TravTek Evaluation
Orlando Test Network Study

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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.

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Traffic Operations Research and
Development

NOTICE

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16. Abstract

The Orlando Test Network Study was one of a series of 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 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 this study was to evaluate the effects of alternative driver interfaces on driver performance, navigation performance, driver perception, driver preference, and willingness-to-pay.

A controlled experiment was conducted in which up to six TravTek vehicles traveled the same origin to destination (O/D) pairings to evaluate six alternative information presentation configurations: five TravTek alternatives and a control configuration. Three visual display conditions were tested: a moving map display, a symbolic guidance display, and a condition with no visual display. Two aural conditions were tested in combination with the three visual conditions: synthesized voice guidance and no voice guidance. The six information presentation configurations were evaluated both in the day and at night. Five of six combinations utilized the TravTek and one configuration (no visual display and no voice guidance) was considered the Control condition. The drivers in the Control condition had to plan and navigate to their destination as "they normally would" without the use of automated route planning and route guidance. Data from 3 18 drivers are presented.

TravTek benefits to individual drivers included travel time savings and a reduction in perceived workload. Both the moving map and simplified turn-by-turn visual displays were very effective compared to the Control condition, particularly when the visual displays were supplemented with synthesized voice guidance. 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.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Flhd	Symbol
	LENGTH			
in	inches	254	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
	AREA			
in2	square inches	645.2	square millimeters	**mm²**
ft2	square feet	0.093	square meters	m2
yd2	square yards	0.636	square meters	m2
ac	acres	0.405	hectares	ha
mi2	square miles	2.59	square kilometers	km2
	VOLUME			
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.765	liters	L
ft3	cubic feet	0.026	cubic meters	m3
yd3	cubic yards	0.765	cubic meters	m3
NOTE: Volumes greater than 1000 I shall be shown in m3.				
	MASS			
oz	ounces	26.35	grams	**g**
lb	pounds	0.454	kilograms	**kg**
T	short tons (2009 lb)	0.907	megagrams (or 'metric ton")	**Mg (or "t")**
	TEMPERATURE (exact)			
"F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	"C
	ILLUMINATION			
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m2	cd/m2
	FORCE and PRESSURE or STRESS			
lbf	poundforce	4.45	newtons	N
lbf/in2	poundforce per square inch	6.69	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
mm	millimeters	0.039	inches	in
m	meters	3.26	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
	AREA			
mm2	square millimeters	0.0016	square inches	in2
m2	square meters	10.764	square feet	ft2
m2	square meters	1.195	square yards	yd2
ha	hectares	2.47	acres	ac
km2	square kilometers	0.366	square miles	mi2
	VOLUME			
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m3	cubic meters	35.71	cubic feet	ft3
m3	cubic meters	1.307	cubic yards	Yd3
	MASS			
9	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
	TEMPERATURE (exact)			
"C	Celcius temperature	1.8C + 32	Fahrenheit temperature	"F
	ILLUMINATION			
lx	lux	0.0929	foot-candles	fc
cd/m2	candela/m2	0.2919	foot-Lamberts	fl
	FORCE and PRESSURE or STRESS			
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch ,	lbf/in2

SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E360.

(Revised September 1993)

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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). The TMC broadcast updated travel times for TravTek traffic links to the TravTek vehicles once each minute. The TravTek vehicles broadcast their link travel times back to the TMC for transmission to the other TravTek vehicles. The vehicles had software and computers that provided route planning, route guidance, and a data base of local services and attractions.

The Orlando Test Network Study was one of several evaluation studies conducted as part of the operational test. This study examined the effectiveness of the TravTek route planning and route guidance user interface. The primary purpose of this study was to evaluate the effects of alternative driver interfaces on driver performance, navigation performance, driver perception, driver preference, and willingness-to-pay.

The methodology called for up to six TravTek vehicles to travel the same origin to destination pairs (O/D's) to evaluate six alternative information presentation configurations: five TravTek alternatives and a control configuration. Both visual and aural modalities were examined. Three visual display conditions were tested: a moving map display, a symbolic guidance display, and a condition with no visual display. Two aural conditions were tested in combination with the three visual conditions: synthesized voice guidance and no voice guidance. The six information presentation configurations were evaluated both in the day and at night. Five of six combinations utilized the TravTek Navigation mode and one configuration (no visual display and no voice guidance) was considered the Control condition. The drivers in the Control condition had to plan and navigate to their destination as "they normally would" without the use of automated route planning and route guidance.

A total of 322 drivers participated in the Orlando Test Network Study. Of these drivers, 249 completed each of three origin/destination (O/D) trips. The results showed that vehicles using the TravTek navigation system derived a large saving in trip planning time compared to the Control condition. Vehicles using TravTek also showed a significant en route travel time saving.

Near accident (close call) and abrupt maneuver performance measures indicate that driver performance with the TravTek configurations was at least as good as that in the Control configuration. Drivers' subjective workload estimates suggest a reduction in visual effort when using the TravTek system compared to the Control configuration. Furthermore, in

questionnaire responses, drivers indicated that TravTek helped them drive more safely and helped them find their way. Although there were no significant differences among the six display configurations with respect to the probability of making a wrong turn, there were qualitative differences in the types of turn errors that drivers made. That is, when using conventional navigation techniques drivers were most likely to err by bypassing planned turns. With TravTek configurations, rather than overlooking a turn, drivers were more likely to turn too soon or in the wrong direction

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 an additional $28 per week 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. Despite the finding that the sound quality of the Voice Guide was most frequently identified as the least liked TravTek feature, and the feature that most needed improvement, TravTek's Voice Guide was also the most frequently named "favorite" TravTek feature. Evidence is also presented that suggests that the TravTek system was easy to learn and easy to use.

INTRODUCTION

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 Evaluation consisted of a series of behavioral, engineering, and modeling studies designed to evaluate the TravTek system from multiple perspectives. The Orlando Test Network Study was a behavioral and systems study to evaluate the benefits of:

- Alternative TravTek visual and aural display configurations.
- TravTek's route planning and route guidance functions,

The study examines benefits with respect to:

- Trip efficiency.
- Navigation performance.
- Driving performance.
- Driver preference.
- Driver perception.
- Willingness-to-pay,

TravTek system goals may be viewed from multiple perspectives. From a driver's perspective, goals included navigation assistance, congestion avoidance, reduction in trip times, and access to information about unfamiliar areas. 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 fuel economy, and increased safety. The perspective of the Orlando Test Network Study is primarily that of the drivers. The objective of the Orlando Test Network Study was to assess the influence of in-vehicle TravTek display configurations on driver navigation and driving performance as well as to assess driver preferences. Trained observers rode with volunteer test participants to record performance measures while the participants drove to unfamiliar destinations. Use of five TravTek vehicle configurations and a control configuration was observed both at night and during the daytime.

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 were important to the objectives of the Orlando Test Network Study. The reader may refer to Rillings and Lewis for additional details about the system.(') 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.

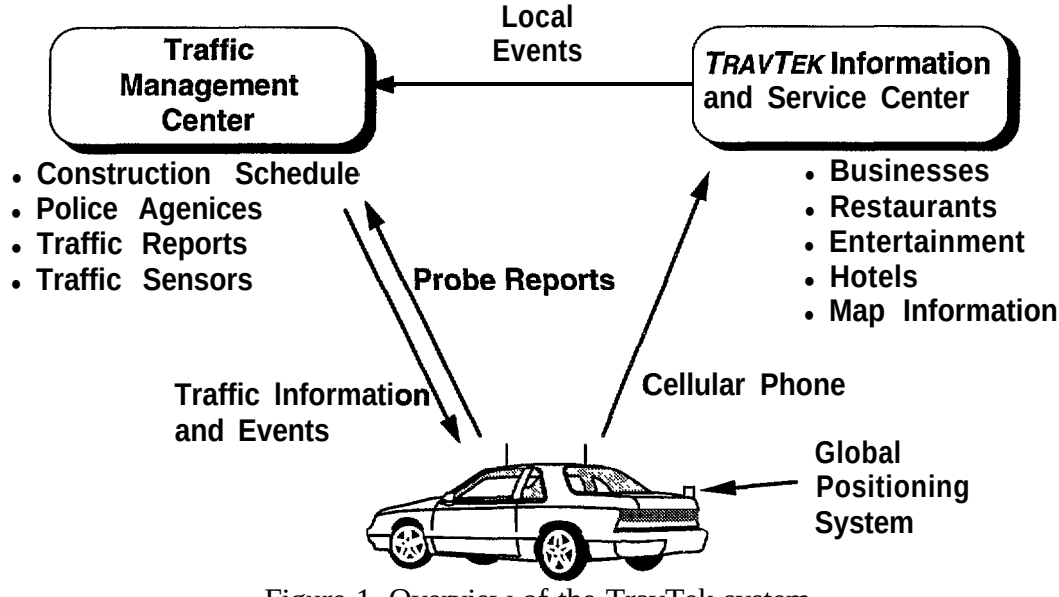

Figure 1. Overview of the TravTek system.

