. The discussion section is intended to integrate the findings across issues and measures of performance.

Issue: Does the Availability of Real-Time Traffic Information and Electronic Navigation Assistance Improve Trip Efficiency?

Two sources of data address measured trip efficiency: logs kept by the research assistants (observers) and the in-vehicle data log. Measures of performance from observer logs are:

- Travel time, including trip planning time and en route time.
- Trip distance
- Congestion, or level of service.

The in-vehicle log measure of performance for trip efficiency is congestion, or level of service, as defined by vehicle speed with respect to road class.

Observer Log Findings

Trip efficiency can be defined in many different ways, not all of which are independent. For instance, the fastest route may not be the shortest in terms of distance. Similarly the fastest route between an origin and destination may not be the least congested. Because the TravTek system was designed to minimize travel time, the travel time measure is addressed first.

Travel Time

When traveling to unfamiliar destinations, planning time is an important but easily overlooked component of total trip time. Therefore we examine the effect of using the TravTek system on both planning time and time en route.

Planning Time. There were 203 drivers with valid trip planning times.’ Of these, 82 were in Navigation Plus mode, 75 in Navigation mode, and 46 were in Services mode. Mean planning time is shown as a function of vehicle mode in figure 8. The effect of vehicle mode on planning time was significant, $F(2,200) = 116.98, p < .001$. As can be seen, planning time for drivers in the Control condition was considerably longer than for those in either of the TravTek planning modes.

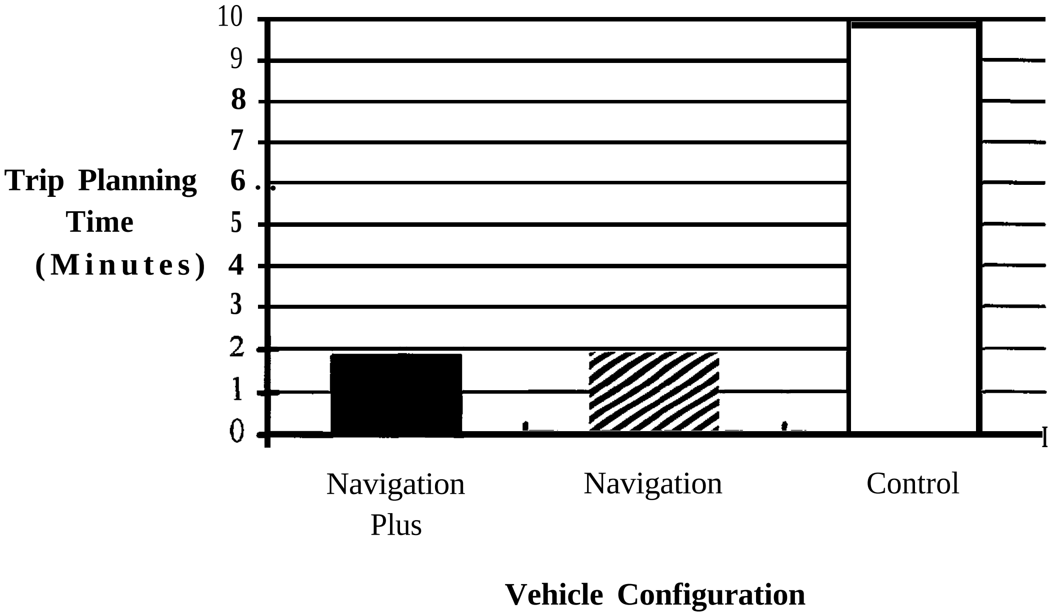

Figure 8. Trip planning time as a function of vehicle configuration.

En Route Time. It should be noted that en route time is only listed for drivers who completed their planned trips. For all three configurations there was a subset of drivers who failed to complete the trip for one reason or another. Some became hopelessly lost, whereas others simply expressed a desire to quit. Because the number of drivers who failed to finish the drive between origin and destination was small, and because some of the records are vague as to why the drivers failed to finish, we have not analyzed the reasons for failure to complete. Table 5 shows the percentage of drivers who completed

5 Most of the invalid planning times were missing because the observer failed to record a time. In a few cases the recorded times could not be deciphered.

their O/D. There is a trend for drivers in the Control configuration to finish less often. However, this trend is not statistically reliable.

Table 5. Number of drivers that completed O/D's as a function of vehicle configuration.

Configuration	*Started*	*Finished*	*Percentage that Finished*
Navigation Plus	85	83	97.6%
Navigation	78	77	98.7%
Control	51	45	88.2%
Total	214	*205*	*95.8%*

Figure 2 shows the travel time findings for all yoked triads that completed trips. A triad is defined as three vehicles that completed the same O/D on the same afternoon with one vehicle in the Navigation Plus configuration, one vehicle in the Navigation configuration, and one in the Control configuration. A total of 36 yoked triads (108 drivers) completed trips. There were 15, 8 and 13 triads on O/D's 1, 2 and 3 respectively.

Table 6 shows the analysis of variance summary table for the analysis of en route travel times as a function of vehicle configuration and O/D pair. There was a significant O/D by configuration interaction that makes interpretation of the main effects of O/D pair and configuration problematic. Post hoc analyses with the Scheffe method were used to clarify the interaction. The Navigation Plus configuration on O/D 2 had significantly shorter travel times than (1) the Control configuration on all O/D's, and (2) the Navigation configuration on O/D 1. The Navigation drivers on O/D 2 also had a significantly shorter travel time than the Control configuration on O/D's 2 and 3. In this analysis, the results are consistent with a travel time benefit with route guidance, but no reduction in travel time was observed with the availability of real-time traffic information.

Table 6. Analysis of variance summary table for travel time of all triads.

Source of Variation	*SS*	*df*	*MS*	*F*	*p* <
O/D Pair	.28	2	.14	15.78	.001
Configuration	.14	2	.07	7.68	.001
O/D by Configuration	.21	4	.05	5.95	.001
Error	.88	99	.01		
R^2 = 0.390					

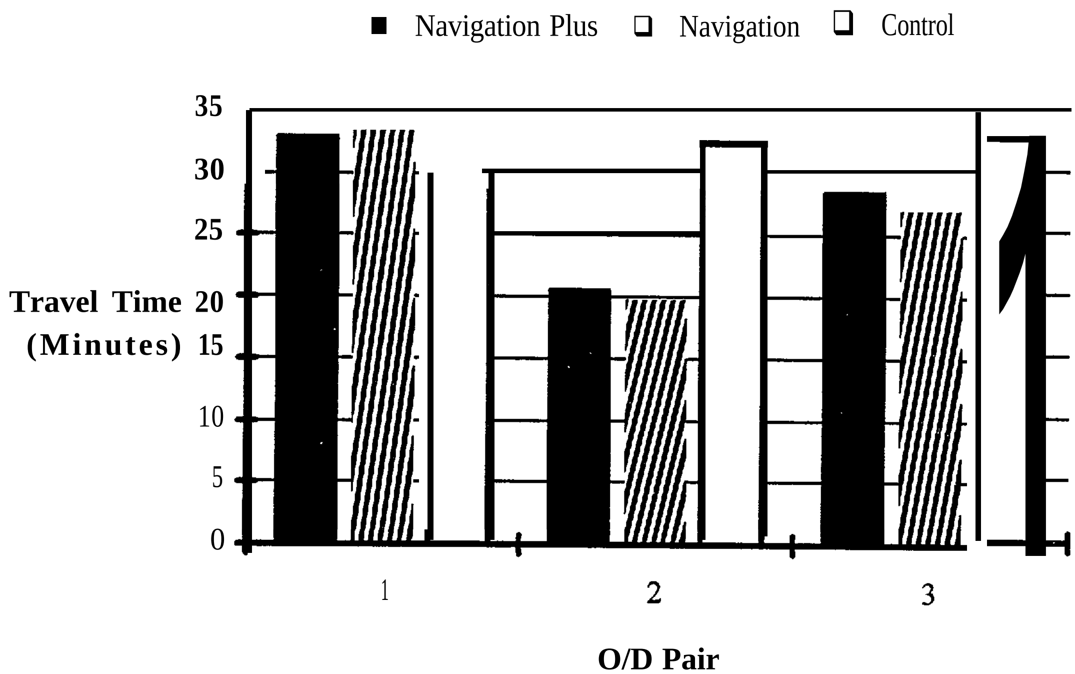

Figure 9. Travel time as a function of vehicle configuration and O/D.

The above findings are based on 37 triads. On those days when yoked triads could not be filled, yoked dyads were tested. Dyads consisted of Navigation Plus and Navigation configuration pairs. There were 67 of these dyads (134 drivers). Note that these dyads include drivers from the triads reported above in addition to drivers for whom there was no yoked Control configuration. Figure 10 shows the travel times for the 67 dyads.

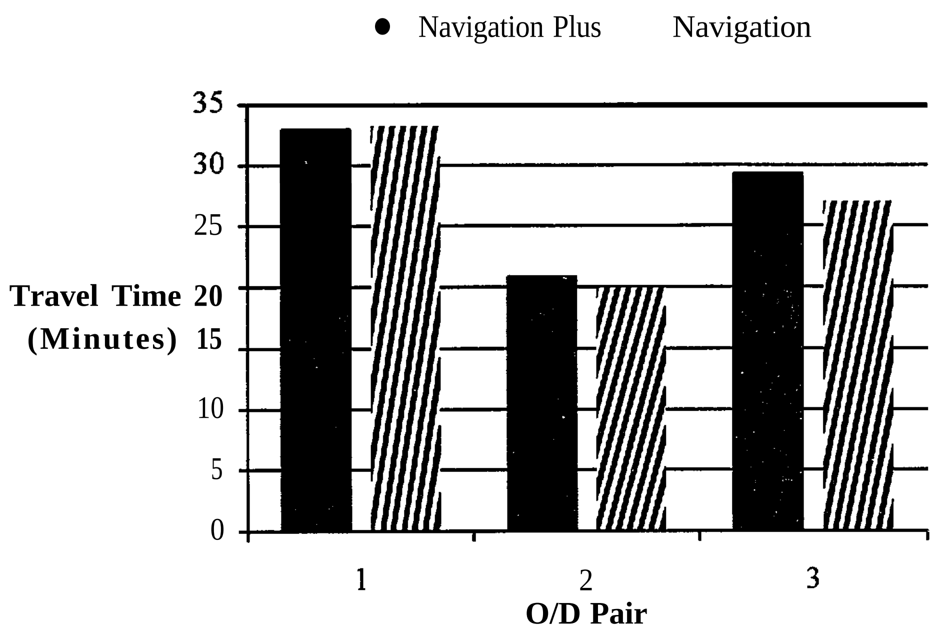

Figure 10. Travel times for yoked dyads.

As shown in table 7, there is no effect of real-time traffic information using the data for the 67 dyads. There is a significant main effect of O/D: the three O/D's are not equivalent with respect to travel time.

Table 7. Analysis of variance source table for travel time of yoked Navigation Plus and Navigation drivers.

Source of Variation	*SS*	*df*	*MS*	*F*	*p<*
O/D	0.95	2	0.48	84.25	0.000
Configuration	0.01	1	0.01	1.77	0.186
O/D by Configuration	0.01	2	0.00	0.79	0.457
Error	0.72	128	0.01		
$R^2 = 0.573$					

Some Navigation Plus cars selected the same route as the Navigation vehicles. For Navigation Plus and Navigation vehicles that take same route, no travel time difference is expected. If Navigation Plus is to yield a travel time benefit, that benefit is expected when the real-time information results in a route different from that taken by the Navigation vehicles. Therefore, travel times were compared for only those dyads for which, because of real-time information, the Navigation Plus driver was provided a different route. There were 50 yoked pairs (100 drivers) where the Navigation Plus member of the pair followed a planned route that was different from the route planned for the Navigation configuration. The travel time results for these pairs were nearly identical to those shown in figure 10. There was no significant difference in travel times between Navigation Plus and Navigation configurations.

However, not all Navigation and Navigation Plus drivers followed the route planned by the TravTek system. Some made wrong turns. Wrong turns are examined more extensively under the driving performance issue. Here we report a comparison of Navigation Plus versus Navigation pairs where neither driver made a wrong turn and the Navigation Plus driver was given a different route. There were 38 yoked pairs for which neither driver made a wrong turn and for which the Navigation Plus driver received a different route. Again, there was no significant travel time difference between Navigation Plus and navigation, Figure 11 shows the average travel times for yoked pairs that had no wrong turns and for which the Navigation Plus vehicle planned a different route.

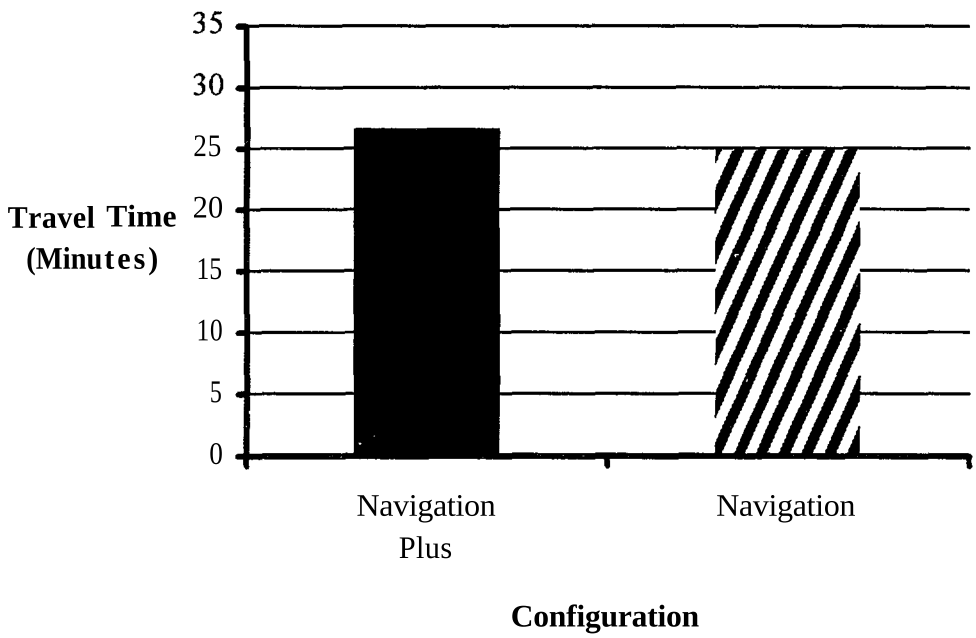

Figure 11. Travel times for all Navigation Plus and Navigation yoked pairs that made no wrong turns and for which the Navigation Plus configuration received a different route.

No travel time benefit from real-time traffic information was observed. Interpretation of this finding is left for the discussion session. However, it is appropriate to caution that these findings apply not to the value of real-time traffic information per se. Rather, these findings apply to the value of the information that was available (a) during this test, (b) to vehicles equipped with the TravTek software, (c) on O/D's similar to those used in this test, and (d) for vehicles driven largely by tourists. Better traffic information, different route planning software, tests on a network with qualitatively different alternative routes, or with locally familiar drivers could yield different results.

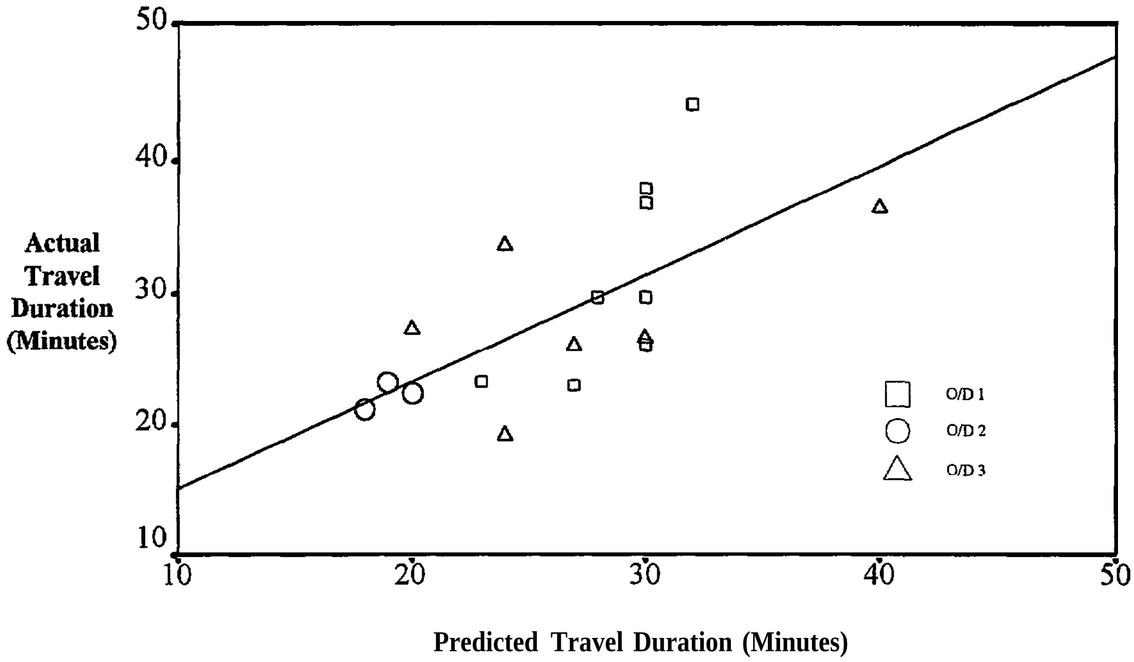

Figure 13. Predicted and actual travel times for Navigation Plus vehicles that were given a different route.