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 traffic information inputs to route planning. Some of the features of the TravTek system were:

- **Navigation —** A variable-scale color map was displayed on a 128 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 a horizontally centered icon positioned three-fourths of the distance from the top of the screen. When the vehicle was in DRIVE the map was displayed with 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 subject 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 a maneuver-by-maneuver *Guidance Display* and a *Route Map.* The Route Map showed the planned route as a magenta line traced

over the Navigation display moving map. 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. Human factors issues that were considered in the design of the TravTek driver interface are discussed by Carpenter, Fleischman, Dingus, Szczublewski, Krage, and Means.(2 The Guidance Display had been designed to reduce information density, compared to a moving map, while providing the information the driver needs to navigate. Information density was thought to contribute to a tendency for some drivers to gaze at Route Map like displays for periods that were longer than the designers felt desirable. 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. Should the driver deviate from a planned route, an OK New Route button was provided on the steering wheel hub. The TravTek system always offered drivers the opportunity to select a new route whenever it detected a deviation from its planned route. The new route took into account the vehicle's current location and heading and thus took into account that the previously planned route might not be the best one given the new circumstances.

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. Because evaluation of real-time information benefits was not an objective of the Orlando Test Network Study, the real-time information function was disabled for this study. The study was not conducted during peak travel periods. During non-peak travel periods the routes selected by the TravTek system were usually the same regardless of real-time information availability.

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 available to the driver. This enabled the help desk operators to replicate problems encountered by drivers, or to plan routes just as they are planned in the vehicle. In the Orlando Test Network Study, participants in the Control condition (drivers using TravTek vehicles but not using TravTek functions) were permitted to call the help desk for help in planning trips, much as they might call a friend whose home they were having trouble locating.

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.

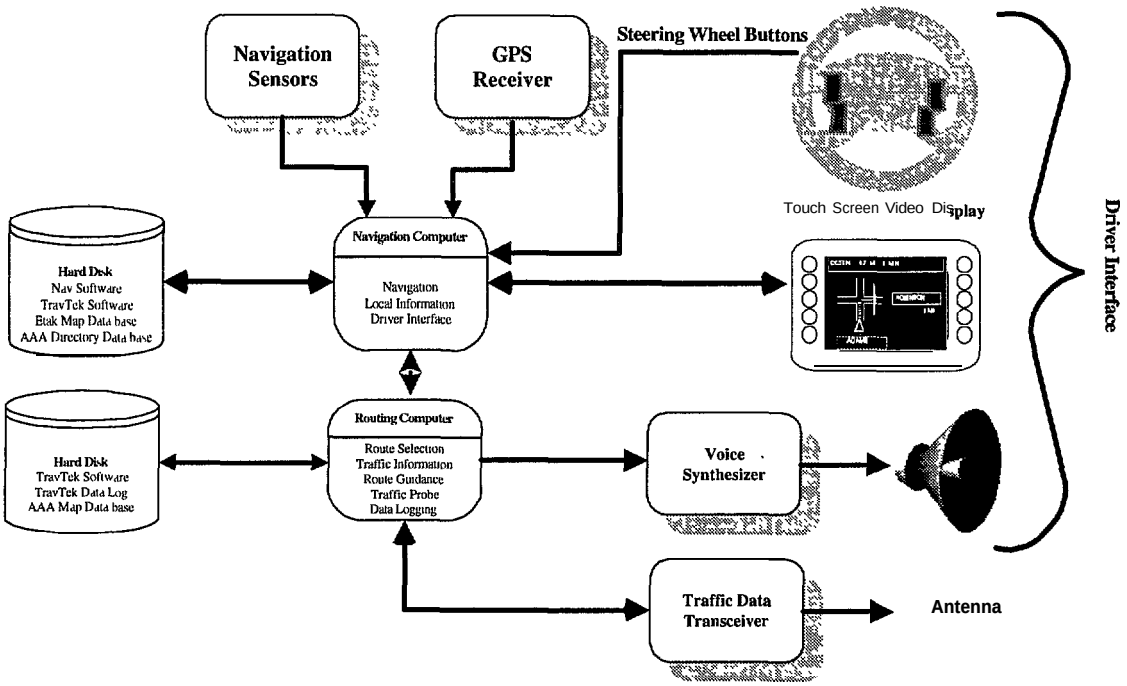

Figure 2. Schematic representation of the TravTek vehicle architecture.

PURPOSE OF TEST

The Orlando Test Network Study addressed five primary issues:

1. Does TravTek improve driver navigation?
2. Does TravTek improve overall driver performance?
3. Does driver interface usability vary with display configuration?
4. Do drivers perceive TravTek as useful, usable, and safe?
5. Do drivers prefer particular TravTek display configurations?

The following section details the Orlando Test Network Study objectives in addressing 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, Orlando Test Network Study objectives are described for each of the five primary issues.

Issue 1: Does TravTek improve driver navigation?

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

Table 1. Does TravTek improve driver navigation?

Objective	Hypothesis	Measure Of Effectiveness	Measure Of Performance	Data Source
Assess the influence of TravTek display configurations on driver navigation performance	TravTek's route planning function results in reduced trip planning time, travel time and travel distance and these benefits vary as a function of display configuration, and ambient light	I. Trip Length	• Trip Planning Time - Time En Route • Distance En Route	• Observer
	TravTek Route guidance displays reduce navigation error and this benefit varies as a function of display configuration, and ambient light	2. Navigation Errors	• Reach Destination (yes or no) • Number of Wrong Turns • Time off Route	• Observer

Together, trip planning time and time en route are referred to as *travel time.* Trip distance includes both distance traveled on the planned route and distance traveled due to navigational errors. 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. Furthermore, the Guidance Display, which was designed to reduce information density relative to the Route Map, might reduce attentional demands on the driver at the expense of providing insufficient information. Therefore, we examine the effect of display 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 to notice deviation from the planned route are also examined.

The data used to address this issue were recorded by observers who rode with participants during test runs.

Issue 2: Does TravTek improve overall driver performance?

Driver performance variables not directly related to navigation are explored under issue 2. Whereas the TravTek system is intended to aid drivers in navigating to destinations, and to avoid congestion while doing so, use of TravTek while operating a moving vehicle might affect other aspects of the driving task. The impact of using TravTek might improve driving performance to the extent that it frees drivers of some need to attend to navigation thus enabling them to devote more attention to basic driving tasks. However, if the TravTek system distracts drivers, or draws more attention to navigation than would otherwise be required, TravTek might detract from driver performance. The objective here, was to assess the effect of TravTek on driving performance and subjective workload.

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

Table 2. Does TravTek improve overall driver performance?

Objective	Hypothesis	Measure of Effectiveness	Measure of Performance	Data Source
• Assess the effect of TravTek on: • Driver performance • Workload	• Driver performance varies as a function of display format and ambient light • Driver workload varies as a function of display format and ambient light	• Driving performance or quality • Driver workload	• Maneuver abruptness • Number of accidents • Number of near accidents • Subjective workload	• Observer

In this study driving performance is 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. For a detailed analysis of the effects of the TravTek system on driver performance where additional instrumentation was used, the reader is referred to the *TravTek Evaluation Task C3 Camera Car Study* final report.(3)

Driver performance measures are not independent of navigation performance. For instance, maneuver abruptness was defined as: (a) getting into the proper turn lane 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 for the particular driver. All of the abruptness measures were relative to the way the driver normally drives, and required the assumption on the part of the observer that the abruptness of the turn 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. Subtle changes in demands on the driver might only be observable in performance during rare emergency situations or when the driver becomes fatigued. In an attempt to assess effects of TravTek that might not be readily observable in performance measures, subjective workload measures were obtained. Subjective workload measures were 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 on an effort continuum at which performance is reliably degraded.(4) Thus, subjective workload measures may be sensitive to task differences that performance measures are not. However subjective workload measures require the assumption that drivers are aware of changes in demands on their limited attentional capacity.

Accidents and near accidents are examined to assess the effect of the TravTek system on safety.

The data used to address this issue were recorded by observers who rode with participants during test runs.

Issue 3: Does driver interface usability vary with display configuration?

In part, the usability of TravTek can be inferred from the findings under the first two issues. Under issue 3, additional data that reflect on the usability of TravTek are examined.

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

Research objectives associated with usability are summarized in table 3.

Table 3. 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 use • TravTek is easy to learn	• Usability • Learnability	• Errors in learning • Trials to correct responding	• Observer

Issue 4: Do drivers perceive TravTek as useful, usable, and safe?

Regardless of what benefits our measures of navigation and driving performance suggest, if drivers do not perceive the benefits, the realization of those benefits in a deployed system may be dubious. That is, if drivers do not perceive system benefits, they are unlikely to purchase or use the system. Therefore it is reasonable to explore drivers' stated perceptions of the TravTek system. Research objectives associated TravTek on driver perceptions of usefulness, usability, and safety are summarized in table 4.

Table 4. Is the TravTek system perceived as useful, usable, and safe?

Objective	Hypothesis	Measure of Effectiveness	Measure of Performance	Data Source
Assess drivers' perception of TravTek display configurations	Driver perception of TravTek varies as a function of display configuration	• Driver Perception	Subjective Measures: • Utility • Usability • Safety	• Questionnaire • Debrief (Observer)

Study participants' responses to questionnaire items relating to the usefulness, usability and safety of the TravTek system are presented. Also presented are summaries of what study participants had to say'in semi-structured debriefings in which they were free to comment on whatever aspects of TravTek they chose. Many of the user comments reflect usability considerations.

Issue 5: Do drivers prefer particular TravTek display configurations?

No matter how many TravTek benefits are identified or perceived, if people do not purchase TravTek like systems, those benefits will not be realized. Under issue 5, driver preferences for TravTek features and the dollar amount that study participants estimated that they are willing to pay are examined. Willingness to pay for the TravTek system is assessed for (a) a new car, (b) any other car (e.g., current or used), or (c) in a rental car. In addition to assessing willingness-to-pay for the TravTek system, willingness-to-pay is assessed for the navigation, route guidance, and real-time information features.

Research objectives associated with determination of display preferences and willingness-to-pay are summarized in table 5.

Table 5. Do drivers prefer particular TravTek displav configurations?

Objective	Hypothesis	Measure of Effectiveness	Measure of Performance	Data Source
Assess driver preferences for alternative TravTek display configurations	• Drivers will prefer some display configurations over others	• Like-ability ratings • Comments	• Subjective ratings • Debriefing comments	• Questionnaire • Debriefing
Assess driver 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

METHODS

DURATION OF TEST

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

TEST CONFIGURATIONS

Test configurations varied with respect to whether route planning and route guidance were automated or not, and with respect to the how planned routes were displayed.

Route Planning and Route Guidance

TravTek Configuration. The navigation configurations used in this study provided drivers with TravTek route planning and navigation guidance. The vehicles used for this study did not utilize real-time traffic information. Route planning was based on nominal travel times (generally based on the speed limit). The TravTek vehicles used in this study always planned the same route from a given origin to a given destination.

Control Configuration. In the Control configuration, drivers did not have access to TravTek 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 help desk operator. If they elected to use the help desk, the help desk operator asked where they were, and where they wanted to go. The operator then provided scripted turn-by-turn instructions. The routes provided by the help desk operators 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 to 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. In the Control configuration, drivers were required to describe the entire route to the observer before they left the origin. This was to ensure that the observer could detect wrong turns.

Displays

The Orlando Test Network Study evaluated three visual display configurations crossed with two aural display configurations. The visual display configurations were:

- The Guidance Display.
- The Route Map.
- No-visual display.

The’aural display configurations were:

- Voice Guide On.
- Voice Guide Off.

Guidance Display. Figure 3 provides an example of the Guidance Display. The Guidance Display presented a heading-up format with the TravTek vehicle’s present position represented by an arrowhead icon. Below the arrowhead icon text provided the name of the road that the vehicle was on. At the top of the display, distance to the destination, and estimated time to the destination were presented in text. The next maneuver along the route and the relationship of present position to that maneuver were represented by a geometric approximation to the shape of the intersection where the maneuver was to occur. Tic marks above the arrowhead icon represented distance to the maneuver point. On limited access roadways, each tic mark represented 0.32 km (0.2 mi), otherwise each tic mark represented 0.16 km (0.1 mi). Tic marks were displayed when the vehicle was within 1.45 km (0.9 mi) of the maneuver point, or 3.06 km (1.9 mi) on limited access roadways. Distance to the next maneuver was also shown in text below the next street name. A large solid arrow indicated the direction of the maneuver. The name of the road at the next maneuver was presented to the right of the solid arrow. If the next maneuver required two turns in rapid succession, then text underneath the next street name would indicate the direction of the second turn, for example “then left,” or “then right.”

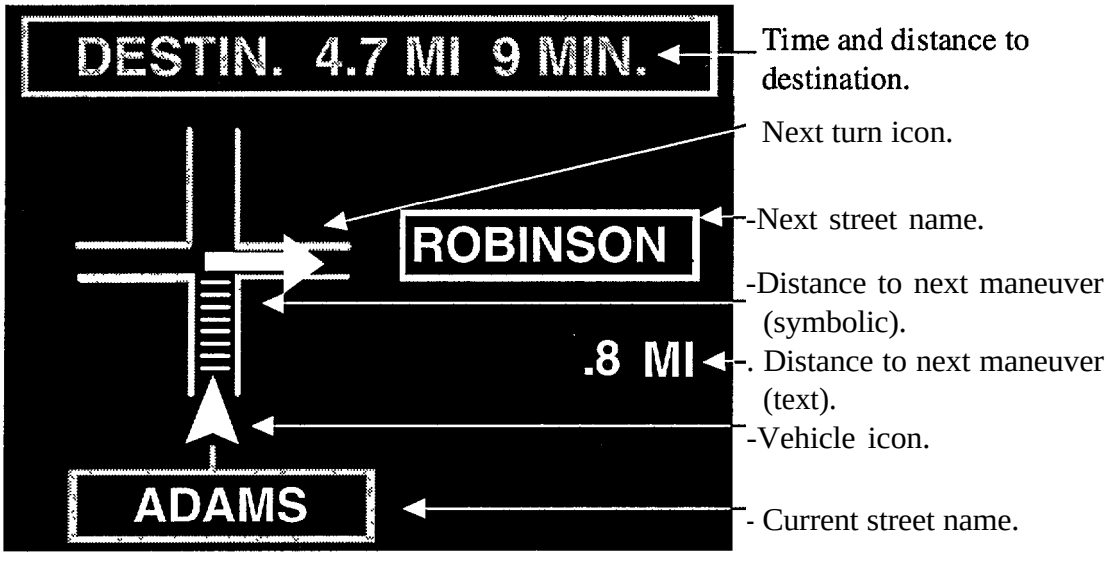

Figure 3. The TravTek Guidance Display.

Route Map. The Route Map display is illustrated in figure 4. The text banner at the bottom of the example, was shown whenever the vehicle deviated from the planned route. 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 displayed three-quarters of the distance from the top of the display and centered horizontally. 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 0.2, 0.4, 0.8 1, l-61, 3.22, 8.05, 16.1, 32.2, and 64.4km(1/8, 1/4, 1/2, 1,2,5, 10,20, and40 mi).

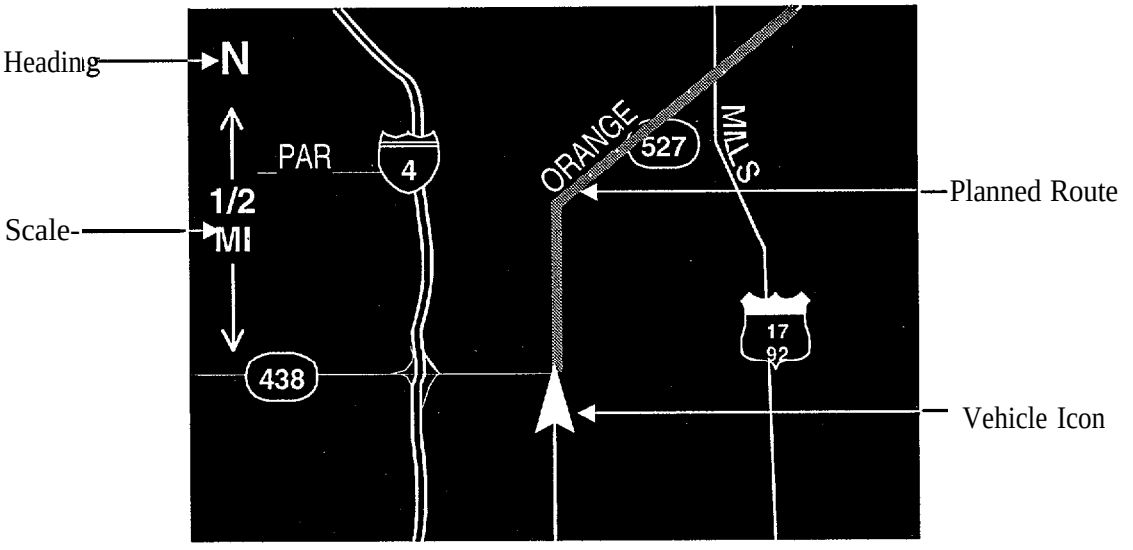

Figure 4. The TravTek Route Map displays the planned route as an overlay on the heading up map display.

No-Visual Display. In the Control condition, no TravTek visual displays were used to present the route information.

Voice Guide. Synthesized voice guidance provided much of the same information that was available on the Guidance Display, that is:

- Directions to get on route at beginning of trip or after deviating from planned route.
- Announcement of next maneuver “in nine tenths miles” (1.45 km), or “in one and nine tenths miles” (3.06 km) on limited access roadways.
- Announcement of next maneuver “in one tenths miles” (0.16 km), or “in two tenths miles” (0.32 km) on limited access roadways.
- Turn direction and street name.
- Off-route warning.
- Proximity to destination announcement.

Although a voice only condition was included in this study to enable separation of the contributions of voice and visual display to driver performance, the voice system was not specifically designed to be used without the presence of a visual display. Driver performance with, and preferences for, a Voice Guide that was optimized to be used without reference to visual displays might yield performance different from that observed in this study.

Summary of Display Configurations Tested. In summary, six configurations were tested:

1. TravTek's Guidance Display with synthesized Voice Guide.
2. TravTek's Guidance Display without synthesized Voice Guide.
3. TravTek's Route Map Display with synthesized Voice Guide.
4. TravTek's Route Map Display without synthesized Voice Guide.
5. TravTek's Voice Guide without TravTek visual displays.
6. A Control condition with neither TravTek's visual displays or synthesized Voice Guide.

TEST CONDITIONS

TravTek Traffic Network

The TravTek Network consisted of 1488 traffic links within the area of coverage for the TravTek system. The TravTek coverage area encompassed approximately 3 108 km2 and included most of the Orlando metropolitan area. The Orlando Test Network Study was conducted on three origin to destination pairs (O/D's) that were located in the central part of the coverage area. Because the O/D's may be key to the generalizability of findings in this study, they are described in detail in the next section.