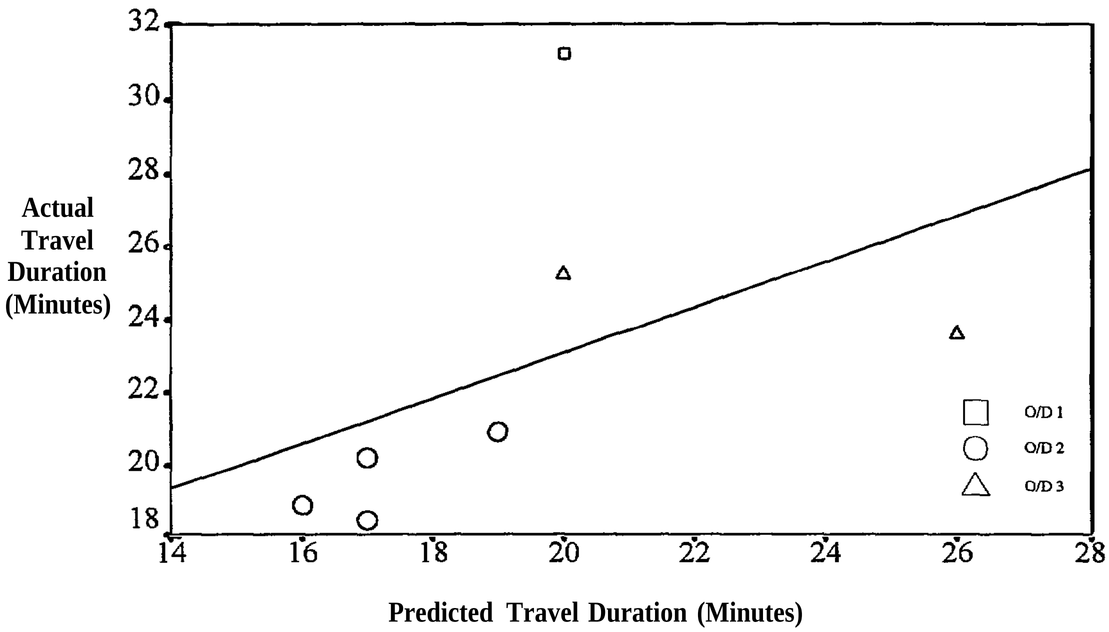

Figure 14. Predicted and actual travel times for Navigation Plus vehicles that were given the same route as Navigation vehicles.

Planning Efficiency

Travel times were only analyzed for drivers that completed the trip: For drivers who did not reach the destination (n = 12) travel time is undefined. The proportion of trips completed did not vary as a function of vehicle mode, X^2 (2) = 0.50. It appears that the present findings are not the result of fewer drivers completing trips in one vehicle configuration than in others.

Travel Distance

Whereas TravTek was designed to optimize travel time, another definition of an efficient trip is one that minimizes the travel distance. Figure 15 shows trip distance as a function of O/D pair and vehicle configuration for all Navigation Plus, Navigation and Control triads with completed trips. There were 28 such triads (84 drivers) with data available for this analysis.

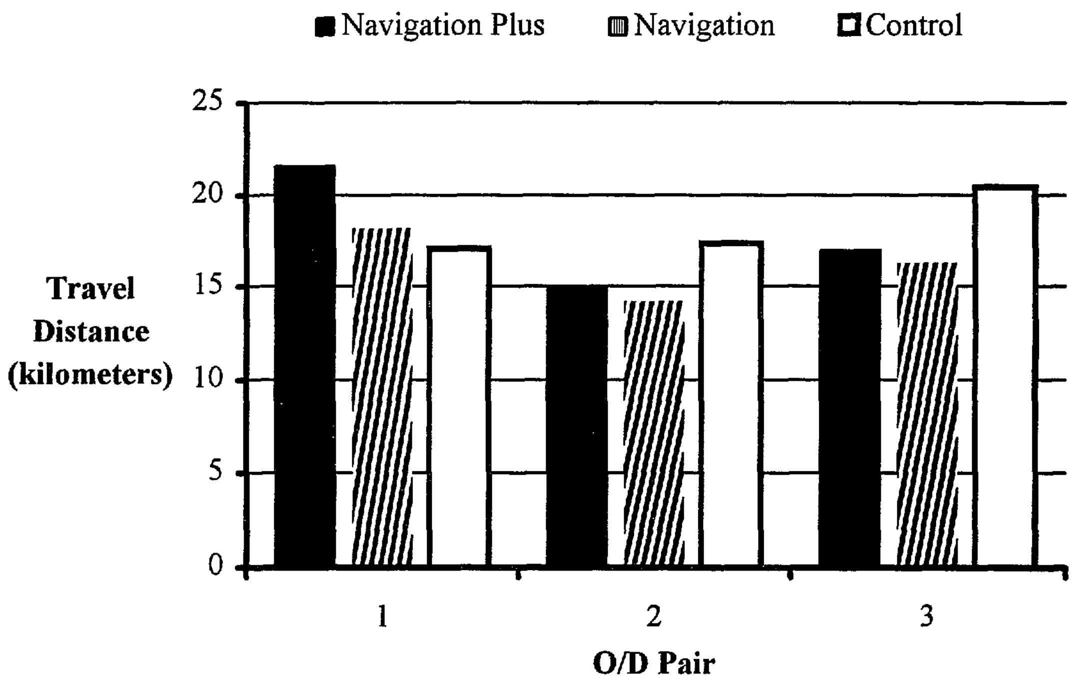

Figure 15. Travel distance for all yoked triads with complete trips.

As shown in table 8, the main effects of configuration and O/D, and their interaction, were statistically significant. The post hoc tests showed that on O/D 1 the Navigation Plus configuration traveled significantly farther than Navigation and Control configurations. On O/D's 2 and 3, the Control configuration traveled significantly farther than the TravTek configurations.

Table 8. Analysis of variance source table for travel distance of all yoked triads that completed their trips.

Source of Variation	*SS*	*df*	*MS*	*F*	*p* <
O/D	0.11	2	0.05	10.02	0.001
Configuration	0.04	2	0.02	4.06	0.021
O/D by Configuration	0.10	4	0.02	4.51	0.003
Error	0.40	75	0.01		
$R^2 = 0.383$					
Adjusted $R^2 = 0.317$					

Figure 16 shows the travel distance for all yoked dyads of Navigation Plus and Navigation drivers with completed trips. This analysis included 62 yoked dyads (124 drivers) with almost equal distribution across O/D's (19, 20 and 23 dyads, respectively). Note that these dyads include drivers from the above analysis of triads and additional dyads for whom there were no yoked Control configurations. The interaction between O/D and vehicle configuration was significant, $F(2, 118) = 6.44, p < 0.01$. The interaction is the result of travel distances for O/D 1 exceeding those for O/D's 2 and 3.

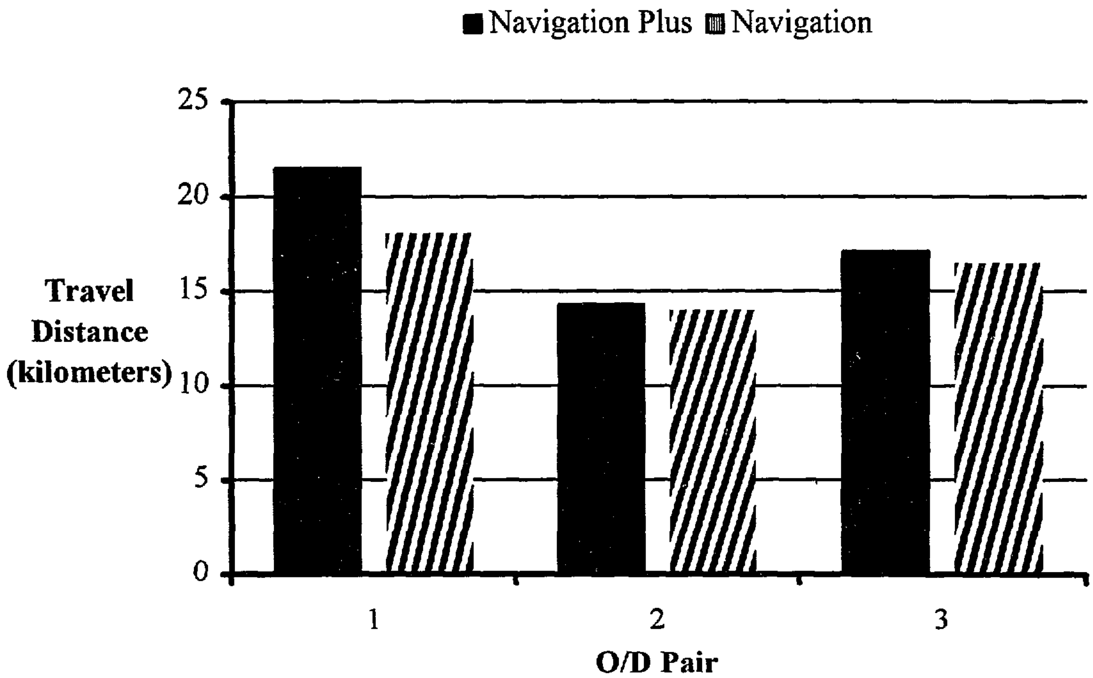

Figure 16. Travel distance for all yoked pairs of Navigation Plus and Navigation drivers that completed their trips.

Figure 17 shows the travel distance findings for only dyads for which (a) the Navigation Plus vehicle took a different route, and (b) no driver made a wrong turn. Only 13 dyads met these criteria. Only the O/D effect was significant.

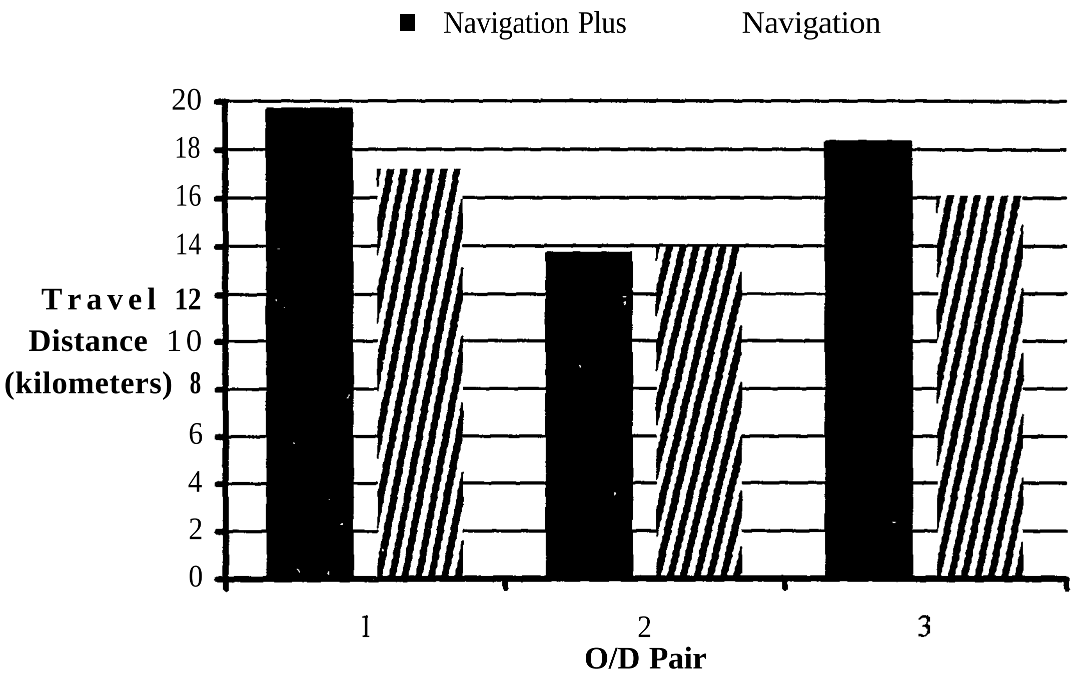

Figure 17. Travel distance for all Navigation Plus/Navigation dyads where the Navigation Plus configuration planned a different route, and no driver made a wrong turn.

Congestion Levels Encountered

For each driver, the observer's ratings of congestion were averaged over road class. Four road classes were defined:

- Limited access.
- Arterials (included principal arterials and collectors).
- Local Roads.
- Ramps.

Congestion was coded as:

1 = Low.

2 = Moderate.

3 = High.

Thus an average congestion level of 1.5 would be midway between low and moderate congestion, Table 9 shows the mean congestion level ratings across all road classes. Note that the sample sizes vary widely because not all drivers used all road classes. In particular, Navigation Plus drivers who took alternative routes frequently avoided the freeway and thus limited access roadways and ramps.

Table 9. Overall congestion rating summaries.

	Limited Access	*Arterials*	*Locals*	*Ramps*
Mean Rating	2.13	1.40	1.06	1.21
Standard Error	0.05	0.03	0.01	0.03
Sample Size	181	218	218	185

Because the Navigation Plus vehicles select routes with the shortest travel time, and because congestion tends to increase travel time, it was expected that, on average, the Navigation Plus vehicles would encounter lower levels of congestion than the Navigation and Control vehicles. To characterize congestion encountered over an entire trip, mean *weighted* congestion rating across limited access roads, arterials, and ramps was computed.[6] Because there was virtually no congestion encountered on local roads, and because local roads did not account for a major portion of most trips, local road ratings were not included in the mean.

No significant differences between configurations were detected either as a function of O/D's or congestion, $F < 1.0$. However, the sample size for this analysis was small: 22 triads. When considering only Navigation Plus and Navigation pairs, where the Navigation Plus member of the pair took an alternative route, the sample size is 45 pairs. For these dyads, a trend towards Navigation Plus encountering less congestion begins to become apparent, $F(1, 84) = 3.08, p < 0.10$.

Although distance on ramps was small, a congestion rating was always recorded for ramps, thus giving them greater weight than their contribution to travel time warrants. Furthermore, there was little congestion on the ramps and the Navigation vehicles were more likely than Navigation Plus vehicles to traverse ramps.' Therefore it is appropriate to compare Navigation Plus and Navigation configurations only for arterial and limited access roads. With average congestion based only on ratings for arterials and limited access roadways, the difference between Navigation Plus and Navigation is statistically significant, $F(1, 84) = 4.61, p < 0.05$. This effect accounted for 4 percent of the total variance. Again, this analysis included only Navigation Plus and Navigation pairs where the Navigation Plus member of the pair took an alternative route. Table 10 shows the

6 A weighted mean takes into account the sample size of the component means. Thus if the if the mean for 5 arterial ratings was 2 and the mean for 2 limited access ratings was 2.5, the weighted mean would be ((5 * 2) + (2 * 2.5))/(5 +2)

7 Orlando does not use ramp metering.

mean congestion ratings as a function of vehicle configuration for the three analyses discussed here.

Table 10. Mean congestion ratings recorded by observers as a function of vehicle configuration.

	Navigation Plus	*Navigation*	*Control*
Triads (n = 22)	1.62	1.76	1.69
Dyads on Limited Access, Arterials and Ramps (n = 45)	1.49	1.59	—
Dyads on Limited Access and Arterials (n = 45)	1.59	1.77	—

In summary, whereas no travel time benefit was observed with the addition of real-time traffic information, there is converging evidence that use of real-time information has the potential for travel time saving. Given that when taking alternative routes the Navigation Plus vehicles may travel farther, and, or, on lower class roadways, it is revealing that Navigation Plus travel times were not significantly longer than Navigation travel times.

In-Vehicle Log Findings

The research assistants were trained to rate congestion according to level of service guidelines provided in the Transportation Research Board's *Highway Capacity Manual.*[(3)] However, those guidelines require subjective judgments on the part of the rater: with more than 20 raters, none of whom were professional traffic engineers, considerable variability in observer calibration can be expected. Resources did not permit formal measurement of inter-rater reliability.