Origin/Destination Pairs

Three O/D's were selected for the evaluation. These same O/D's were used in two other TravTek evaluation studies: the Camera Car Study, and the Yoked Driver Study.(3,5)

Pre-defined OLD's were necessary to assess, with a relatively small number of trials, the effects of vehicle configuration. More than one O/D was used to minimize the possibility of obtaining results that are unique to a specific O/D. To minimize variability in dependent measures, such as travel time, that were attributable to O/D differences rather than to the experimental manipulation (that is, vehicle configuration), the three O/D's were roughly equated for the following factors:

- Approximate travel time of 20 min during off-peak hours.
- Distance between origins and destinations.
- Number of left and right turns.
- Distance on limited access roadways.
- Number of traffic sensors.
- Number of traffic control signals.
- Level of Service.
- Average number of required stops.
- Number of lanes.

- Direction of flow (i.e., one way, two way).
- Number of intersections or access roads.

With so many factors to equate, no set of real-world O/D's could exactly meet all the criteria. Equating O/D's was complicated by the fact that only the origin and destination were supplied to the drivers. Many different paths could be taken to get from an origin to a destination. Because the route planning mode used for the Orlando Test Network Study always used the same travel time inputs, the system always planned the same routes. Routes selected by drivers in the control condition (no TravTek condition) could be different from those planned by TravTek. In addition, drivers in any test configuration could have unintentionally deviated from their planned routes. Temporary road conditions such as street flooding or construction could also have resulted in alternate routes being taken. Thus the O/D's could be only roughly equated. Maps with the selected O/D's and TravTek's "FASTEST" route between them are depicted in figures 5,6, and 7. These O/D's are hereafter referred to as O/D 1, O/D 2, and O/D 3, respectively. Note that all three routes included a stretch of I-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 were used as part of TravTek's planned route and that could have been used to a greater or lesser degree by drivers who planned their own routes.

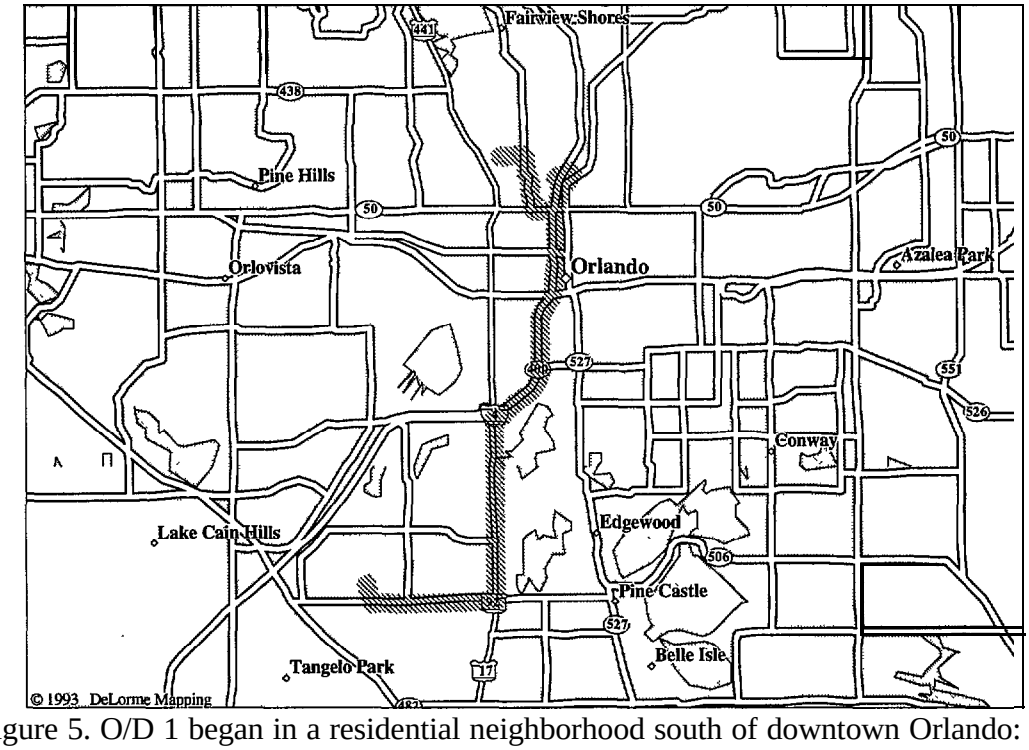

Figure 5. O/D 1 began in a residential neighborhood south of downtown Orlando: and west of Orange Blossom Trail. It ended in a residential neighborhood north of downtown Orlando.

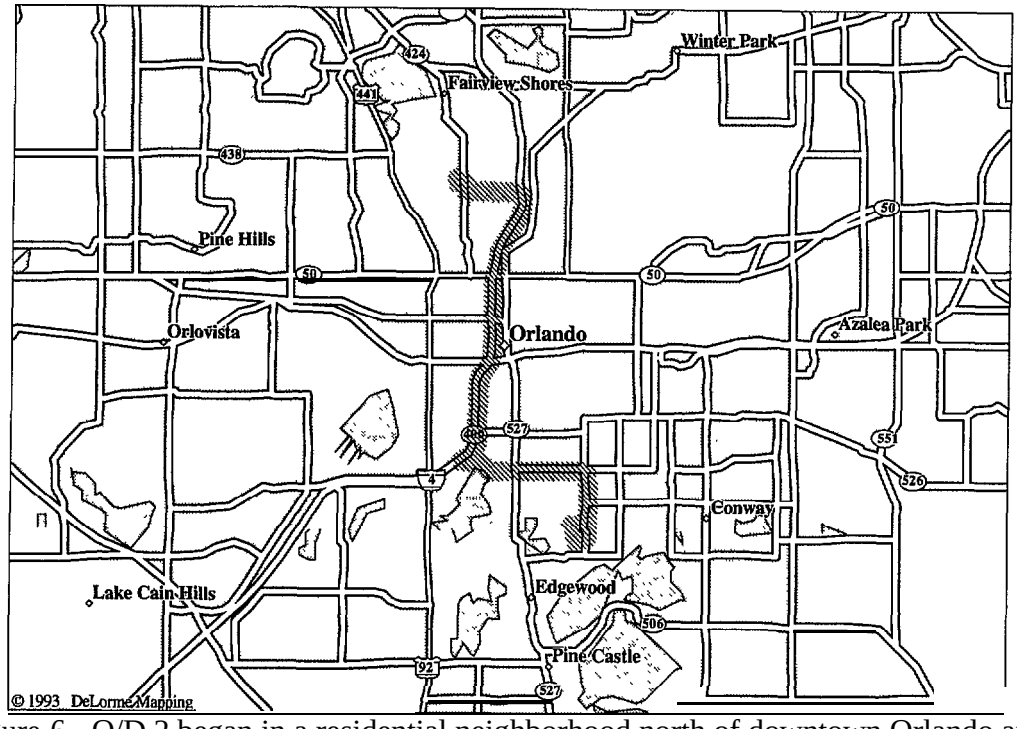

Figure 6. O/D 2 began in a residential neighborhood north of downtown Orlando and ended in a residential neighborhood south of downtown and east of Orange Avenue.

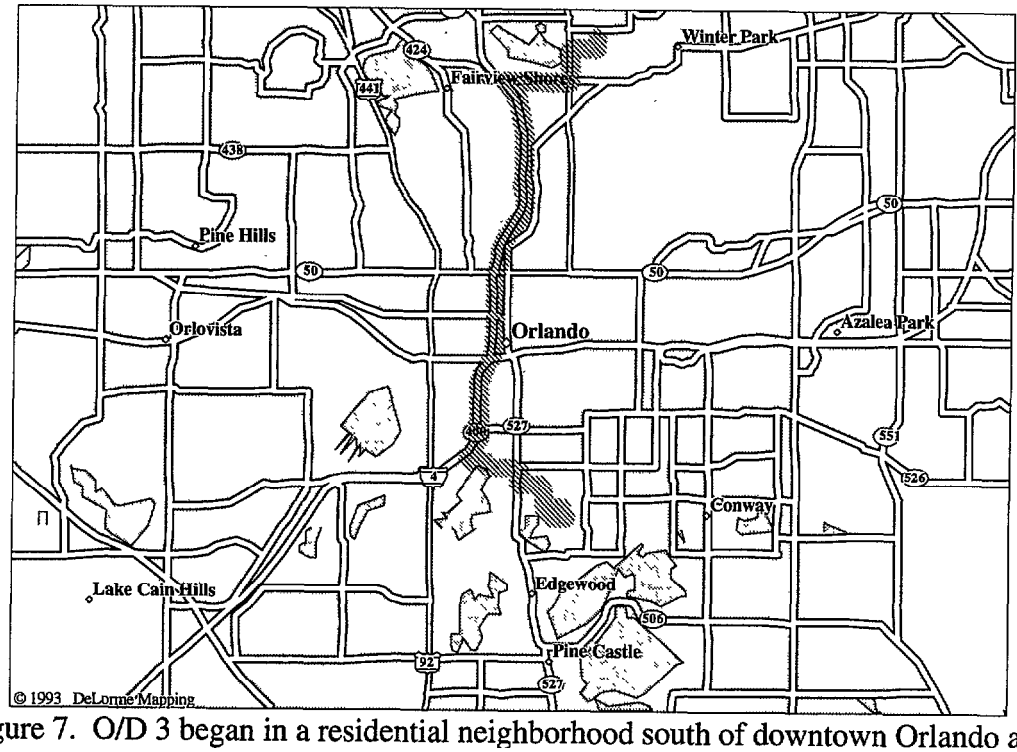

Figure 7. O/D 3 began in a residential neighborhood south of downtown Orlando and ended in a residential neighborhood north of downtown and east of Orlando Avenue.

Ambient Lighting

Ambient lighting was an environmental variable in the Orlando Test Network Study. Half of the subjects were tested during the day and half at night. Daylight tests were conducted between 9 AM and noon. Night time tests were conducted between 8 PM and midnight. As will be seen in the results, traffic was lighter during the evening tests than it was during the day. Therefore, the night versus day comparisons, while instructive, must be made with caution: not only was the lighting environment different, but the traffic environment was different as well.

Drivers

Drivers were recruited at a major Orlando tourist attraction. A TravTek exhibit was set up 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, remuneration was not emphasized during recruitment. Participation in the study required approximately 5 h, and most of the volunteers were vacationers. Therefore, it can be assumed 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 following their recruitment. Recruitment was conducted Sunday through Thursday and testing was conducted Monday through Thursday.

There were 322 individuals who volunteered to participate as drivers. After completing a briefing, pre-tests, and training run(s), four drivers dropped out before beginning the first O/D. There were 3 18 drivers who drove in one or more of the three test O/D's. Of the 322 drivers, 165 drove during the day and 157 drove at night. Sample sizes for various statistical tests in this report vary slightly because of missing data. Performance data might be missing for a number of reasons, but missing data generally resulted from isolated failures by observers to record specific data points such as the time the vehicle was placed in gear or an odometer reading. Also, respondents occasionally failed to respond to individual questionnaire items. Rather than exclude all participants with missing data, we have striven to include 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 exclusion. Three tests were used to assess familiarity with Orlando.

The first of the three familiarity tests asked the participants to rate, on a 1 to 6 scale, "your awareness of Orange County roadways." The anchors for this rating were (1) "never been to Orlando," and (6) "know as well as a cab driver." Of the 322 participants, 292 provided valid responses to this question. Fifty-seven percent of the participants (195)

rated themselves a 1 on the scale. Ninety-eight percent (286) rated themselves 3 or less. Only one participant selected the highest rating.

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). Valid responses were obtained from 3 18 participants. Of the valid responses, 91 percent (290) failed to correctly identify any of the intersections. Only 1 participant was able to identify as many as 5 of the intersections correctly.

A third assessment asked how long the participant had lived in Orlando. Valid responses to this question were obtained from 3 14 participants. Among valid responses, 93 percent (291) stated that they 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 did participate.

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, auditory, area familiarity, and the map skill assessments. Pre-test findings that did not help clarify the results of the driving and navigation performance measures are not included in this report.

The Snellen test of foveal visual acuity was administered. The Snellen test uses high-contrast letters of varying visual angles. Drivers with worse than 20/40 Snellen acuity using both eyes were excluded from participation.

Observers

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

- Pre-drive orientation.
- On-road training.
- On-road evaluation of learning.

- Data recording.
- Debriefing.

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

Pre-drive and en route training of drivers 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. The hop buttons were located on the steering wheel hub and provided a manual means of correcting for possible errors in the vehicle's computation of its location.

On-road evaluation of learning comprised three tasks: (1) quizzing drivers' understanding of the system; (2) rating drivers' proficiency in entering destinations; and (3) scoring performance of various TravTek drive functions.

On each test O/D, the observers recorded information about the following:

- Odometer reading at 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 (entering turn lane).
- Turn abruptness.
- Drivers' subjective workload ratings.
- Near accidents or close calls.
- Driver comments.
- Wrong turns.

Further descriptions of what observers recorded are provided in the Detailed Test Procedures section and in the Results section.

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 interactions with the TravTek interface. Thus every button press, whether on the steering wheel hub or on the TravTek touch screen, was recorded. The kinds of data recorded in this log were extensive and the current description is not intended to be exhaustive. Other data logged 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 (in m/hr sampled l/s).

Debriefing

Upon completion of three test O/D's, 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 more frequently occurring responses.

Questionnaire

A common questionnaire was used across four TravTek Evaluation studies: the Renter and Local User Study, the Orlando Test Network Study, and the Camera Car Study.(See references 3, 5, and 6) Although a core set of questions was the same across all studies, the Renter questionnaires consisted of three variations, each tailored to the vehicle configuration that the driver received. The remaining questionnaires were the same. The Orlando Test Network Study questionnaire was administered to the drivers after on-road testing. 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.

DETAILED TEST PROCEDURES

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

Test Schedule

Testing was conducted Monday through Thursday. Testing was not performed on Friday because evening traffic flows on that day vary considerably from the other week days. Six vehicles and six observers were available for the morning and evening tests (six in the

morning and six in the evening). Thus it was feasible to conduct 12 tests in 1 day. However, often fewer than six participants volunteered, or appeared, for testing sessions.

Participants began with a classroom briefing on (1) the TravTek system, (2) test procedures, and (3) safety considerations. Morning briefings began at 8 AM. Evening briefings began at 7 PM. The briefings took about 15 min. Subsequent to the briefing, participants took two map skills tests: the Building Memory and Card Rotation tests.(7) These tests were followed by the hearing and vision evaluations. After a brief break, participants were transported to the TravTek vehicles where they were provided a vehicle orientation. This orientation included use of the windshield wipers, headlights, windows, remote mirror controls, and electric seat controls as well as use of the TravTek system.

At approximately 9:40 AM or 8:40 PM, participants began the on-road training. This training accomplished three goals:

- It provided the participants with an opportunity to program five destinations with the TravTek system.
- It provided the researchers with the opportunity to observe participants planning a trip without benefit of the TravTek system.
- It got the vehicle from the embarkation point to the origin of the first 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 O/D's followed the same procedures that were used for the test O/D's. The procedure was to hand the driver a card that contained the street names of the 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 Guidance without TravTek visual display.
- Control (Plan and navigate "the way you normally would without TravTek").

On a training O/D that utilized the TravTek visual display, the observer instructed the driver to turn off of the planned route. This intentional wrong turn provided an opportunity to demonstrate what the TravTek system does when a wrong turn is made, and to demonstrate the OK New Route feature. When a TravTek vehicle deviated from a planned route (planned using the routing computer), a voice message announced "Your car 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 and displayed the message:

OFF-ROUTE. OK NEW ROUTE?

The use of the HOP LEFT and HOP RIGHT buttons on the steering wheel hub were demonstrated on a training O/D that utilized the Route Map.

While traversing training O/D's the observers quizzed the drivers on the TravTek system. The quizzed information had been presented earlier in the training, usually during the classroom briefing. Observers also asked the drivers to demonstrate their understanding of the system by asking them to use 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. A description of the questions that were asked and the functions that were exercised is deferred to the Results section.

At approximately 10: 10 AM for morning sessions, or 9: 10 PM for evening sessions, participants arrived at the first test O/D origin. The sequence of test events was as follows:

- The observer programmed the TravTek system to the assigned configuration (e.g., Route Map with Voice Guide or Route Map without Voice Guide).
- The driver was given a card with the name of the destination intersection.
- The driver planned the route by either:
  - Entering the destination in the TravTek system.
  - Calling the Help Desk.
  - Using a paper map."

Once drivers completed trip planning, they were instructed to begin their trip. If more than one vehicle was at an origin at the same time, then vehicles departed at intervals no less than 2 min apart.2

At the origin, the observers recorded:

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

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1 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.

2 Readers familiar with the Yoked Driver Study may recall that in that study vehicles departed the origin at precise 2-min intervals. This was in an effort to ensure that Yoked Driver Study vehicles encountered nearly identical network traffic conditions but did not visually follow one another. Because traffic was generally not a factor at the times the Orlando Test Network Study was run, test vehicles left origins whenever they were ready as long as there was at least a 2-min interval between vehicles.

En route, the observers recorded:

- Subjective workload ratings:
  - Upon beginning the trip.
  - Upon leaving the residential neighborhood.
  - At eight pre-designated cross streets.
  - 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 (close calls).
- Abrupt maneuvers.
- Driver comments.

At the destination the observer recorded arrival time and the odometer reading. Each O/D trip was expected to take about 20 min. The test procedure was repeated for each of three test O/D's.

Upon completion of the test O/D's, participants began the 30-min drive back to the embarkation. Oral debriefings were conducted during this return trip. Upon arrival back at the embarkation point, morning participants took about 20 min to complete the questionnaire. By 1:00 PM the morning participants were thanked for their participation and given $25. Evening participants were given a questionnaire packet to be completed and returned by mail. By 11:55 PM the evening participants were thanked for their participation and paid $25.

RESEARCH DESIGN

Because there were six experimental conditions, and because the participants' time was limited, each participant contributed to only three of the conditions. Half the participants were assigned to the conditions for which Voice Guide was off, and half were assigned to the conditions for which the Voice Guide was on. That is, a repeated measures, or within groups, research design was used. As shown in table 6, each driver who completed the study was tested with all three visual display configurations, but in only one of the Voice Guide, or Time of Day conditions. Table 6 shows the actual sample sizes for the trip planning time measure: note that the sample size is the same for all three visual display levels because the same individuals were tested at each level, and only drivers who completed all three test O/D's are included in the counts.