Whereas the observers logged congestion as they perceived it, the in-vehicle log recorded vehicle speed. On uncongested roads the average vehicle is expected to maintain a speed that approximates the posted speed limit. When roads become congested, average speed decreases. A second measure of congestion (one that does not rely on human observation) was defined as speed less than 75 percent of the posted speed. To prevent a bias against arterials, where vehicles can be expected to slow or stop for traffic control signals, the drop below 75 percent of the posted speed was required to exceed 90 s. Ninety seconds was selected as a representative cycle time for signalized intersections.

Vehicle speeds were logged once per second. The in-vehicle software calculated speed based on a count of wheel rotations per unit of time. The time unit depended on a computer interrupt that was somewhat variable. Therefore, whereas individual l-s speed estimates contained large error, averages over 16 s were quite accurate.' For each 16-s in

8 This accuracy was assessed by measurements taken in the Camera Car Study from which highly accurate speed measures were obtained at a 10 Hz sampling rate. Trimmed

terval, a 25-percent trimmed mean was computed. [9] For limited access, arterial, and local road classes, the speed limits were assumed to be 89, 56, and 48 km/h, respectively. If the speed of the vehicle on the current road segment was below 75-percent of the assumed speed limit for a period of more than of 90 s, then each 16-s interval within the period was scored as congested. A one was recorded for each 16-s interval for which the congestion criterion was met, otherwise a zero was recorded.

Congestion averages for each driver were calculated for limited access and arterial roadways. Local roads and ramps were excluded from this analysis because they had very little congestion and did not account for a major portion of the trips. Table 11 shows the mean congestion level by vehicle configuration (that is, the average of the zeros and ones for each driver).

Table 11. Overall congestion level by vehicle configuration.

	Navigation Plus	*Navigation*	*Control*
Mean	.370	.417	.406
Standard Error	,036	.035	.039
Sample Size	42	47	25

Sample size varies in table 11 because the data are for all drivers for whom in-vehicle log data was available: the sample does not exclude data from incomplete yoked triads or dyads. There are no statistically reliable differences in congestion in table 11. However, the trends in table 11 (Navigation Plus encountering the least congestion and Navigation encountering the most congestion) are similar to the results from observers ratings shown in table 10.

For the 114 drivers represented in table 11, distance traveled was calculated for each road class. Table 12 shows the mean distance traveled by configuration and road class.

Table 12. Mean distance traveled by vehicle configuration and road class.

	Navigation Plus	*Navigation*	*Control*
Limited Access	6.02 km	6.50 km	5.02 km
Arterial	7.87 km	6.26 km	8.77 km

---

mean speeds calculated from the in-vehicle log produced a 0.99 correlation with the more accurate camera car measures that did not depend on counts of wheel rotations.

9 Twenty-five percent represents 4 of the 16 values. The four highest and four lowest speed values for every 16-s interval were dropped from computation of the mean. Thus the speed estimates for every 16-s interval are based on the eight speed samples that remain after extreme values are dropped.

A significant road class by configuration interaction was obtained $F(2, 222) = 6.13$, $p < 0.01$. Post hoc tests showed that the Control and Navigation Plus configurations traveled significantly farther on arterials than on limited access roads. Navigation vehicles did not show a statistically reliable difference between distance traveled on arterials and limited access roads.

The above tables show the data for all drivers, including those who lacked one or both yoked companions. To compare the three vehicle configurations when they were subject to the same network conditions, in-vehicle congestion and travel distance were examined for only yoked triads where: (1) all three configurations completed the same origin-destination pair on the same day, and (2) in-vehicle log data were available. A total of 14 triads was obtained.

Again, there were no significant differences in congestion encountered among the three vehicle configurations $F(2, 39) = 0.35$. A significant road class by vehicle configuration interaction was obtained, $F(2, 78) = 7.78$, $p < 0.001$. This interaction can be seen in table 13 where Control vehicles show a marked preference for arterials, whereas the Navigation Plus and Navigation configurations traveled about an equal distance on the limited access and arterials.

Table 13. Mean distance traveled by vehicle configuration and road class for yoked triads.

	Navigation Plus	*Navigation*	*Control*
Limited Access	7.41 km	6.36 km	3.80 km
Arterial	7.05 km	6.30 km	9.18 km

Because congestion would be expected to be the same for Navigation Plus and Navigation vehicles that take the same route, congestion encountered by dyads where the Navigation Plus member took a different route was examined. There were 22 yoked dyads (44 drivers) for which (a) in-vehicle data were available, and (b) the Navigation Plus vehicle planned a different route. Table 14 shows the mean congestion level by configuration for the 22 dyads. In this case a trend for the Navigation Plus vehicle to encounter less congestion is seen, $F(1, 42) = 3.93$, $p < 0.10$. This trend is similar to that found with the observers' ratings of congestion.

Table 14. Mean congestion level by vehicle configuration for 22 yoked dyads.

	Navigation Plus	*Navigation*
Mean	.321	.461
Standard Error	,051	.049
Sample Size	22	22

Table 15 shows the mean travel distance, as recorded in the in-vehicle log, by configuration and road class for yoked dyads. In those cases where the Navigation Plus vehicle planned a route different from that taken by the Navigation configuration, there is a trend for the Navigation Plus vehicle to travel farther, $F(1, 84) = 3.52$, $p < 0.10$.

Table 15. Mean distance traveled by vehicle configuration and road class for 22 yoked dyads.

	Navigation Plus	*Navigation*
Limited Access	7.07 km	6.21 km
Arterial	8.21 km	6.58 km

The observer data and in-vehicle log data provide corroborating evidence that the Navigation Plus configuration vehicles traveled farther and encountered less congestion than the Navigation vehicles.

Issue: Does the Availability of Real-Time Traffic Information and Electronic Navigation Assistance Improve Overall Driver Performance?

Measures of performance used to examine the effect of real-time traffic information, navigation planning, and route guidance on driver performance are:

- Accidents.
- Close Calls (near accidents).
- Maneuver abruptness.
- Subjective Driver Workload.
- Perceived driving performance benefits.

Accidents

There were no traffic accidents that involved any Yoked Driver Study participants. Given that Yoked Driver Study participants logged fewer than 16 000 km, this finding is not particularly revealing. It does suggest that no aspect of the TravTek in-vehicle system is inherently unsafe. It does not suggest whether the TravTek system results in a vehicle that is less safe or more safe than comparable vehicles without the system.

Close Calls

Whereas there were no accidents involving Yoked Driver Study participants, there were occurrences that the observers logged as near accidents or “close calls.” Overall, the observers recorded 14 close call that involved 10 Yoked Driver Study participants. Table 16 provides a breakdown of the close call data. Whereas the number of close calls is too small to support any statistical analysis, there is a trend toward a greater number of close calls in the Control condition. This trend is consistent with a contribution of the TravTek guidance displays to safety, but should not be interpreted as demonstrating such a contribution. The close call rate may have been influenced by the fact that the drivers were largely tourists who drove on unfamiliar roads while navigating to hard to fmd destinations .

Table 16. Close-call or near-miss statistics as a function of vehicle configuration.

	Navigation Plus	*Navigation*	*Control*	*Total*
Number of Drivers	90	79	53	222
Number of Close Calls	5	5	5	15
Drivers Contributing Close Calls	3	3	4	10
Proportion of Drivers within Configuration that Contributed One or more Close Calls	0.033	0.038	0.075	

Maneuver Abruptness

The observers recorded three measures that relate to drivers' preparedness to change lanes or turn. These measures were:

- Abrupt turns.
- In turn lane early or late.
- Turn signals early or late.

For these variables the observers were instructed not to rate a driver's performance per se. Rather, they were asked to rate actions; (1) relative to how the driver normally performs, and (2) with respect to whether, in the observer's opinion, that action was related to the driver's navigational awareness. Maneuvers that might fit the above criteria included: turning suddenly and without warning, turning at higher than usual speed, or veering across several lanes of traffic in order to stay on the planned route. Similarly, for signal use or preparing to turn, the action was not rated on an absolute scale. Rather, these were rated (1) relative to how the driver normally performed each action, and (2) whether a deviation from the norm appeared related to navigation.

The observers rated each turn as abrupt or not abrupt. Turn-signal use and turn-lane entry were recorded as either early, normal, late, or none. If there was not an appropriate turn lane (either right lane, left lane, or a painted turn bay), turn-lane entry was recorded as none. If the driver did not use their turn signal, the observer recorded "none."

Table 17 provides a breakdown of trips where the trip is classified as *Normal* if no abrupt turns were noted. It does not include trips with early or late turn signal use, or early or late entry into a turn lane. It can be seen that abrupt maneuvers were recorded on about 20-percent of all trips and that this did not vary with vehicle configuration.

Table 17. Incidence of trips on which at least one abrupt turn was recorded.

	Vehicle Configuration			
	Navigation Plus	**Navigation**	**Control**	**Total**
Normal	**69 (80%)**	61 (78%)	37 (80%)	167 (80%)
Abrupt	17 (20%)	17 (22%)	9 (20%)	43 (20%)
Total	86	78	46	210

Table 18 shows the incidence of abrupt turns comparing only Navigation Plus and Navigation configurations where the Navigation Plus vehicle took a different route. The trend towards the Navigation Plus vehicles experiencing fewer trips with abrupt turns is not statistically reliable, $p > 0.10$.

Table 18. The incidences of trips with one or more abrupt turns when the Navigation Plus vehicle selected an alternative route.

	Vehicle Configuration		
	Navigation Plus	**Navigation**	**Total**
Normal	44 (83%)	37 (70%)	81 (76%)
Abrupt	9 (17%)	16 (30%)	25 (24%)
Total	53	53	106

To further explore unanticipated maneuvers, a composite variable was created that is the sum of abrupt turns, early and late turn signal application, and early and late turn lane entry. Table 19 shows the distribution of the composite variable as a count of the number of trips for which the sum was zero, one, or greater than one. As with abrupt turns, the frequency of all abrupt maneuvers does not appear to be related to vehicle configuration. Because Navigation Plus vehicles tend to be routed on longer trips, or trips on lower class roads, it is desirable check to whether this routing might affect driving performance. Therefore, the composite variable was examined for dyads where the Navigation Plus configuration took an alternative route. The results of this comparison are shown in table 20. Difference between Navigation Plus and Navigation configurations in number of abrupt maneuvers is not statistically reliable.

Table 19. The frequency of trips with abrupt maneuvers.

	Vehicle Configuration			
	Navigation Plus	**Navigation**	**Control**	**Total**
Normal	35 (41%)	29 (37%)	14 (3 0%)	78 (37%)
One Abrupt Maneuver	13 (15%)	10 (13%)	9 (20%)	32 (15%)
More than One Abrupt Maneuver	38 (44%)	39 (50%)	23 (50%)	100 (48%)
Total	86 (100%)	78 (l00%)	46 (100%)	210 (100%)

Table 20. Frequency of trips with abrupt maneuvers by Navigation Plus and Navigation pairs for trips when the Navigation Plus configuration took an alternative route.

	Vehicle Configuration		
	Navigation Plus	**Navigation**	**Total**
Normal	25 (48%)	18 (34%)	43 (41%)
One Abrupt Maneuver	5 (09%)	6 (11%)	11 (10%)
More than One Abrupt Maneuver	23 (43%)	29 (55%)	52 (49%)
Total	53 (100%)	53 (100%)	106 (100%)

Wrong Turns

To this point in the analysis, wrong turns have been considered a confounding variable. That is, when examining the effect of real-time traffic information on travel time, drivers who made wrong turns were screened out to ensure that ability to follow the navigation plan was not influencing the result. However, wrong turns are, of themselves of interest. If, as a result of real-time information, Navigation Plus vehicles are routed on arterials rather than limited access roadways, the opportunity for making navigational errors increases. The increase is because the number of intersections encountered is greater on arterials. Here we examine the effect of vehicle configuration on the number of navigational errors, i.e., wrong turns.

Only drivers who finished the test O/D were included in the wrong turn analysis. Table 21 shows the number of drivers from yoked triads who made wrong turns. Among the triads, there are no statistically reliable trends that indicate differences in probabilities of wrong turns as a function of configuration.

Table 21. Number of drivers who made wrong turns as a function of vehicle configuration (yoked triads).

Configuration	***Number of Wrong Turns by Individual Driver***							***Total***	***Number of Drivers***	***Percentage of Drivers***
	0	***1***	***2***	***3***	***4***	***5***	***6***			
Navigation Plus	24	11	0	3	0	0	1	26	15	38.5%
Navigation	24	10	4	0	1	0	0	22	15	38.5%
Control	23	10	3	1	1	0	1	29	16	41.0%
Total	71	31	7	4	2	0	2	77	46	39.3%

For Navigation Plus/Navigation dyads, table 22 shows the number of drivers who made wrong turns as a function of configuration. Although the Navigational Plus configuration drivers made more wrong turns than the drivers in the Navigation configuration, this trend is not statistically reliable.

Table 22. Number of drivers who made wrong turns as a function of vehicle configuration (yoked dyads).

Configuration	***Number of Wrong Turns by Individual Driver***							***Total***	***Number of Drivers***	***Percentage of Drivers***
	0	1	2	3	4	5	6			
Navigation Plus	42	21	2	3	1	1	1	49	29	40.8%
Navigation	48	13	7	1	1	1	0	39	23	32.4%
Total	90	34	9	4	2	2	1	88	52	36.6%

Table 22 shows wrong turn frequencies for all Navigation Plus and Navigation dyads. However, a difference in wrong turn frequency between these two configurations would only be expected, if at all, when the Navigation Plus configuration planned a different route. Table 23 shows the number of wrong turns for those dyads for which the Navigation Plus vehicle planned a different route. The number of drivers making two or more wrong turns has been collapsed into one category. For the relationships shown in table 23, there is no statistically reliable difference in frequency of wrong turns as a function of vehicle configuration.

Table 23. Number of drivers in each wrong turn classification for dyads where the Navigation Plus driver received an alternative route.

Configuration	*0 Wrong Turns*	*I Wrong Turn*	*> I Wrong Turn*
Navigation Plus	22	16	7
Navigation	28	9	8
Total	50	25	15

The probability of making a wrong turn was not independent of the O/D pair driven. In table 24 it can be seen that, disregarding vehicle configuration, drivers were more likely to make wrong turns on O/D's 1 and 3 than on O/D 2. It does not appear that this trend is independent of vehicle configuration. In table 25, it can be seen that the control drivers were most likely to make wrong turns on O/D 2, whereas Navigation Plus and Navigation drivers were more likely to make wrong turns on O/D's 1 and 3.

Table 24. Number of drivers who made wrong turns as a function of O/D (yoked triads).

OD	***Number of Wrong Turns by Individual Driver***							***Total***	***Number of Drivers***	***Percentage of Drivers***
	0	*1*	*2*	*3*	*4*	*5*	*6*			
1	27	14	4	2	1	0	1	38	22	44.9
2	22	5	1	0	0	0	1	13	7	24.1
3	22	12	2	2	1	0	0	26	17	43.6
Total	71	31	7	4	2	0	2	77	46	39.3

Table 25. Percentage of drivers in yoked triads who made at least one wrong turn. [10]

Vehicle Configuration	*O/D*		
	1	**2**	**3**
Navigation Plus	56%	10%	38%
Navigation	*50%*	*10%*	*46%*
Control	*29%*	*56%*	*46%*

Table 26 shows the number of wrong turns as a function of O/D for Navigation Plus and Navigation Dyads. Here it can be seen that TravTek drivers were most likely to make wrong turns on O/D 1.

10 The percentages apply to rows. For instance, 56 percent of Navigation Plus drivers made at least one wrong turn on O/D 1 while only 10 percent of Navigation Plus drivers made at least one wrong turn on O/D 2. The percentages do not add to 100 because the percentages apply to the total number of drivers in the configuration per O/D. Thus for each cell in the table the possible range of values is 0 to 100 percent.

Table 26 shows the number of wrong turns as a function of O/D for Navigation Plus and Navigation Dyads. Here it can be seen that TravTek drivers were most likely to make wrong turns on O/D 1.

Table 26. Number of drivers who made wrong turns as a function of O/D (yoked dyads).