Table 6. The Orlando Test Network Study experimental design with sample size for trip planning times measure.

Between Groups Variables		***Visual Display (Repeated Measure)***		
Voice Guide	**Time of Day**	**Guidance Display**	**Route Map**	**No Visual Display**
Off	**Day**	55	55	55
	Night	46	46	46
Off Total		101	101	101
On	Day	71	71	71
	Night	64	64	64
On Total		135	135	135
Total Sample		236	236	236

Before arrival for testing, each participant was assigned to a Voice Guide level (On or Off) and an order of visual display testing. The three O/D's were always experienced in the same order, however the order in which the three visual displays were experienced was counterbalanced across drivers. The only qualification on'random assignment was that an attempt was made to balance age group (25 to 34,35 to 54, and 55 and older) and gender across the experimental conditions and orders.

Data sources were:

- Research assistant (observer) records.
- Pre-Tests and driver profile.
- Training logs.
- Post-experiment debriefs.
- TravTek in-vehicle log.

The primary dependent variables were:

- Travel time, including trip planning time and en route time.
- Trip distance.
- Congestion, or level of service.
- Number of close calls (near accidents).
- Maneuver abruptness.
- Subjective workload.
- Perceived driving performance benefits.
- Stated willingness-to-pay.
- Number of trials required to learn.
- Subjective ratings of usability and utility.

For navigation and driving performance measures, the primary independent variables were:

- Voice Guide (On or Off).
- Visual Display (Guidance Display, Route Map, or No Visual Display).
- Time of Day (day or night).

The nature of the recruiting effort, that is, recruitment of tourists visiting an Orlando attraction, precluded stratified sampling that would ensure that the recruits were typical of the general driving population in the United States. In particular, the recruitment procedure resulted in a participant pool that tended to possess above average incomes, over-represented middle-aged individuals, and under-represented female drivers. Furthermore, older adults and females were less likely than others to volunteer for the night test sessions. Therefore, for the primary driving performance measures, we do not report findings with respect to driver age, gender, or income. Where results with respect to these demographic variables are reported, the reader is cautioned to keep in mind the unique characteristics of the sample population.

RESULTS

In the introduction, five issues were presented:

1. Does TravTek improve driver navigation?
2. Does TravTek improve overall driver performance?
3. Does driver interface usability vary with display configuration?
4. Do drivers perceive TravTek as useful, usable, and safe?
5. Do drivers prefer particular TravTek display configurations?

In this section, the data collected to address these issues are presented largely in the order that the issues were posed. However, some measures of performance associated with a later issues may have implications for interpretation of measures of performance examined earlier. 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 reader should suspend final judgments until all the relevant performance measures are integrated. The discussion section is intended to integrate the findings across issues and measures of performance.

Issue 1: Does TravTek improve driver navigation?

The TravTek system and alternative TravTek display configurations were assessed for their effects on trip length and navigational errors.

Trip length served as a measure of effectiveness of the TravTek route planning function. The measures of performance that were used to examine trip length were: trip planning time, time en route, and trip distance. It was hypothesized that TravTek's route planning function would result in reduced trip planning times, en route times, and trip distances.

Whereas total travel time and trip distance are important measures of the effectiveness of an in-vehicle navigational aid, the frequency and severity of navigational errors may provide explanations for some of the travel length effects. Therefore we examined:

- The frequency that drivers in the various conditions successfully completed trips.
- The number of wrong turns.
- Time off route.

In addition, the types of errors that led to wrong turns were examined to provide some insight into qualitative differences in navigational errors associated with the six experimental conditions.

Unless otherwise noted, the data presented here were recorded by the research assistants. Athough the research assistants were very dedicated, there were inevitable gaps in the data. Thus the sample sizes for planning time, time en route, and trip distance varied

slightly due to the occasional omission in times or odometer readings. To ensure comparability, these analysis only include those drivers who completed all three OD's.

Trip Planning Time. Trip planning measurement varied slightly depending on whether the trial used TravTek or the Control configuration. When TravTek was used, the time between when the driver was given the card that identified the destination and the time that the TravTek system presented the first maneuver was recorded. This method included a nearly constant machine planning time of about 30 s. In the Control condition, the time between when the card was given and when the driver declared that planning was complete was recorded.

Planning Time analysis revealed a three-way interaction of Voice Guide, Time of Day, and Visual Display, $F(2,468) = 12.18$, $p < 0.001$. Figure 8 shows mean planning times for the three Visual Display conditions as a function of Voice Guide and Time of Day. Planning times were longer when traditional techniques (i.e., No Visual Display and Voice Guide Off) were used. Regardless of time of day, there were no significant differences in planning times among conditions that used TravTek for route planning.

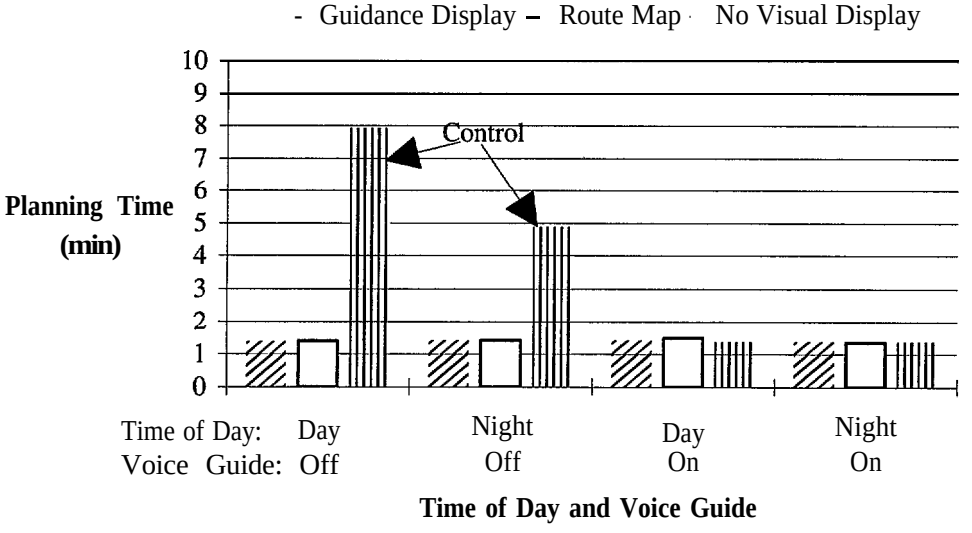

Figure 8. Trip planning times as a function of Visual Display, Time of Day, and Voice Guide.

Because the route planning interface was the same for both the Guidance Display and Route Map, and for trips with Voice Guide and No Visual Display, it is not surprising that planning times are the same for the conditions in which the TravTek system was used to plan routes. However, the finding that conventional trip planning took longer during the day than at night, $F(1, 101) = 15.15$, $p < 0.001$, was unexpected. This finding may have been the result of more drivers deciding to call the TISC help desk at night rather than to read a map in dim light. Unfortunately, complete records of calls to the help desk are not available. The incomplete records that are available are suggestive: Of confirmed help

desk calls in the No Visual Display with Voice Guide Off configuration, 3 were made during the day and 18 at night.

Time En Route. Time en route was defined as the time elapsed from when the vehicle was put into gear at an origin to the time when the driver correctly acknowledged that the destination had been reached. That is, even when the vehicle reached the destination, the trip was not considered complete unless the driver recognized that the destination had been reached. Only those drivers who completed all three O/D's and had valid en route times were included in the analysis.

Figure 8 shows mean en route travel time as a function of Visual Display, Voice Guide, and Time of Day. Two significant effects were observed. The more important finding was an interaction of Visual Display and Voice Guide factors, $F(2,482) = 22.27$, $p < 0.001$. It can be seen in figure 8 that this interaction was the result of travel times in the Control conditions (i.e., no visual display, Voice Guide off) that were significantly longer than in the conditions that used TravTek for route guidance. The time of day effect was also significant, $F(1,241) = 67.43$, $p < 0.001$. Daytime travel times were reliably longer than nighttime travel times.

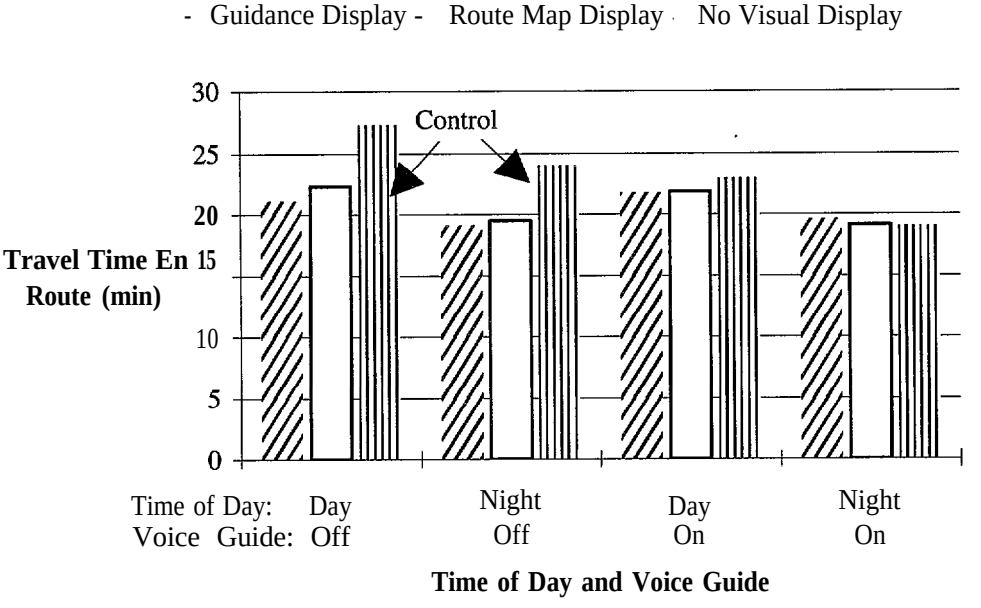

Figure 9. Travel time en route as a function of Visual Display, Voice Guide, and Time of Day.

The time of day finding was unanticipated. If anything, reduced visibility was expected to result in longer travel times at night. The most likely explanation for the shorter trip times at night is the lighter traffic. The observers were trained to rate congestion according to level of service guidelines provided by the FHWA Highway Capacity Manual.(8) Congestion was recorded on a three point scale: low, moderate, and high (1, 2, and 3, respectively). Thus an average congestion level of 1.5 would indicate congestion mid-way between low and moderate. One congestion rating was made for each road taken on a trip.

Congestion ratings were then averaged across roads for each O/D. Figure 10 shows the mean congestion ratings, with standard errors, as a function of Time of Day and O/D. The difference between day and night is reliable for all three O/D's, $F(1,244) = 25.93$, $p < 0.001$. A statistically reliable Time of Day by O/D interaction was also obtained, $F(2,488) = 16.20$, p c 0.001. The interaction is the result of a larger difference between day and night on O/D 3. Recall that the O/D's were always driven in the same order. The constant decrease in congestion across O/D's 1 through 3 at night is consistent with decreasing traffic as midnight approached. The daytime increase in congestion on O/D 3 is consistent with increasing traffic as the mid-day peak approached.

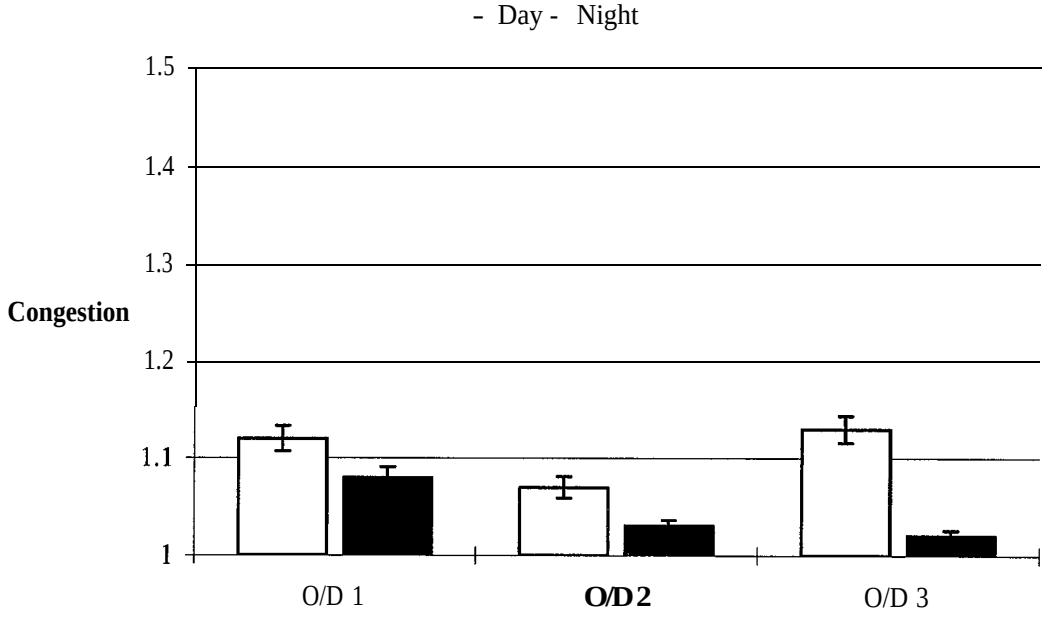

Figure 10. Mean congestion levels as a function of time of day and O/D.

Trip Distance. Whereas planning time and time en route were used to explore trip length using time measures, trip distance was used to examine navigation performance (and trip length) as a function of the distances traversed.

Figure 11 shows the mean trip distances and standard errors as a function of Visual Display, Voice Guide, and Time of Day. There were 204 drivers (612 trips) for which valid travel distances were available. No statistically reliable trip distance effects were obtained.

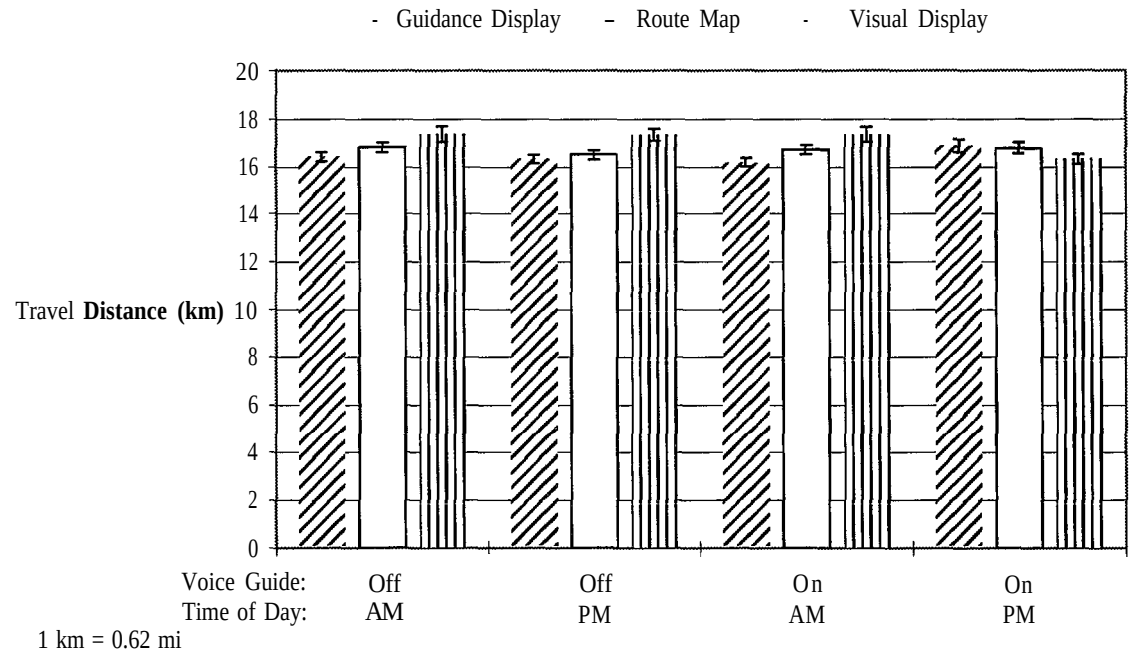

Figure 11. Travel distance as a function of Visual Display, Voice Guide, and Time of Day.

Navigation Errors. Navigation errors were analyzed from three perspectives:

- The percentage of drivers who arrived at their destination, i.e., completed trips.
- The number of wrong turns.
- Time spent off of planned routes.

Table 7 shows the percentage of drivers who completed trips as a function of Visual Display and Voice Guide. The percentages are based on all drivers who began an O/D and includes all drivers who began at least one O/D. Among the drivers who did not complete three O/D's, most dropped out between O/D's (after finishing one O/D but before starting the next). There were a number of reasons why drivers did not finish O/D's that they began. Some became hopelessly lost whereas others simply expressed a desire to quit. Because the number of drivers who failed to finish was small, and because some of the records are vague as to why drivers failed to finish, we have not analyzed the reasons for failure to complete. However, several patterns can be seen in the completion data.

With the Guidance Display, all drivers reached their destination. Likewise, all drivers who used the Route Map with Voice Guide reached their destination. One driver using the Route Map without Voice Guide failed to complete a started trip. With the Control configuration, 7 percent of drivers failed to complete their trip. With Voice Guide only, six drivers or 4 percent failed to finish. When used as it was designed to be used, that is with a visual display supplemented with voice guidance, all drivers reached their destinations. Control configuration drivers and drivers using the Voice Guide alone were less likely to reach their destination. The TravTek navigation guidance system increased the probability that drivers would successfully complete planned trips to unfamiliar destinations.

Table 7. Percentage of drivers completing O/D's by Visual Display and Voice Guide conditions.

Visual Display	*Voice Guide*	*Number Started*	*Number Finished*	*Percent Finished*
Guidance Display	On	157	157	100%
	Off	137	137	100%
Route Map	On	154	154	100%
	Off	137	136	99%
No Visual Display	On	155	149	*96%*
	Off	131	122	93%

The number and location of wrong turns can be expected to have an impact on the travel time and travel distance. It would be expected that as the number of wrong turns increases, the total distance traveled would also increase. However, given the TravTek routing algorithm (that avoided residential streets, for example), it was sometimes possible to make a wrong turn and reduce travel distance.

In analyzing wrong turns, only drivers who finished all three O/D's and had valid wrong turn data were included in the analyses. Valid data were available for 245 drivers, 735 trips. Wrong turns were made on 361 (49 percent) of the trips. The largest number of wrong turns that occurred on a single trip was 5. The occurrence of more than two wrong turns on a single trip was infrequent. Therefore, in the analysis that follows, these trips were collapsed into a category of "greater than 1 wrong turn."