OD	*Number of Wrong Turns by Individual Driver*							*Total*	*Number of Drivers*	*Percentage of Drivers*
	0	*1*	*2*	*3*	*4*	*5*	*6*			
1	20	16	6	3	2	2	1	61	30	60.0
2	38	3	1	0	0	0	0	5	4	9.5
3	32	15	2	1	0	0	0	22	18	36.0
Total	90	34	9	4	2	2	1	88	52	36.6

The nature of wrong turns. To provide an indication of why drivers made wrong turns, the actions that resulted in the wrong turns were examined. For each driver that made at least one wrong turn, the action that led to driver's first wrong turn was classified. The classification categories used are shown in table 27. It can be seen that when drivers in the TravTek configurations made wrong turns, they tended to turn at the wrong place or in the wrong direction: that is, they made errors of commission. Drivers in the control configuration tended to make errors of omission: that is, they tended to continue on where a turn was planned. Intuitively, this makes sense. The TravTek system informs drivers when a turn is required, so that the driver's task is to identify where the turn is planned. Drivers in the control condition have no reminders that a planned turn point is imminent, and thus are more likely to not turn at all.

Table 27. Description of maneuvers that resulted in a driver's first wrong turn.

Configuration	*Turned in Wrong Direction*	*Turned Too Early*	*Other Wrong Turns*[11]	*Did Not Turn*
Navigation Plus	2 (13%)	3 (20%)	6 (40%)	4 (26%)
Navigation	3 (20%)	4 (27%)	4 (27%)	4 (26%)
Control	1 (07%)	1 (07%)	1 (07%)	12 (80%)
Total	6 (13%)	8 (18%)	11 (24%)	20 (44%)

Table 28 presents the data shown in table 27 with the first 4 categories of wrong turn collapsed into the category "Committed Inappropriate Turn." The trend for TravTek

[11] Other wrong turns included: turning when instructed to "bear"; getting trapped in an off ramp lane after TravTek directed the driver to the ramp lane; and turning when the voice alerted to the driver that the next turn was in 1.45 km.

drivers to make errors of commission and control drivers to make error of omission is statistically reliable, X^2 (2) = 11.52, $p < 0.005$.

Table 28. Wrong turn classification for Navigation Plus and Navigation triads as a function of vehicle configuration.

	Omitted Turn	*Made Inappropriate Turn*
Navigation Plus	4	11
Navigation	4	11
Control	12	3

Wrong Turn Descriptions. For O/D 1, a content analysis was performed on the wrong turns made by drivers in the Navigation Plus and Navigation configurations. Because the Navigation configuration always planned the same route, these wrong turns are described first.

In figure 18, the three locations where wrong turns occurred most frequently in the Navigation configuration are indicated by circled numbers that correspond to the numbered descriptions that follow:

1. When heading North on Edgewater, TravTek instructs the driver to turn left onto Yates Street, Drivers reported the street sign at Yates Street to be difficult to see. Yates Street is in proximity to several other parallel streets. Seven drivers missed this turn.

2. When heading North on Edgewater, TravTek instructs the driver to bear right to stay on Edgewater. Edgewater makes a slight jog to the right just beyond where the instruction is given. However, at the point where TravTek provides the instruction, the driver can not see the jog but can see Lakeview Street. Six drivers turned right onto Lakeview Street.

3. After the driver exits Interstate 4 and turns right onto Ivanhoe, TravTek immediately instructs the driver to turn left to get back on to Interstate 4. Some drivers found this maneuver confusing, and for speedier drivers the instruction came too late. Five drivers did not make the left turn to get back onto I-4.

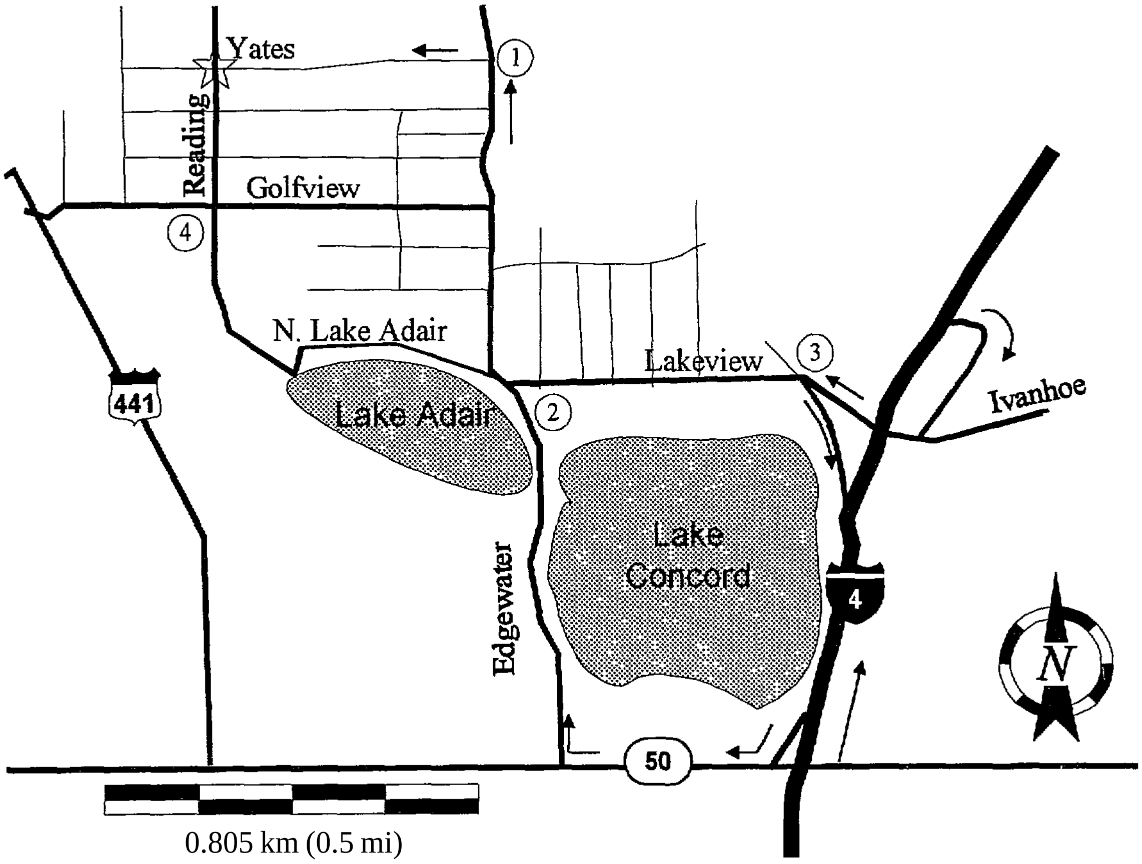

Figure 18. The locations where Navigation Plus and Navigation configuration drivers most frequently made wrong turns on O/D 1.

Several Navigation Plus drivers made wrong turns on O/D 1 at the same locations described for the Navigation drivers. Three made wrong turns at the location labeled 1, 7 made wrong turns at location 2, and 3 made wrong turns at location 3. There were two other locations where Navigation Plus drivers frequently made wrong turns:

4. When heading east on Golfview Street, TravTek instructs the driver to turn left on to Reading Drive. Four drivers did not make this left hand turn onto Reading Drive.

5. (Not shown in figure 18) When heading East on Interstate 4, TravTek instructs the driver to get off at US 441/17-92. There are two exit ramps for US 441/17-92 off Interstate 4, one for east bound traffic and one for west bound traffic. TravTek did not specify which ramp to take. Three drivers took the incorrect ramp.

The latter two locations are on alternative routes that were not offered to Navigation configuration drivers.

Recovering from a Wrong Turn. Once they deviated from the planned route, drivers in the TravTek configurations differed from drivers in Control configuration as to how they recovered. Drivers have three options after deviating from a planned route: (a) they can return to the previously planned route, (b) they can plan a new route from their present position, or (c) they can abandon the trip. With the TravTek system, drivers can return to the previously planned route either by: (a) making a U-turn and rejoining the route indicated by the magenta line on the route map display, or (b) pressing "OK NEW ROUTE" to request a new route from their current position. Drivers in the control condition can also make a U-turn, but planning a new route from their current position is problematic because, as tourists, they are presumably not familiar with the area. Drivers in the control condition sometimes decided to ask for help in planning a new route.

Table 29 shows what drivers did to recover from their first wrong turn. This table includes all drivers who finished the trip, and therefore does not include drivers who abandoned the trip. The effect of configuration on how the driver got back onto the planned route was statistically reliable, $X^2(3) = 16.98$, $p < 0.05$. The majority of drivers with the TravTek configurations pressed the "OK New Route" button for a new route. The majority of drivers with control configuration (85%) returned to a previously planned route. For drivers in the Control condition returning to a planned route could be done by (a) turning back to original route, or, (b) describing to the observer a new route. TravTek drivers could return to a planned route by returning to the point of deviation or by explaining to the observer precisely how they planned to converge with the previously planned route.

Table 29. How drivers got back onto a planned route.

Configuration	*Pressed OK New Route Button*	*Returned to a Planned Route*	*Called Help Desk*	*Asked for directions at Gas Station*
Navigation Plus	17 (59%)	12 (41%)	0 (00%)	0 (00%)
Navigation	6 (55%)	5 (45%)	0 (00%)	0 (00%)
Control	0 (00%)	11 (85%)	1 (08%)	1 (08%)
Total	23 (43%)	28 (53%)	1 (02%)	1 (02%)

Delay in detection of leaving the planned route. Figure 19 shows the mean time delay before drivers noticed they were off route. Only delays for the first wrong turn are included in the mean. The figure includes all drivers who finished their trip. Control configuration drivers took considerably longer than the TravTek drivers to notice they were off their planned route. The configuration effect is statistically reliable, $F(2, 58) = 4.83, p < 0.05$.

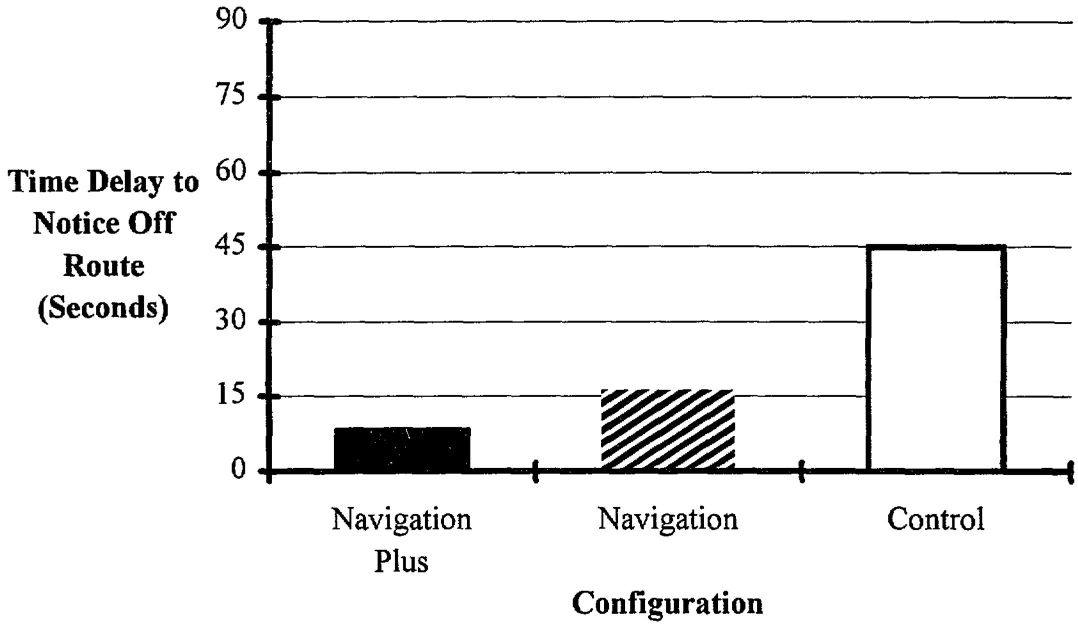

Figure 19. The time delay before drivers noted that they were off the planned route was significantly longer for the Control configuration.

Time off route, Figure 20 shows average time off-route for all drivers that completed their trip. Time off route includes the above reported time to detect being off route and time until the driver was back on _a_ planned route. Drivers who said they would return to the previous route were considered back on a planned route once they announced their intention and were taking actions congruent with that intention. Drivers who pushed the "OK New Route" button were not considered back on a planned route until (a) the system finished planning the new route, and (b) the vehicle was on that planned route. There are no statistically reliable differences in time off-route between configurations. For drivers using TravTek, there was no significant difference in time off route between those who elected to press "OK New Route" and those who chose to return to the route already planned.

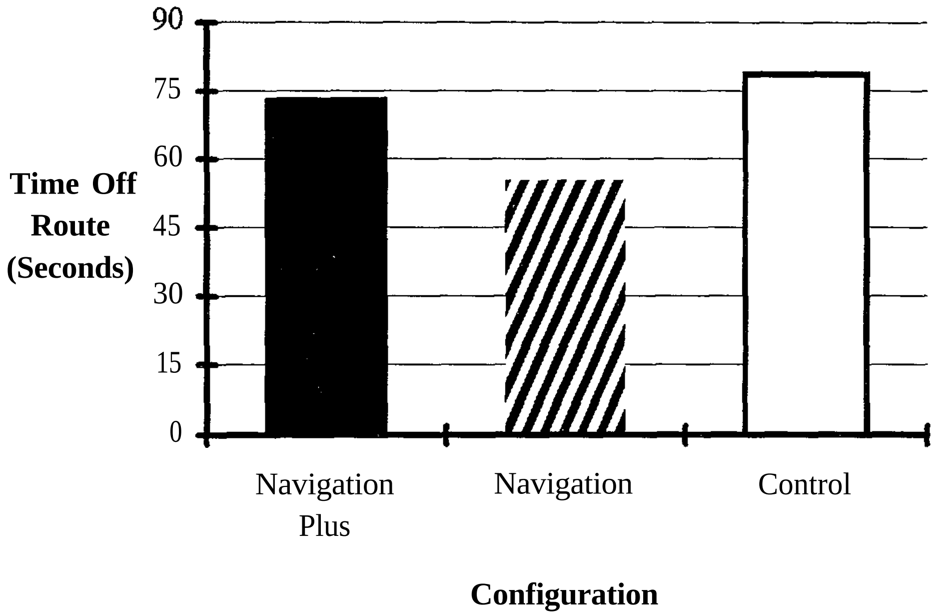

Figure 20. Total time elapsed between going off route and returning to a planned route.

Subjective Workload

Drivers rated their subjective workload on three dimensions: time stress, visual effort, and psychological stress. Ratings on each dimension were given on a three point scale: "low," "moderate," or "high." For analysis, low, moderate, and high were coded as 1, 2 and 3 respectively.

Time stress was defined in terms of the amount of time available for completion of driving and navigation tasks. Anchors for the low, moderate, and high ratings were provided during the pre-drive briefing. A low rating was to indicate that there was time to spare, such as for carrying on conversation or tuning the radio. A moderate rating was to indicate that there was just enough time to accomplish the driving and navigation tasks. It was suggested that with moderate time stress the driver would avoid distractions such as conversation. A high rating was to indicate that there was insufficient time to fully attend to driving and navigating. Examples provided for high time stress were ignoring scanning for an exit or ignoring a TravTek message in order to attend to the roadway.

Visual effort was defined in terms of the amount of visual scanning required. An example of low visual workload was feeling comfortable looking about, such as at scenery or billboards. It was further suggested that under moderate visual effort the visual scanning necessary for driving and navigating could be accomplished comfortably, but that there was no spare visual capacity. Under high visual effort it was suggested that the driver would have to delay looking at things necessary for driving or navigation. As an example, it was suggested that under high visual effort the driver might have to ignore signs and concentrate solely on the forward roadway.

Psychological stress was defined in terms of feelings of confusion, frustration, physical danger, and anxiety. Low psychological stress was defined as feeling confident and secure. Moderate psychological stress was defined as mildly confused or frustrated, such as not being sure you are on your planned route or feeling anxious about the actions of other drivers. High psychological stress was defined as feeling extremely stressed, as one might feel after a near accident or when totally lost and confused as to how to get home.

The observers prompted drivers for the 3 workload estimates on 10 occasions. The data reported here do not include workload ratings for parts of trips that were off planned routes. For analysis, the ratings from the 10 occasions were averaged into 4 categories based on the segment of the trip they were obtained from:

1. Planning: The first rating was given as soon as possible after the car was put in gear, and applied to "when you were planning your trip."

2. Start: The second rating applied to navigation from the start of the (moving) trip until the vehicle left the residential street(s).

3. En Route: All subsequent ratings, except the last, applied to en route workload on arterials or limited access roadways. In most cases there were seven of these ratings and the mean of those ratings is reported here.

4. Finish: The last workload rating applied to the residential area at the end of the trip and included workload associated with identification of the destination intersection.

Table 30 summarizes the subjective workload ratings as a function of the four trip segment categories. The data in table 30 are for all yoked triads that completed their trips. Analysis of variance yielded main effects for vehicle configuration, $F(2, 163) = 3.15$, $p < 0.05$, and type of workload (i.e., Time Stress, Visual Effort, or Psychological Stress), $F(2, 326) = 12.71, p < 0.001$. Ratings did not vary as a function of part of trip, nor were any interactions significant. Post hoc tests showed that visual effort ratings were significantly greater than time stress, $F(1, 163) = 16.35$, $p < .001$. Time stress and psychological stress did not differ from each other, $F(1, 163) = 1.14$, $p > 0.20$. In other words, drivers considered visual effort to be the greatest source of their workload.

The configuration effect was the result of drivers in the Control configuration rating their workload higher than those in the Navigation Plus and Navigation configuration. Navigation Plus and Navigation pairs did not differ significantly from each other.

Table 30. Mean workload ratings for yoked triads as a function of vehicle configuration, type of workload, and trip segment (category).

	Category			
Time Stress	*Planning*	*Start*	*En Route*	*Finish*
Navigation Plus	1.13	1.06	*1.08*	1.01
Navigation	1.18	1.21	1.08	1.09
Control	1.25	1.18	1.13	1.14
Visual Effort				
Navigation Plus	1.13	1.13	1.12	1.10
Navigation	1.19	1.21	1.23	1.19
Control	*1.43*	1.29	1.30	*1.32*
Psychological Stress				
Navigation Plus	1.11	1.14	1.10	1.09
Navigation	1.15	1.25	1.11	1.15
Control	1.14	*1.14*	1.19	1.25

Overall, drivers rated their workload as low, regardless of configuration or workload type: in no case did average workload ratings exceed 1.5. Whereas there is a tendency for workload to be rated lowest with Navigation Plus, this tendency never reaches statistical reliability, even when only Navigation Plus and Navigation dyads are considered. In any event, (a) TravTek reduced the workload associated with navigating to a strange destination, and (b) diversion to lower class roadways to avoid congestion did not significantly affect workload.

What Drivers Said about TravTek 's Effect on Performance

What drivers said about how TravTek affected their performance comes from questionnaires and debriefings. Neither the questionnaires nor debriefings required or requested drivers to limit their observations to experiences that took place during the experimental runs. It appears that Yoked Driver Study participants did not limit their observations to the yoked experimental runs because no significant differences were found in questionnaire responses between Navigation Plus, Navigation, or Control drivers. Because all drivers, including Control configuration drivers, were trained in the same manner and experienced all the TravTek features that can be accessed while driving, this is not surprising. The chief incentive to volunteer and participate was the “opportunity to drive the car of the future.” All volunteers were given that opportunity both during training before the experimental run, and after completion of the experimental run (on the drive back to the tourist attraction where recruiting and training took place).

Furthermore, participants in the Yoked Driver Study and the Orlando Test Network Study were given identical training and were tested on the same O/D pairs.[12] OTNS participants were also given the same questionnaire and debriefing as Yoked Driver Study participants. No differences in response trends to questionnaire items were detected between OTNS and Yoked Driver Study participants. Therefore, OTNS and Yoked Driver Study questionnaire data were merged. The merging of the data from these two groups considerably enhances the reliability for multivariate data analyses that rely on stability of the correlation matrix of questionnaire items.

The questionnaire can be found in appendix D of the *Yoked Driver Study Detailed Test Plan.*(14) Yoked Driver Study participant responses to the questionnaire are summarized in the *Yoked Driver Study Questionnaire Results, "Your* TravTek *Experience."*(15) There were 23 1 items in the questionnaire. From these items, 14 were selected that seemed most strongly related to driving or driver navigation performance.[13] For all of these items, drivers provided a rating on a six-point Likert scale on which one represented "strongly disagree" and six represented "strongly agree." Figure 21 depicts the scale used for all performance related questions. Participants were instructed to circle the number that best represented their perception.

Strongly Disagree					Strongly Agree
1	2	3	4	5	6

Figure 2 1. Questionnaire items related to driving performance were rated on a six point Likert scale.

Table 3 1 shows the 14 questions and the mean responses for 393 drivers, 189 from the Yoked Driver Study and 204 from the OTNS. It can be seen that for most of the items in table 3 1 "strongly agree" represented a favorable rating, whereas for the "interfered with.. ." items "strongly disagree" represented a rating favorable to TravTek. For ease of interpretation of multivariate analyses, it is desirable to have all "similar" responses, in

---

12 Another TravTek controlled experiment that was conducted using the same O/D pairs. The purpose of the OTNS was to evaluate TravTek display configurations. The OTNS vehicles did not use real-time traffic information in route selection.

13 There were 190 questions in the Yoked Driver Study Questionnaire. Of these, 50 questions were initially selected that might potentially reflect driver perceptions of performance. The list of 50 was further narrowed to the 14 that are reported here through a process that considered: (1) Were they truly performance related? (2) Are they closely conceptually related to at least three other variables? Selection of variables to be included in a factor analysis, is a subjective process. It is particularly subjective, as was the case here, when these decisions are made after design of the questionnaire.

this case favorable responses, represented in a numerically similar manner. For this reason, and to aid in correction of a marked skewness, all items except the "interfered with..." items were reflected. That is, all scores were subtracted from seven. This transformation rendered values of 1 to correspond to "strongly agree" and values of 6 to correspond to "strongly disagree" for the reflected items. Before submitting item scores to factor analysis, a log transformation was applied to compensate for a positive skew in the distribution. The means shown in table 3 1 were computed before reflecting or otherwise transforming the data.

Table 3 1. Items from the Yoked Driver Study and Orlando Test Network Study questionnaire that were selected to represent driver opinion of the TravTek system's effect of on driver performance.

Question	*Abbre-viation*	***Man***
The TravTek system's Guidance Display helped me pay more attention to my driviug.	GD ATTN	4.8
The TravTek system's Guidance Display helped me find my way.	GD FIND	5.7
The TravTek system's Guidance Display interfered with my driving.	GD INTF	2.0
The TravTek system's Route Map helped me pay more attention to my driving.	RM ATTN	4.5
The TravTek system's Route Map helped me find my way.	RM FIND	5.4
The TravTek system's Route Map interfered with my driving.	RM INTF	2.0
The TravTek system's Voice Guide feature helped me pay more attention to my driving.	VG ATTN	5.1
The TravTek system's Voice Guide feature helped me find my way.	VG FIND	5.4
The TravTek system's Voice Guide feature interfered with my driving.	VG INTF	1.7
Overall, the steering wheel buttons helped me pay more attention to my driving.	SWB ATTN	4.6
Overall, the steering wheel buttons interfered with my driving.	SWB INTF	1.9
Overall, the TravTek system helped me pay more attention to my driving.	TT ATTN	5.0
Overall, the TravTek system helped me find my way.	TT FIND	5.7
Overall, the TravTek system interfered with my driving.	TT INTF	1.7

The correlation matrix of the 14 items (after reflex and log transformations) is shown in table 32. The correlation matrix was submitted to an exploratory factor analysis with an initial principal components solution, followed by factoring with communalities in the diagonals and extraction of four factors with eigenvalues greater than one. The four factor solution was subjected to a quartimax rotation for simplified structure. The factor structure for the quartimax solution is shown in table 33.

Table 32. Correlation matrix of 14 questionnaire items that concerned driving performance.

	GD ATTN	*GD FIND*	*GD INTF*	*RM ATTN*	*RM FIND*	*RM INTF*	*VG ATTN*	*VG FIND*	*VG INTF*	*SWB ATTN*	*SWB INTF*	*TT ATTN*	*TT FIND*	*TT INTF*
GD ATTN	*1.00*													
GD FIND	0.32	1.00												
GD INTF	0.48	0.20	1.00											
RM ATTN	0.61	0.20	0.33	1.00										
RM FIND	0.21	0.30	0.13	0.54	1.00									
RM INTF	0.28	0.14	0.56	0.47	0.41	1.00								
VG ATTN	0.40	0.21	0.14	0.35	0.16	0.01	1.00							
VG FIND	0.23	0.29	0.10	0.18	0.20	0.05	0.71	1.00						
VGINTF	0.16	0.12	0.35	0.15	0.12	0.35	0.43	0.43	1.00					
SWB ATTN	0.41	0.19	0.18	0.45	0.16	0.09	0.51	0.29	0.20	1.00				
SWB INTF	0.22	0.11	0.46	0.23	0.10	0.45	0.14	0.17	0.44	0.40	1.00			
TT ATTN	0.63	0.28	0.35	0.60	0.25	0.23	0.54	0.35	0.22	0.60	0.26	1.00		
TT FIND	0.22	0.45	0.19	0.29	0.37	0.21	0.30	0.34	0.22	0.30	0.23.	0.40	1.00	
TT INTF	0.28	0.12	0.50	0.27	0.21	0.51	0.14	0.16	0.43	0.21	0.60	0.39	0.23	1.00

It should be noted that the factor labels in the first row of table 33 are the analysts' interpretation. A cutoff of 0.50 was used to determine which items loaded on which factors. The five "interfered with.. ." items loaded on the first factor that was labeled "Interfered with my driving." This factor accounted for 35.6 percent of the variance among the 14 items. Four of the five "helped me pay more attention..." items loaded on the second factor. "Voice guide helped me pay more attention. .." also had a substantial loading on this factor, so the factor was labeled "Helped me pay more attention to my driving." The second factor accounted for 13.7 percent of the variance among items. The third factor appears to be related to perceptions of the effect of voice guidance on driving. "Voice guidance helped me find my way" and "voice guidance helped me pay more attention to my driving" loaded strongly on this factor. In addition, "Voice guidance interfered with my driving" also had a substantial loading on this factor. The third factor accounted for 10.4 percent of the variance. Three of the four "helped me find my way" items loaded on the fourth factor. The voice guide does not appear to have been as strongly associated with way finding as other TravTek features. This is a relative finding as the mean rating for "helped me find my way" was the same for the route map and the voice guide.

Overall, the drivers indicated that TravTek had a favorable effect on their driving performance. They disagreed with statements that TravTek features interfered with their driving and agreed with statements that asserted that TravTek (a) helped them pay attention to their driving, and helped them find their way. The voice guide received very favorable ratings but appears to have been considered as distinct from other features.

Table 33. Factor structure for the four factor solution with quartimax rotation.

	Factors			
Item	Interfered with my driving	Helped me pay more attention to my driving	Voice	Helped me find my way
Overall, the TravTek system interfered with my driving	0.80	0.15	0.09	0.07
Overall, the Steering Wheel Buttons interfered with my driving	0.77	0.14	0.19	-0.05
The TravTek system's Route Map interfered with my driving	0.75	0.12	-0.23	0.34
The TravTek system's Guidance Display interfered with my driving	0.72	0.30	-0.07	0.06
The TravTek system's Voice Guidance interfered with my driving	0.60	-0.03	0.58	0.05
Overall, the TravTek system helped me pay more attention to my driving	0.19	0.81	0.23	0.16
The TravTek system's Guidance display helped me pay more attention to my driving	0.22	0.79	-0.01	0.14
The TravTek system's Route Map helped me pay more attention to my driving	0.23	0.74	-0.14	0.38
Overall, the Steering Wheel Buttons helped me pay more attention to my driving	0.12	0.71	0.33	-0.02
The TravTek system's Voice Guide helped me find my way	0.06	0.18	0.81	0.26
The TravTek system's Voice Guide helped me pay more attention to my driving	0.00	0.51	0.74	0.09
The TravTek system's Route Map helped me find my way	0.15	0.19	-0.10	0.78
The TravTek system's Guidance Display helped me find my way	0.04	0.14	0.20	0.67
Overall, the TravTek system helped me find my way	0.14	0.16	0.32	**0.66**

Issue: What are Drivers Willing to Pay For TravTek Features and Functions?

Participants were asked how much they would be willing to pay for TravTek and various TravTek functions. Participants were asked how much they would be willing to pay for TravTek as a complete system as well as for selected components of the system. Four payment contexts were explored:

- The amount participants would be willing to pay for a system such as the one they drove.
- The amount participants would be willing to pay for TravTek functions as options on a new car.
- The amount participants would be willing to pay for TravTek functions as add-ons to an existing car.
- The amount participants would be willing to pay for TravTek functions in a rental car.

Responses to these questions were indicated by placing an X on a line that had tick marks representing dollar values at equally spaced intervals. Figure 22 provides an example of a willingness-to-pay scale used in the questionnaire.

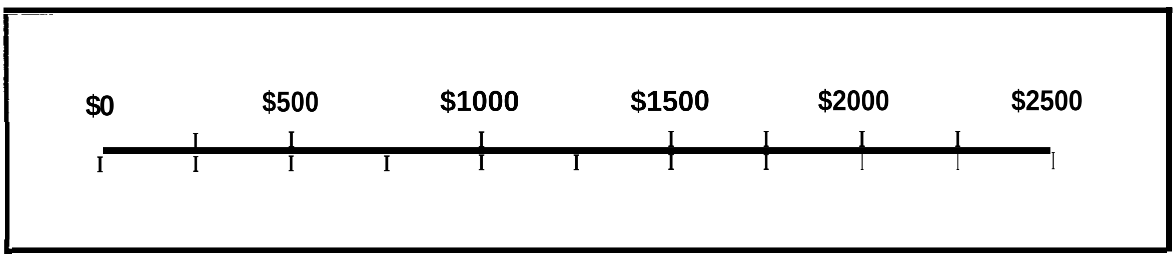

Figure 22. An example of a willingness-to-pay scale in the questionnaire.

Table 34 provides a summary of responses to the willingness-to-pay questions. The range of values participants had to select from, and the mean across participants from both the *Yoked Driver Study* and the *Orlando Test Network Study* are shown. Participants indicated that they would be willing to pay about $1000 dollars for the TravTek system. Regardless of whether the participants were rating individual TravTek features as options in a new car, or as add-ons to any car, they were consistent in ranking the value of TravTek features. Participants were willing to pay the most for Route Guidance, followed by Navigation, followed by Traffic Information. A multivariate analysis of variance showed that participants were willing to pay significantly more for TravTek features as options in a new car than as add-ons to any car, $F(1,325) = 4.30$, $p < 0.05$. There was also a significant interaction between type of car (new or any) and individual features, $F(4, 322) = 239.73$, $p < 0.001$. The interaction indicates the magnitude of the difference in willingness-to-pay (between an option on new car and as and add-on to any car) was significantly greater for the route guidance feature than for other features.

Table 34. Summary of responses to the willingness-to-pay questions.

Question	*Scale Range:*	*Mean*
How much would you be willing to pay for a TravTek system such as the one you drove?	$0 - $2500	*$970*
How much would you be willing to pay for the following features AS SEPARATE OPTIONS IN A NEW CAR?		
1. NAVIGATION ONLY	$0 - $2500	$442
2. ROUTE GUIDANCE ONLY	$0 - $2500	$571
3. ONLY UP-TO-DATE TRAFFIC INFORMATION	$0 - $2500	$299
Total TravTek With All Features	$0 - $4000	$1293
How much would you be willing to pay for the following features AS AN ADD-ON TO ANY CAR?		
1. NAVIGATION ONLY	$0 - $2500	$422
2. ROUTE GUIDANCE ONLY	$0 - $2500	$532
3. ONLY UP-TO-DATE TRAFFIC INFORMATION	$0 - $2500	$277
Total TravTek With All Features	$0 - $4000	$1228
How much extra per week would you be willing to pay for the following features AS AN OPTION ON A RENTAL CAR?		
1. NAVIGATION	$0 - $25	$10
2. ROUTE GUIDANCE	$0 - $25	$11
3. UP-TO-DATE TRAFFIC INFORMATION	$0 - $25	$6
Total TravTek With All Features	$0 - $100	$34

To further explore the stated willingness-to-pay measures, willingness-to-pay was examined as a function of income. Three income categories were defined:

- Under $40,000.
- $40,000 through $79,999.
- $80,000 and over.

The willingness-to-pay data did not appear to derive from a normally distributed sampling population: in particular, for some questions, a substantial number of drivers indicated they would pay nothing ($0). The means shown in Table 34 include all respondents, including those who estimated that they would pay $0. However, for the income group analysis of willingness-to-pay, it was decided to exclude participants who indicated $0. Table 35 shows the proportion of drivers who indicated they would not pay for TravTek or its functions as a function of income. Very few participants were unwilling to pay for the route guidance feature, with values ranging between 1.4 percent and 8.7 percent. The middle income group had a high proportion of respondents that did not want to pay for the navigation feature alone (moving map without route guidance). After excluding those who indicated that they would pay nothing, income group was found not to be a reliable predictor of the amount participants said they were willing to pay, $p > 0.05$.

Another way of examining willingness-to-pay, is to plot a cumulative frequency distribution of the amount respondents said they would pay. These plots appear in figure 23 through figure 26, and include respondents who said they would pay nothing. The amount participants said they were willing to pay is shown on the abscissa. The cumulative frequency of respondents willing to pay the amount on the abscissa is shown on the ordinate. Thus figure 23 can be interpreted as follows:

- All respondents were willing to pay at least $0 for a TravTek system "such as the one they drove."
- Fifty percent of the drivers were willing to pay at least $1000.

The marginal weekly rental value for 50-percent market penetration was just under $30. However, the Rental Users Study, that provides willingness-to-pay estimates from approximately 2500 drivers who actually rented TravTek vehicles, is probably a better source of data for rental value estimation.(10)

Table 35. Proportion of participants who said thev would pay nothing.

Question	*Household Income*		
	< $40,000	$ 40,000 < $80,000	>$80,000
How much would you be willing to pay for a TravTek system such as the one you drove?	0.03 1	0.015	0.013
How much would you be willing to pay for the following features AS SEPARATE OPTIONS IN A NEW CAR?			
1. NAVIGATION ONLY	0.088	0.189	0.083
2. ROUTE GUIDANCE ONLY	0.026	0.065	0.014
3. ONLY UP-TO-DATE TRAFFIC INFORMATION	0.189	0.275	0.250
Total TravTek With All Features	0.034	0.027	0.027
How much would you be willing to pay for the following features AS AN ADD-ON TO ANY CAR?			
1. NAVIGATION ONLY	0.088	0.198	0.130
2. ROUTE GUIDANCE ONLY	0.043	0.087	0.014
3. ONLY UP-TO-DATE TRAFFIC INFORMATION	0.205	0.328	0.261
Total TravTek With All Features	0.043	0.067	0.014
How much extra per week would you be willing to pay for the following features AS AN OPTION ON A RENTAL, CAR?			
1. NAVIGATION	0.103	0.159	0.159
2. ROUTE GUIDANCE	0.059	0.049	0.043
3. UP-TO-DATE TRAFFIC INFORMATION	0.191	0.282	0.300
Total TravTek With All Features	0.059	0.041	0.056
~ Sample Size”	116	185	70

14 The sample size varies slightly (±5%) for each question because of occasional failures to respond.

Figure 23. Estimated market penetration for the TravTek system "such as the one you drove."

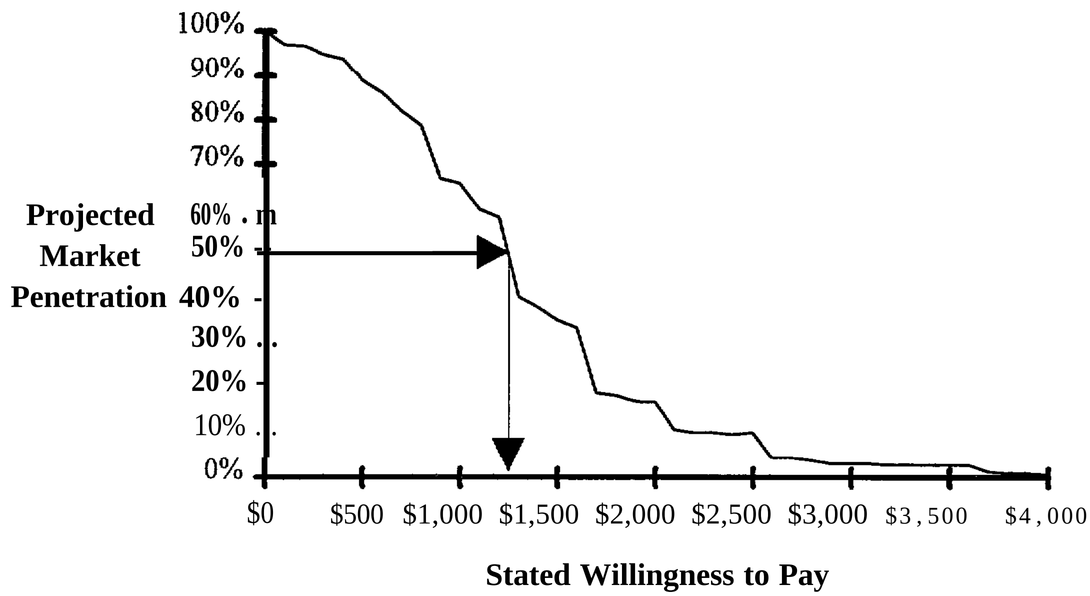

Figure 24. Estimated market penetration for the TravTek system purchased as "options on a new car."

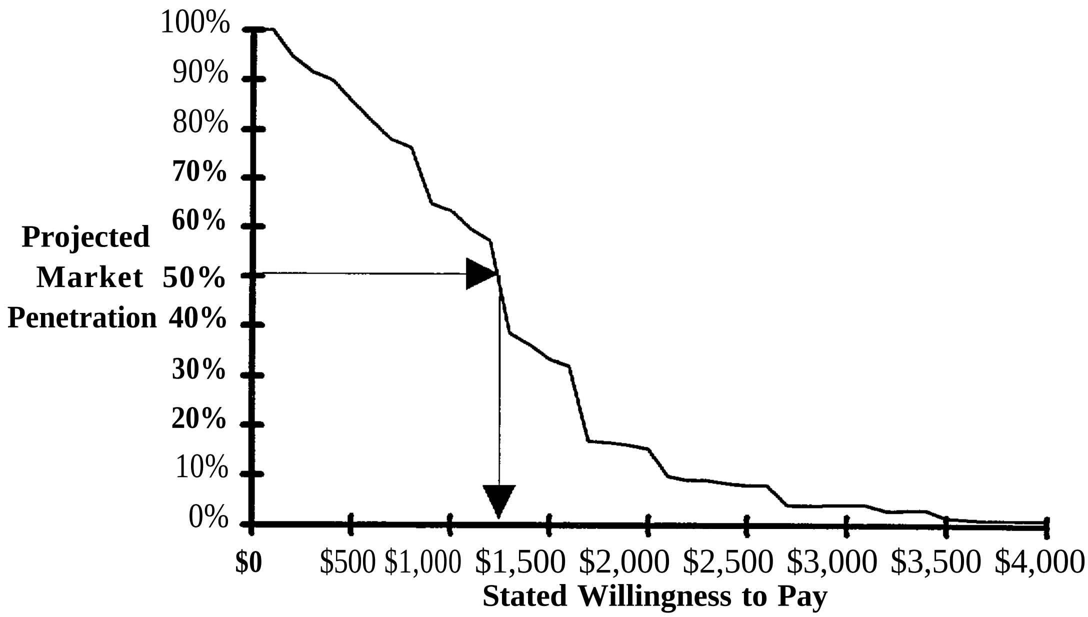

Figure 25. Estimated market penetration for the TravTek system purchased as “an add-on to any car.”

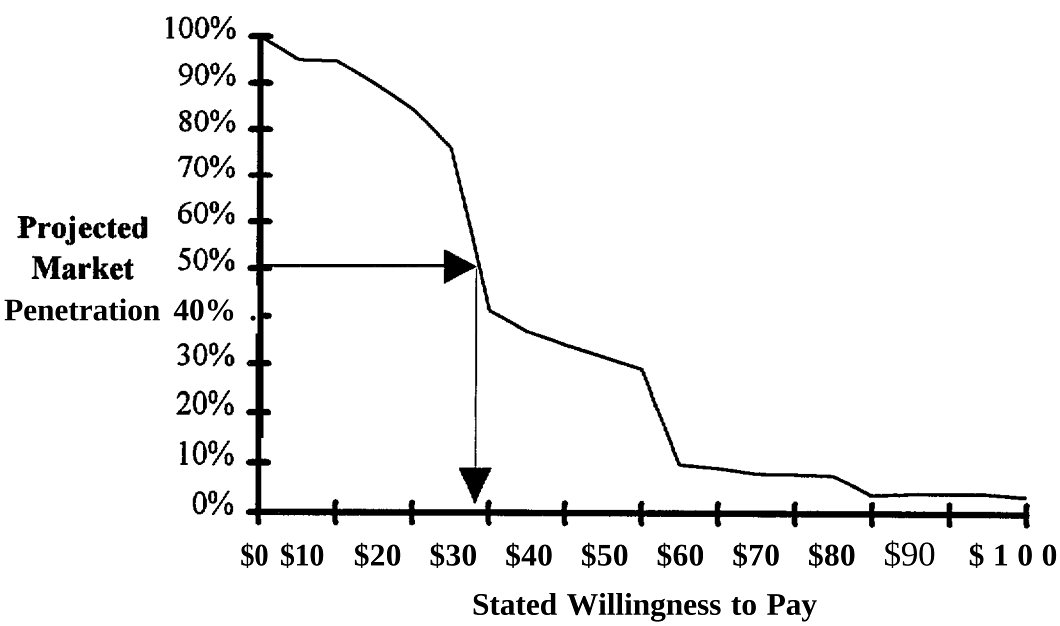

Figure 26. Estimated market penetration for the TravTek system as added cost on a weekly rental rate.

Issue: Is the TravTek System Usable and Useful?

Usefulness or Utility

Two sources of data are available to evaluate the usefulness, or utility, of the TravTek system: driver performance and driver opinion. One of those sources, performance, has already been discussed under the trip efficiency issue. That is, the TravTek system was useful in reducing travel time. The utility of TravTek is evaluated in this section based on what Yoked Driver Study drivers had to say in the questionnaires and debriefings,

The participants in the Yoked and OTNS studies were largely visitors to the Orlando area. One of the questionnaire items asked the participants to state whether the TravTek system would be useful for "out-of-town business driving," "out-of-town vacation driving," and "at home driving." Of 441 respondents, 96-percent said that they thought TravTek would be useful for out-of-town business driving, 2-percent said TravTek would not be useful, and 2-percent did not answer. Of the same respondents, 99-percent said that they thought TravTek would be useful for out-of-town vacation driving; no one said TravTek would not be useful for vacation driving; and l-percent did not answer. When asked if they thought TravTek would be useful for at home driving only 39-percent said yes, 55-percent said it would not be useful, and 6-percent did not answer. Table 36 shows responses to the useful for at home driving question as a function of age group and gender. The at home finding was similar regardless of gender. However, drivers in the youngest age group were most likely to say that TravTek would be useful at home. Drivers in the oldest age group were least likely to say that TravTek would be useful for at home driving.

Table 36. Frequency of judgments as to whether the TravTek system would be useful for at home driving.

	Useful	*Not Useful*
25 to 34		
Female	14	15
Male	44	51
35 to 54		
Female	26	37
Male	64	81
55 and older		
Female	4	18
Male	20	37
Total	172	239

In addition to rating the utility of the TravTek system for at home and out of town driving, participants rated the usefulness of individual navigation aid components of the TravTek system. Participants were asked to rate the usefulness of the following TravTek features:

- Routing method.
- Guidance display.
- Route map.
- OK new route.
- Voice function.

Only two questionnaire items specifically asked if the a feature "was useful." However, because this analysis focuses on navigation guidance, the "helped me find my way" question may be an acceptable surrogate for "was useful."

Only one questionnaire item included both the "was useful" and "helped me find my way" ratings. That item asked for these drivers to rate the TravTek system's voice guide feature. The correlation between the "was useful" response and "helped me find my way" response was 0.89. "Helped me find my way" is used here as a surrogate for a system utility, or "was useful" question.

Both the *Yoked Driver Study* and the Orlando *Test Network Study* are included in the data reported here. The questions used to evaluate driver ratings of the utility of TravTek routing and navigation aid, are shown in table 37. All questions were rated on a scale from 1 to 6, with 1 representing "strongly disagree" and 6 representing "strongly agree." The mean ratings for each question are given in the right column of table 37. Driver ratings of the utility of TravTek as a routing and navigation aid were high and did not differ as a function of age group or gender ($p > 0.05$).

Table 37. Mean ratings for questionnaire items used to assess TravTek's utility as a routing and navigation aid.

Question	*Mean Rating (Standard Deviation)*
The TravTek System's Screen for Choosing the Routing Method was Useful.	5.71 (0.59)
The TravTek System's Guidance Display Helped Me Find My Way.	5.69 (0.63)
The TravTek System's Route Map Helped Me Find My Way.	5.40 (0.99)
The TravTek System's OK New Route Feature Helped Me Find My Way.	5.48 (0.98)
The TravTek System's Voice Guide Feature was Usefill.	5.49 (1.01)
The TravTek System's Voice Guide Feature Helped Me Find My Way.	5.47 (1 .00)

Usability and Learnability

The usability issue has been partially explored under the driver performance issue. There, it was shown that on some measures the TravTek system showed a positive impact on driving performance. For other measures, no significant effect on performance was detected. Here we examine usability from a learnability perspective and then examine questionnaire data to report what drivers said about the usability of the TravTek system.

While driving the TravTek vehicle on introductory training runs, drivers were asked a series of questions by the research assistants (observers). These 11 questions, shown in the left column of table 38, probed for understanding of how to use the system. Each question was asked five times or until the driver answered correctly twice consecutively. If the driver answered incorrectly then the research assistant provided the correct answer. The information required to answer the questions correctly had been presented previously during the classroom briefing and, or, in the vehicle before starting the on-road training. The number of trials until drivers could answer the correctly can be interpreted as a measure of ease of learning.

For each question, table 38 shows the percentage of drivers who answered correctly each time the question was asked. It can be seen that most of the drivers answered correctly on every occasion. This pattern was true for young, middle aged, and older drivers, and for both females and males. For the question "what TravTek functions can be accessed while the car is moving" females were significantly more apt to answer correctly than males, $X^2 (1) = 4.26$, $p < 0.05$. Overall, driver's seemed to have no trouble understanding the concepts covered by the questions, and this ease of comprehension varied little as a function of age or gender.

Table 38. The percentage of drivers who answered system information questions correctly each time they were asked.

Question	*Gender*	
	Female	***Male***
If you type a wrong letter when entering a street name, how can you correct the mistake?	71.9	71.3
How do you enter a space in a street name? For example, how do you enter the space in "Orange Blossom?"	82.5	77.9
How do you return to the previous menu?	72.6	70.3
How can you return to the main menu?	62.9	56.7
Is it necessary to enter all the letters of a street name?	93.8	94.1
If TravTek shows that you are traveling on street A, but you are actually on street B that runs parallel to A, what should you do?	83.6	78.4
If an "OFF ROUTE" message occurs, what should you do?	79.4	75.8
On the TravTek route map, when can you zoom in or out?	58.7	72.4
How long can you wait before pressing "OK NEW ROUTE" for a new route?	84.1	82.1
To hear the last message again, how long can you wait before pressing REPEAT VOICE	82.8	86.8
What TravTek functions can be accessed while the car is moving?	84.4	71.1

At the beginning of each training route, research assistants recorded driver proficiency at entering a destination. Entering a destination was evaluated using eight tasks: pressing NAVIG, selecting ENTER DESTINATION, selecting INTERSECTION, entering first street, entering second street, confirming the intersection, choosing not to SAVE DESTINATION, and choosing the routing method. An example of the checklist used by the research assistants is shown in figure 27. Drivers were rated as proficient, hesitant, or requiring a prompt from the observer.

Task	Proficient						Hesitant						Requires Prompt					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Press NAVIG																		
Select ENTER DESTINATION																		
Select INTERSECTION																		
Enter First Street																		
Enter Second Street																		
Confirm Intersection																		
Save Destination (NO)																		
Choose Routing Method																		

Figure 27. An example of the training checklist used to rate driver proficiency in entering a destination.

Proficiency was defined as the number of trials required before the driver successfully performed a task twice in succession without hesitation or prompting. Thus the best (lowest) possible score was one and could be attained by performing without hesitation on the first two trials. Table 39 shows the mean number of training runs needed to achieve proficiency as a function of gender and age group. The means are averaged over the eight tasks listed in figure 27. The sample size for each of the cells is shown in parentheses. There were no significant differences in trials to proficiency as a function of either age or gender ($p > 0.05$): regardless of age group or gender, drivers averaged a little over two trials to reach proficiency.

Table 39. Mean number of training runs to attain proficiency at entering a destination by gender and age group.

	Female	*Male*	*Total*
Younger	*2.45* (18)	*2.20 (47)*	*2.28 (65)*
Middle	1.98 (30)	2.09 (71)	*2.06* (101)
Older	2.59 (14)	*2.45 (24)*	*2.50 (38)*
Total	*2.26 (62)*	2.19 (142)	2.21 (204)

During training O/D's, drivers were asked to perform the following functions that were controlled by steering hub button presses:

SWAP MAP	Toggled the visual display between the route map and the guidance display
TRAFFIC REPORT	Triggered a synthesized voice message of traffic incidents along the planned route
WHEREAMI	Triggered a synthesized voice report of current heading, the name of the current street and the nearest cross street ahead
VOICE GUIDE	Toggled voice guidance on and off.

Drivers were also asked to adjust the synthesized voice volume. Volume control was done with the radio volume control (on the dashboard) while the synthesized voice was delivering a message.

The driver was considered proficient with a function when performance was correct on two consecutive training O/D's. Once rated proficient, the driver was not asked to perform the function again. The mean number of errors per driver, averaged over all five functions, is shown in table 40. There were no significant effects for age or gender. Overall, fewer than 1 in 10 drivers made an error in performing any of the five functions.

Table 40. Average number of errors (sample size in parentheses) in performing each of five system manipulation tasks.

Age	*Female*	*Male*	*Total*
26 through 34	0.056 (18)	0.090 (48)	0.080 (66)
35 through 54	0.063 (32)	0.106 (72)	0.093 (104)
55 and above	0.100 (14)	0.166 (29)	0.144 (43)
Total	0.069 (63)	0.113 (142)	0.092 (222)

Debriefing Findings

After completion of the experimental O/D, and while driving back to the point of embarkation for the test drive, drivers were debriefed by the observers. The debriefings were semi-structured. Each driver was asked the same seven questions, but the intent was to encourage the drivers to talk about their impressions rather than to target specific areas of interest. The seven questions were:

- Overall, what impressions do you have about TravTek now that you've had a chance to "drive the future?"
- What was your favorite feature?
- What was your least favorite feature?
- While driving with TravTek, were there any situations where TravTek was especially helpful? Why?
- While driving with TravTek, were there any situations where TravTek was not helpful? What happened?
- Did the orientation you were given prepare you for driving with TravTek?
- Can you think of anything that could be improved about TravTek to make it better? What?

Debriefings were obtained from 208 drivers: 47 from the Control configuration; 76 from the Navigation configuration; and 85 from the Navigation Plus configuration. Because drivers tended to give the same responses regardless of the configuration in which they were tested, the findings reported here are from all drivers regardless of configuration.

For each question, an analyst examined individual driver responses to identify categories into which similar responses could be categorized. All driver responses were then sorted into those categories. The frequency of responses in each category is reported in here. No responses were discarded. However some unique responses (responses that were not similar to those of any other driver) are not reported here only as “other.” The debriefing results are presented in table form. As can be seen in table 41, which summarizes responses to a questions about overall impressions of TravTek, the tables are organized into four columns. The first column presents a short descriptive name for categories identified by the analyst. The short descriptive name, presented in boldfaced type, is followed by brief clarifying remarks. The second column of the tables provides the number of drivers that gave a particular response. Because drivers could, and often did, provide multiple responses to the debriefing questions, the there were more responses than there were categories. The third column of the tables provides a percentage that represents the frequency of a given response relative to all responses. The fourth column gives the percentage of drivers who gave the particular response.

Driver responses to the question “Overall, what impressions do you have about TravTek now that you’ve had a chance to ‘drive the future?“’ are summarized in table 41. It can be seen that most of the drivers reported their overall impressions of TravTek to be favorable.

Table 4 1. Overall, what impressions do you have about TravTek now that you've had a chance to test drive the future?

Response	*Frequency*	*Percent of Responses*	*Percent of Drivers*
Strongly liked — stated they liked TravTek very much.	93	39.9%	44.7%
Liked — stated they liked TravTek.	76	32.6%	36.5%
Awesome — TravTek described as awesome, amazing, impressive.	14	6.0%	6.7%
Fascinating — described TravTek as interesting.	11	4.7%	5.3%
Friendly — described TravTek as user-friendly.	7	3.0%	3.4%
Fun — described TravTek as entertaining.	6	2.6%	2.9%
Within expectations — commented that they found TravTek to be about what they had anticipated.	5	2.1%	2.4%
Other — Catch all category for responses that were made by only one driver.	5	2.1%	2.4%
Helpful — described TravTek as providing assistance with navigation in an unfamiliar area.	3	1.3%	1.4%
Needs improvement — commented that they liked TravTek but thought it needed some revision.	3	1.3%	1.4%
Unfriendly — described the keyboard interface to be cumbersome.	2	0.9%	1.0%
Problem with performance — commented that TravTek functioned improperly.	2	0.9%	1.0%
No response — did not answer this question.	2	0.9%	1 .0%
Saves time — commented that TravTek saved them time.	2	0.9%	1.0%
Decreases stress — commented that TravTek reduced their anxiety.	2	0.9%	1.0%

Table 42 summarizes driver responses to the debriefing question "What was **your** favorite feature?" The Voice Guide feature was mentioned most often as the favorite feature. This finding is interesting because the voice feature was also the most frequently cited "least favorite" feature. Generally, drivers expressed favorable opinions of the aural turn-by-turn instructions. What they did not like was the sound quality of the synthesized voice. That drivers did not like the sound of the voice, but still rated voice guidance favorably, suggests strong acceptance of the voice guidance concept. This acceptance is so strong that even an implementation that received much criticism was still cited as a "most favorite" feature.

Table 42. What was your favorite feature?

Response	*Frequency*	*Percent of Responses*	*Percent of Drivers*
Voice guidance — liked aural turn-by-turn instructions: some said that the voice enabled them to concentrate on driving without having to look at the screen.	65	23.9%	31.3%
Guidance display — reported liked the turn-by-turn display. Some said that the guidance display was straightforward and provided clear instruction.	60	22.1%	28.8%
Route guidance — liked the complete TravTek system, which included the Voice Guide, Guidance Display and the Route Map.	33	12.1%	15.9%
Other — Catch all category for responses that were made by only one driver.	17	6.3%	8.2%
Easy to use — liked the user-friendliness of TravTek."	16	5.9%	7.7%
Route Map — liked the detail the route map provided.	15	5.5%	7.2%
OK NEW ROUTE — liked the OK NEW ROUTE function.	13	4.8%	6.3%
Easy to learn — liked how easy the TravTek system was to learn.[15]	9	3.3%	4.3%
Saved time — said saved time TravTek over traditional methods.	8	2.9%	3.8%
Swap map — liked how the swap map button enabled switching between the Guidance Display and Route Map.	7	2.6%	3.4%
Next turn warning — liked the advance warning of the next turn that TravTek provided.	6	2.2%	2.9%
None — Driver declined to name a favorite feature.	5	1.8%	2.4%
Helped me find my way — liked how TravTek helped them navigate."	4	1.5%	1.9%
Services/Attraction — liked the information that was available through TravTek **on** area restaurants, hotels, and attractions.	2	0.7%	1.0%
No response — Driver did not answer this question.	2	0.7%	1.0%
Zoom in/zoom out — liked the ability to change the route map scale.	2	0.7%	1.0%
Traffic information — liked the real-time information.	2	0.7%	1.0%
Routing method choices — liked the option of choosing routing method: fastest, avoid Inter-states, and avoid toll roads.	2	0.7%	1.0%
REPEAT VOICE — found this feature to be useful if the last message was forgotten or not understood.	2	0.7%	1.0%
Makes you feel more confident — liked the added sense of security TravTek provided.	2	0.7%	1.0%

The Guidance Display and Route Map were the second and third most cited favorite features. Clearly route guidance in either visual or aural formats was highly appreciated.

15 This comment may have been suggested by a prompt from the debriefer.

The "Easy to use" and "Easy to learn" ratings should be regarded with skepticism as the observers offered "easy to use or easy to learn" to prompt responses.

The features cited by drivers as their least favorite are shown in table 43. As mentioned above, the most frequently cited least liked feature was the synthesized voice. The Route Map was cited as a most favorite feature by 15 drivers and as a least favorite feature by 10 drivers. Both the Guidance Display and Route Map were frequently cited as a most favorite feature and as a least favorite feature. Of the two, the Route Map was cited less frequently as a most favorite feature and more frequently as a least favorite feature. It is not clear from these findings whether the drivers were reacting to the specific TravTek implementations of the two displays, or to guidance and moving map display concepts.

Table 43. What was your least favorite feature?

Response	*Frequency*	*Percent of Responses*	*Percent of Drivers*
None — declined to name least favorite feature.	58	27.1%	27.9%
Voice quality — the sound or intelligibility of the Voice Guide.	47	22.0%	22.6%
Keyboard interface — the awkwardness of the keyboard; some said the keyboard interface was not user-friendly.	28	13.1%	13.5%
Other — Catch all category for responses that were made by only one driver.	23	10.7%	11.1%
Route Map — Route map display. Some said the Route Map required more effort to use than the guidance display.	10	4.7%	4.8%
Destination entry — The time required to input a destination into the TravTek system.	7	3.3%	3.4%
Bear right/left command confusing — the bear right or left instruction that TravTek provided for a bend in the road. Some said that they got this instruction confused with the turn instruction.	6	2.8%	2.9%
Inability to zoom in or out while moving — the inability to change the scale of the route map while moving.	5	2.3%	2.4%
Tracking problem — how TravTek would misrepresent the vehicle's position.	4	1.9%	1.9%
Guidance Display — Some said they preferred the detail the route map provided.	4	1.9%	1.9%
Location of function buttons — reported difficulty finding the appropriate function button on the steering wheel hub.	4	1.9%	1.9%
30 second time limit — the 30 second time out for use of the REPEAT VOICE button and/or the OK NEW ROUTE features.	4	1.9%	1.9%
Having to be in park to program — the requirement to be in park to program a destination.	3	1.4%	1.4%
Hop right/hop left — the hop right/hop left feature for correcting the vehicle position.	3	1.4%	1.4%
Starting route — did not like instruction to go in a certain direction on a given street name, particularly if the driver did not know which way that was.	2	0.9%	**1.0%**
No response — did not answer this question.	2	0.9%	**1.0%**
Need more warning before turns **—** how TravTek did not instruct them to turn soon enough.	2	0.9%	1.0%
System was confusing — the difficulty using TravTek and driving at the same time.	2	0.9%	1.0%

Responses to the question "while driving with TravTek, were there any situations where TravTek was especially helpful?" are shown in table 44. The OK NEW ROUTE function was most frequently cited as being especially helpful.

Table 44. While driving with TravTek, were there any situations where TravTek was especially helpful?

Response	Frequency	Percent of Responses	Percent of Drivers
Off route message & OK NEW ROUTE feature — the off route message and OK NEW ROUTE feature got them back onto a planned route.	42	18.9%	20.2%
Finding specific destination — TravTek was helpful locating a particular destination.	37	16.7%	17.8%
Distance to next maneuver — the advanced warning TravTek provided for the next turn.	27	12.2%	13.0%
Route guidance — the Voice Guide, Guidance Display, and Route Map.	26	11.7%	12.5%
Other- Catch all category for responses that were made by only one driver.	17	7.7%	8.2%
TravTek was helpful all the time— declined to identify a specific feature.	16	7.2%	7.7%
Instruction to turn — the information TravTek provided as to exactly where to turn.	16	7.2%	7.7%
Guidance display — the clear instruction the turn-by-turn display.	10	4.5%	4.8%
Traffic information — ability to avoid traffic congestion.	7	3.2%	3.4%
None — in no instance was TravTek was especially helpful.	4	1.8%	1.9%
TravTek was generally helpful — TravTek was helpful in most cases.	4	1.8%	1.9%
Driving in residential areas — the detailed directions TravTek provided were helpful when driving in residential areas.	4	1.8%	1.9%
Route map — the detail the route map provided was helpful.	3	1.4%	1.4%
Close proximity maneuvers — TravTek was helpful when two consecutive turns were close together.	3	1.4%	1.4%
Night-time operation — TravTek was helpful with night-time driving.[16]	2	0.9%	1.0%
No response — driver did not answer.	2	0.9%	1.0%
Reduced stress — TravTek was helpful in reducing the anxiety associated with navigating to an unfamiliar destination.	2	0.9%	1.0%

Table **45** shows debriefing responses to the question "while driving with TravTek, were there any situations where TravTek was not helpful?" The most frequent response to this question was "no." Seventeen drivers mentioned that they were confused by the instruction to "bear (right or left) to stay on (street)" instruction. More drivers commented on this instruction as confusing than were observed to make wrong turns because of the instruction. One possible explanation for the confusion is that in most instance, had the

16 The test began before dusk but it was dark by the time the participants finished driving.

system said nothing the driver would have stayed on the same road. The instruction was generated whenever the geometry of the map data base indicated there was a street onto which the driver could "turn" by going straight. The map data base did not contain information as to how the driver might perceive the intersection. In some instances a bear left message may be appropriate, and in others it may not, but the TravTek data base did not, in the opinion of these drivers, correctly distinguish these situations. One driver recommended changing the message to "ahead (street) curves to the (right or left)."

Weird or unusual routing was mentioned by 15 drivers. For a few weeks after the city changed the direction of flow on a particular street, TravTek advised the driver to turn the wrong way on that street. The TravTek data base was updated to correct this problem. Other remarkable routings were an instruction by Navigation Plus to take a section of I-4 that separated through traffic from merging traffic. Travel time on this section of roadway was indeed shorter than on the portion of roadway that was intended for through traffic. However many drivers assumed that the system routed them onto the transitional lanes as preparation to exit. Thus those drivers merged into the right lane (there were three lanes on this transitional section of roadway). They were surprised when TravTek instructed them to merge back onto I-4. A few were trapped by traffic in the right lane and thus had to exit (and make a wrong turn). Another non-intuitive routing had the driver exit I-4 north bound and immediately thereafter enter I-4 south bound. The street used to go under the freeway actually continued on and rejoined the planned route. Had the TravTek route not rejoined the freeway, 1.24 miles (2 km) would have be cut out of the trip. In this instance, TravTek did not take the shorter route because the street, Lakeview, was classified as residential: the TravTek system avoids residential streets except when they are necessary to reach the destination.

Table 45. While driving with TravTek, were there any situations where TravTek was not helpful?

Response	*Frequency*	*Percent of Responses*	*Percent of Drivers*
None — there was no instance where TravTek was not helpful.	***105***	49.8%	50.5%
Other — Catch all category for responses that were made by only one driver.	31	14.7%	14.9%
Bear right/left confusing — TravTek's instruction to bear right/left was confusing.	17	8.1%	8.2%
Weird routing — sometimes TravTek's suggested maneuver did not seem to make sense.	15	7.1%	7.2%
Problems with voice — Some said the voice was difficult to understand. Others said the voice was distracting when it came on while the driver' s attention was required elsewhere.	9	4.3%	4.3%
Using TravTek in parking lots — initial instructions from TravTek were unclear as to how to exit parking lots.	7	3.3%	3.4%
Need more warning before turns — there was not enough advanced warning of upcoming turns.	5	2.4%	2.4%
Instructed to turn too early — the instruction to turn was delivered prematurely.	5	2.4%	2.4%
Specific instance in which the driver became confused — some instructions were confusing.	5	2.4%	2.4%
Tracking problems — it was confusing when TravTek incorrectly displayed the car's current location.	5	2.4%	2.4%
No response — driver did not answer this question.	4	1.9%	1.9%
In heavy traffic — TravTek was distracting while driving in heavy traffic.	3	1.4%	1.4%
Tic marks on guidance display — Some said the last tic mark on the display was difficult to see.	3	1.4%	1.4%
Street names not consistent with street signs — conflicts between street signs **and** street names used by TravTek.	2	0.9%	1.0%

The training given to participants in this study was unique: It is probably not similar to the kind of training users of a commercially deployed system would receive. None-the-less we report driver comments on the training they received in table 46.

Table 46. Did the training you were given prepare you for driving with TravTek?

Response	*Frequency*	*Percentage of Responses*	*Percentage of Drivers*
Yes	153	**68.9%**	**73.6%**
Training was good	25	11.3%	12.0%
Training was too brief	11	5.0%	5.3%
Training was not good	10	4.5%	4.8%
No response — driver did **not** answer this question	10	4.5%	4.8%
Other — Catch all category for responses that were made by only one driver.	8	3.6%	3.8%
No	5	2.3%	2.4%

Suggestions for improvements to the TravTek system are shown in table 47. The quality of the synthesized voice was most frequently cited as needing improvement. The second most requested improvement was for easier input of text into the system. Yoked Study participants entered at least six different destinations into the system and all of those were entered by typing two street names using a touch keypad on the TravTek video display. An example of the touch keypad is shown in figure 28. Four letters or numbers were displayed on each of nine keys. Entering a letter or number was a two step process. First, the key that included the target letter among three others was pressed. This caused presentation of four additional keys at the bottom of the display. Second, the desired number or letter was then selected from the bottom row. It was generally only necessary to enter the first four letters of a street name before pressing DONE. Pressing DONE would bring up a list of streets beginning with those letters. The touch keypad arrangement enabled entry of streets without the requirement for a dedicated keyboard. However many users found the implementation somewhat awkward.

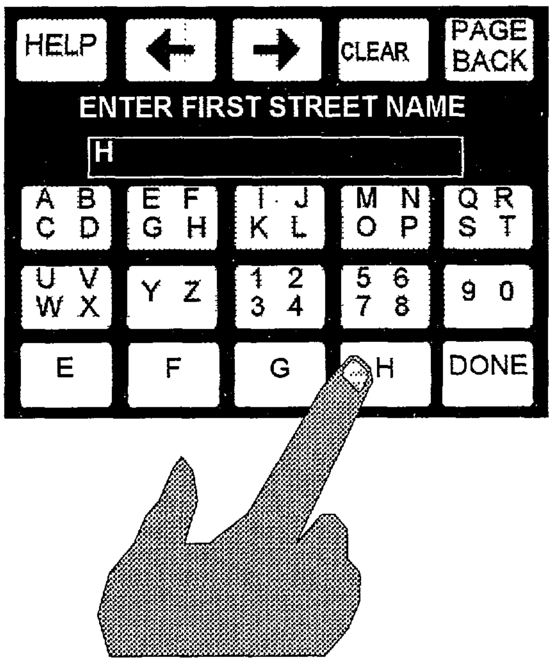

Figure 28. An example of the TravTek "keyboard" interface.

Table 47. can you think of anything that could be improved about TravTek to make it better?

Response	*Frequency*	*Percent of Responses*	*Percent of Drivers*
Improve voice — the clarity of the voice guidance needed improvement.	64	25.7%	30.8%
None — nothing needs to be improved.	47	18.9%	22.6%
Other — Catch all category for responses that were made by only one driver.	46	18.5%	22.1%
Improve keyboard interface — the user-friendliness of the keyboard interface needed improvement.	20	8.0%	9.6%
Heads-up display — the display needs to be positioned so that drivers can keep their head up while driving.	11	4.4%	5.3%
Ability to zoom in and out while driving — the capability to change the scale on the route map while moving.	11	4.4%	5.3%
No response — driver did not answer question.	10	4.0%	4.8%
Capability of voice input — would like to use voice commands to control TravTek.	6	2.4%	2.9%
Screen size **—** a larger visual display is needed.	5	2.0%	2.4%
Bear right/left — change the bear right/left instruction.	5	2.0%	2.4%
Include route preview — the ability to view the entire route before beginning to drive.	4	1.6%	1.9%
More advanced warning of next turn — increase distance before first announcement of direction of next turn.	4	1.6%	1.9%
Provide exit numbers — display freeway exit numbers.	4	1.6%	1.9%
Improve tracking — the computation of present position needs improvement.	3	1.2%	1.4%
Earlier instruction to turn **—** instruction to turn should come sooner.	3	1.2%	1.4%
Eliminate park restriction if passenger in car — permit passenger to enter destination into system while car is in gear.	2	0.8%	1.0%
Provide speed limit information — the speed limit should be displayed.	2	0.8%	1.0%
Provide more information about turns — it would be helpful if TravTek instructed whether the next turn was at a light, stop sign, or a small residential street.	2	0.8%	1.0%

DISCUSSION

As with the Results section, the discussion focuses individually on each study issue:

1. Does the availability of real-time traffic information and electronic navigation assistance improve trip efficiency?
2. Does the availability of real-time traffic information and electronic navigation assistance improve overall driver performance?
3. What are drivers willing to pay for TravTek features and functions?
4. Is the TravTek system usable and useful?

Issue 1: Does the Availability of Real-Time Traffic Information and Electronic Navigation Assistance Improve Trip Efficiency?

In the Results section, travel time was defined as the key measure of performance for trip efficiency. Both trip planning time and en route time were defined as components of travel time. Both of these measures assume that the individual driver is the beneficiary of increases in trip efficiency. Indeed, if there is to be a market for ATIS devices such as the TravTek system, an individual benefit must be expected. However, the individual possessing the TravTek system is not necessarily the only one to benefit from its use. To the extent that the TravTek system contributes to *network efficiency,* all drivers on the network may benefit. Network efficiencies might be derived if TravTek causes vehicles to avoid congested roadways thereby preventing the TravTek vehicles from exacerbating existing congesting. The TravTek *Modeling Study Final Report* examines network efficiency directly.[16] Here, Yoked Driver Study findings that have implications for network travel time benefits are discussed.

With respect to travel planning time, the results are clear: drivers who are unfamiliar with an area and are traveling to a new, hard-to-find destination, can expect to save considerable planning time with TravTek like systems. In this study an 80 percent saving in planning time was observed. Comparable time savings can probably be expected for locally familiar drivers who plan trips to hard to find destinations. Although data from TravTek pilot testing has not been systematically analyzed, locally familiar drivers who participated in pilot testing experienced similar savings when using TravTek to plan trips. Furthermore, the procedures used in this study provided TravTek planning times that were probably longer than typical planning times. Trip planning in this study required drivers to input intersection names. The TravTek system permits the storage of destinations so that on future trips to the same destination, the destination can be quickly selected from a stored list. Improvements in computer processing speed can also be expected to decrease planning time in future systems.

An overall en route travel time benefit attributable to the TravTek route planning and guidance functions was observed. However, this benefit was not observed on all O/D’s, and was only statistically reliable for one of the O/D’s Because the reasons for differences between O/D's are not well understood, generalization of a benefit beyond the O/D's used in this study is problematic. The results suggest an overall travel time benefit to drivers using TravTek like ATIS navigation aids, but further research is required to explain trip specific differences in benefit.

No benefit of real-time traffic information was observed for individual drivers. This finding does not mean that real-time information is not useful. There are several limitations on the present findings. Among these limitations are:

- Drivers were not locally familiar.
- Tests were performed in a single area of the network.
- Tests were conducted in a unique traffic network.
- Only one limited access roadway was available.
- Distance between origins and destinations was relatively short.
- Network had a limited number of major alternative arterials.

Furthermore, evidence was found that, with improved information, benefits to individuals might have been derived. On days when the Navigation Plus vehicles planned a different route, travel times for the Navigation vehicles were significantly longer than on days when the Navigation Plus and Navigation configurations planned the same route. Whereas the Navigation Plus vehicles' stimulus for considering a different route is validated by this finding, evidently the available information was not sufficient to correctly select between available alternatives. Given that the Navigation Plus vehicles planned a different route and traveled significantly farther, and that they traveled farther on arterials (see table 15), the finding of no significant travel time difference between Navigation Plus and Navigation configurations is evidence that the real-time information was at least marginally useful.

Given that the Navigation Plus vehicles drove farther, on average, and did not have significantly longer travel times, they must have taken routes that were less congested than routes taken by Navigation configuration vehicles. Both the observer log and in-vehicle log support the suggestion that the Navigation Plus routes were less congested. Marginally significant trends toward Navigation Plus encountering less congestion were obtained ($0.10 < p < 0.05$).

There also is evidence that a network travel time benefit derived from the real-time information. At the time that the test O/D's were run, I-4 was congested. On the freeway links used by the Navigation configuration, average speed between 5:30 PM and 6:00 PM was 48 to 64 km/h whereas the posted speed limit was not less than 81 km/h.[16] Under congested conditions, each additional vehicle that enters such a slow down adds to the travel time of all vehicles that follow it until the queue of vehicles clears. Thus, if a vehicle entered I-4 at 5:45 PM and traveled 6 km, and if the queue did not clear until 6: 15 PM, that vehicle added a small travel time delay (perhaps less than a second) for every vehicle that followed it for the next 30 min. A half second delay added to the travel time of 1000 vehicles results in a total network delay of 8.33 min. On arterials, congestion occurs as signalized intersections. Assuming congestion is not heavy (that is all vehicles queued at an intersection clear the intersection in one cycle of the signal) the delay added by an additional vehicle lasts only the cycle time of a control signal. The arterials taken by Navigation Plus vehicles in this study were not heavily congested: if they had been, Navigation Plus travel time would have been considerably longer than was observed. Thus, when Navigation Plus vehicles diverted from the Interstate, they effectively reduced their own impact on total network delay and thereby afforded a network travel time benefit.

Issue 2: Does the Availability of Real-Time Traffic Information and Electronic Navigation Assistance Improve Overall Driver Performance?

Five variables were considered in assessing TravTek's effect on driving performance:

- Accidents.
- Close Calls.
- Maneuver abruptness.
- Subjective Driver Workload.
- Perceived driving performance benefits.

Participants in the experiment experienced no accidents. Total distance traveled was low, 16 100 km, so the lack of accidents is not very informative.

The observers logged 15 close calls. Frequency of close calls was too small to support statistical analyses. However, because there were proportionally twice as many close calls with the Control configuration as in the two TravTek configurations, the trend is consistent with a safety benefit for navigating with TravTek.

Assessment of abrupt turns, preparation for turns and turn signal use indicated no significant differences in performance among the three configurations.

Participants rated visual workload significantly lower with two TravTek configurations than in the Control configuration. Although overall workload ratings were quite low, this finding may be suggestive of driving performance and safety benefits. Subjective workload ratings are most useful when task difficulty is below the level where performance decrements can be observed. It is theorized that were the driving task to become more difficult, the conditions in which workload is rated higher are the more likely to show performance decrements or to show decrements earlier.

The significant workload rating reduction was for visual effort. In briefing the workload rating method, visual effort was anchored by examples that stress ability to scan the environment for necessary information. A low visual effort rating was anchored by the case where the driver has spare capacity to look at non-driving related objects. Moderate stress was described as having no spare capacity but still being able to see everything necessary to drive and navigate. High stress was described as not having sufficient ca pacity to look at everything needed to drive and, or, navigate well. Participants rated their visual effort as lower with TravTek than without it. Workload ratings indicated that the TravTek Guidance Display with Voice Guidance reduced drivers' visual effort relative to navigating "as they normally would."

Questionnaire responses were mildly positive in suggesting a perceived safety benefit. Ratings of the item "Do you think TravTek helped you drive more safely" averaged 4.73. The anchors for this question were:

1. Didn't help me drive safely.
6. Helped me drive more safely.

In terms of perceived effects on driving performance, as assessed by questionnaire responses, drivers indicated that:

- TravTek helped them pay more attention to their driving.
- TravTek did not interfere with their driving.
- The Voice Guide helped them pay more attention to their driving; did not interfere with their driving; and helped them find their way.
- TravTek helped them find their way.

Whereas the Voice Guide was rated as favorably as the rest of the TravTek system, the magnitude of the favorable responses did not covary with other favorable responses. Perhaps this was because of sometimes strong negative reactions to the quality of the synthesized speech. Negative reactions to the speech were reflected in the debriefing responses where voice quality was the most frequently cited "least favorite" TravTek feature.

Issue 3: What are Drivers Willing to Pay for TravTek Features and Functions?

Whether as an add-on or as an option on a new car, half the participants indicated they would pay $1,000 or more for a TravTek system like the one they drove. As indicated by the amount they said they were willing to pay, drivers valued TravTek features in the following order:

1. Route Guidance.
2. A moving map display with present location indication.
3. Real-time traffic information.

The findings were similar for value in a rental car. Fifty percent of the participants stated they would pay at least $28/week additional for a system like TravTek in a rental car.

In marketing ATIS devices that feature route guidance and navigation assistance, it appears that emphasis might be best placed on benefits for business and pleasure travel, Nearly all the participants rated TravTek as useful for vacation and business travel, but fewer than 50 percent thought TravTek would be useful for "at home" driving. Although the participants in this **study** were tourists and therefore potentially biased, it seems reasonable for people to expect TravTek like devices to be most useful when they are traveling away from home. However, the reader is referred to the utility and value ratings of participants in the TravTek *Evaluation Task* B_2 *Local Users Study* final report for utility ratings from individuals who used the system for 2 months of "at home" driving.[6]

Issue 4: Is the TravTek Driver Interface Usable and Useful?

As a navigation aid, study participants considered TravTek very useful. On average, respondents strongly agreed with six statements that the navigation functions were either useful or "helped me find my way."

Debriefing responses were equally positive about the utility of the navigation functions. Voice Guidance, the Guidance Display and route guidance were the most frequently cited favorite features. In debriefings, participants identified the OK NEW ROUTE feature as especially helpful.

The usability negatives uncovered during the debriefings were the Voice Guide's sound quality and the touch keypad interface: these turned up as frequently cited least favorite features.

The evidence from training runs suggests that TravTek is easy to learn. Overall, each of the 10 questions concerning system functions was answered correctly on the first trial 75 percent of the time. On average, the observers rated users proficient in destination entry after two destinations had been entered. Finally, most participants were able to correctly demonstrate use of system features such as adjusting the voice volume or swapping the map, the first time they were asked to do so. The complexity of the TravTek system appears to have been well concealed from its users.

CONCLUSIONS

The Yoked Drivers Study demonstrated a travel time benefit from use of the TravTek system for route planning and route guidance. The largest benefit was in trip planning where an 80 percent saving was observed. The en route travel time saving was smaller but still statistically reliable. A benefit to the individual driver from the availability or real-time traffic information was not observed. However a network benefit was posited based on the finding that the vehicles with real-time information avoided contributing to queue build-up on the freeway and did not add substantially to arterial queue build-up.

The findings for real-time information benefits must be viewed with caution as they (1) may not be typical of other networks; (2) may not be the same for locally familiar drivers on the same network; and (3) may be different with better quality real-time information.

There was no evidence from the performance data that the TravTek system presents a safety hazard. Furthermore, subjective workload estimates were lower for the TravTek configurations than for drivers navigating with either a paper map or transcribed instructions. In addition, drivers indicated in questionnaire responses that they drove more safely with TravTek.

Participants indicated that they would be willing to pay about $1000 for system in a new car, or for a TravTek like add-on to an existing car. They also indicated that they were willing to pay an additional $28/week for TravTek features in a rental car. They placed the greatest dollar value on route guidance, less for electronic maps without route guidance, and the least for real-time traffic information.

Overall, participant found the TravTek to be both useful and easy to use. The majority of comments were favorable. It was interesting that the most frequently cited “favorite” feature, the Voice Guide, was also most frequently mentioned as needing improvement.

REFERENCES

1 Fleischman, R. N. (1991). Research and evaluation plans for the TravTek IVHS operational field test. In *Conference Record of Papers at the 2nd Vehicle Navigation and Information Systems (VNIS '91) Conference,* Dearborn, Michigan.

2 Rillings, J. H., and Lewis, J. W. (1991). TravTek. In *Conference Record of Papers at the 2nd Vehicle Navigation and Information Systems (VNIS '91) Conference*, Dearborn, Michigan.

3 *Highway Capacity Manual.* Transportation Research Board, National Research Council, Washington, DC, 1985.

4 TravTek *Evaluation Task C_3 Camera Car Study.* Currently Unpublished. Federal Highway Administration, Washington, DC, 1995.

5 Gopher, D. and Donchine, Emanuel. (1986). Workload-an examination of the concept. In K. R. Boff, L. Kaufman, and J. P. Thomas (Eds.) *Handbook of Perception and Human Performance, New* York: Wiley.

6 TravTek *Evaluation Task C_3 Orlando Test Network Study.* Currently Unpublished. Federal Highway Administration, Washington, DC, 1995.

7 Pelli, D. G., Robson, J. G. and Wilkins, A. J. (1988). Designing a new letter chart for measuring contrast sensitivity. *Clinical Vision Sciences,* **2, 187-** 199.

8 Ekstrom, R. B., French, J. W., Harman, H. H., and Dermen, D. (1976). *Kit of Factor-Referenced Cognitive Tests* 1976. Princeton, NJ: Educational Testing Service.

9 Kozlowski, L. T., and Bryant, K. M. (1977). Sense of direction, spatial orientation, and cognitive maps. *Journal of Experimental Psychology: Human Perception and Performance, 3, 590-598.*

10 TravTek *Evaluation Task B Rental User Study and Local User Study.* Currently Unpublished. Federal Highway Administration, Washington, DC, 1995.

11 TravTek *Evaluation Task F_1 Architecture Study.* Currently Unpublished. Federal Highway Administration, Washington, DC, 1995.

12 *Task C_1 Yoked Driver Study Final Detailed Test Plan.* Unpublished document submitted to Federal Highway Administration.

13 Yoked Driver Study Questionnaire Results, "Your TravTek Experience." Unpublished document submitted to Federal Highway Administration.

14 TravTek *Evaluation Task* E_1 *Modelling Study*. Currently Unpublished. Federal Highway Administration, Washington, DC, 1995.

HSR-12/8-95(500)E W