Table 8 shows the percentage of trips with either one wrong turn, more than one wrong turn, or no wrong turns as a function of the Visual Display and Voice Guide. A Multiway Frequency Analysis was performed to examine the association of Visual Display, Voice Guide, and Time of Day with frequency of wrong turns. (9) No statistically reliable relationship between wrong turns and display configuration was observed. Although there was a tendency for drivers in the Route Map without Voice Guide condition to make more wrong turns, this trend was not statistically reliable, $p > 0.12$.

Table 8. Distribution of trips with one, more than one, and no wrong turns as a function of Visual Display and Voice Guide.

Voice	*Display*	*1 Wrong Turn*	*> 1 Wrong Turn*	*No Wrong Turns*
On	Guidance	31.9%	10.9%	(57.2%)
	Route Map	33.3 %	13.0 %	(53.6%)
	No Visual	34.8%	17.4 %	(47.8%)
Off	Guidance	31.8%	12.1%	(56.1%)
	Route Map	30.8 %	32.7 %	(36.4%)
	No Visual - ***Control***	32.7 %	15.0%	(52.3%)

Table 9 displays the percentage of trips with one or more wrong turns as a function of Voice Guide, Visual Display, and Time of Day. Wrong turn performance was comparable for day and night driving conditions.

Table 9. Distribution of trips with one or more wrong turns as a function of Visual Display, Voice Guide, and Time of Day.

Voice Guide	*Visual Display*	*Day*	*Night*
On	Guidance	40.0%	46.2%
	Route Map	46.6%	46.2%
	No Visual	63 .O%	40.0%
Off	Guidance	40.0%	48.1%
	Route Map	69.1%	57.7%
	No Visual - Control	41.9%	53.8%

Table 10 shows the frequency of wrong turns as a function of O/D. The probability of making a wrong turn was not independent O/D, $X2\ (2) = 34.82$, $p < 0.001$. Wrong turns were more likely to occur on O/D 1 where 64 percent of drivers made one or more wrong turns. For a description of the types of errors that led to wrong turns, refer to the Yoked Driver Study final report.(5) Because the experimental conditions were counterbalanced across O/D pairs, the probability of a wrong turn as a function of O/D should not have affected the outcomes with respect to the experimental conditions.

Table 10. Number of wrong turns as a function of O/D.

OD	*0 Wrong Turns*	*1 Wrong Turn*	*> 1 Wrong Turn*
1	88	100	57
2	174	54	17
3	112	86	47

The total time off a planned route was analyzed for 211 drivers for whom complete data were available. Time off a planned route was defined as the time elapsed between the vehicle leaving the planned route and returning to a planned route. Return to a planned route included:

- Return to the previously planned route at the point of departure, often by making a u-turn.
- Returning to the previously planned route at a point other than the point of departure.
- Planning a new route to the destination and proceeding on the new planned route.

A multivariate analysis of variance was performed on the log of mean time off route, with Visual Display, Voice Guide, and Time of Day as independent variables. The mean was computed separately by driver for each trip, and thus represents, for each experimental condition, the average time off route per trip, regardless of whether any wrong turns were made on a trip. The log transformation (log10(time off route +l) was used because of the extreme positive skew in time off route. This skew was in part due to the large number of zero values in time off route. A main effect of Visual Display was obtained, $F(2,414) = 4.17$, $p < 0.05$. No other effects reached traditional levels of significance. The Visual Display effect is illustrated in figure 12 where it can be seen that average time off route tended to be greater when no visual display was available. It is interesting to note that time off route with no visual display did not appear to differ whether Voice Guide was Off (the control condition) or On.

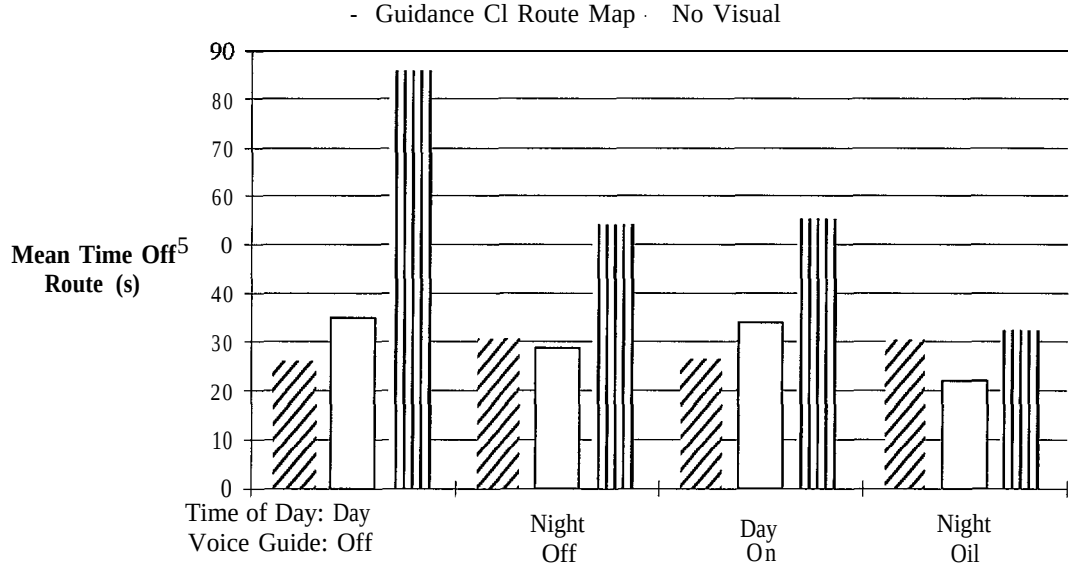

Figure 12. Time off route as a function of Visual Display, Time of Day, and Voice Guide.

Time off route can be influenced by many factors. Some wrong turns are easier to recover from than others. For instance, a recovery may be quicker when a U-turn is possible than when it is not. If a new route must be planned, time to plan that route becomes part of the recovery time. No recovery can begin until the deviation from the planned route is detected. Because TravTek alerts drivers when it detects that they have deviated from the planned route, time to detect navigation errors should be brief when the TravTek system is being used. Indeed, it can be seen in figure 13 that time to detect deviation from the planned route was considerably less when TravTek was used for navigation guidance than

in the Control condition. The figure includes mean delays for all drivers who made wrong turns (that is, it does not include zero values for drivers that did not make wrong turns). The error bars indicate +1 standard error of the mean. Although each driver was observed in each Visual Display condition, not every driver made a wrong turn with each visual display. Therefore, a repeated measures analysis of variance cannot be performed on the delay to notice data. Nor is a between groups analysis of variance strictly appropriate for these data because some drivers did contribute delays to notice for more than one visual display. Visual inspection of figure 13 reveals the means for the control condition to be more than two standard errors greater than the means for the TravTek conditions, and none of the TravTek conditions to differ from each other by more than two standard errors. Given that two standard errors defines the 95-percent confidence interval for a mean, and assuming a normally distributed populations, the delay to detect deviation from the planned route can be concluded to be significantly greater in control condition than in the TravTek conditions. A between groups analysis of variance performed on the log of delay to notice also supports the conclusion that delays are longer in the control condition, $F(2,304) = 5.098$, $p < 0.01$.

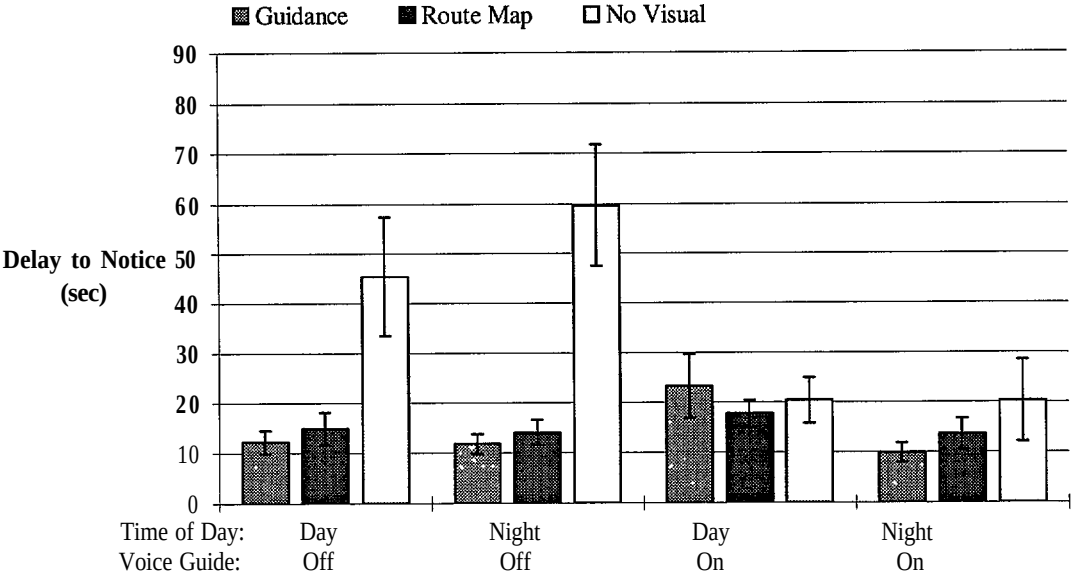

Figure 13. Time to detect deviation from the planned route as a function of Visual Display, Time of Day, and Voice Guide.

In summary:

- Visual Display, Voice Guide, and Time of Day were not significantly related to the probability of making a wrong turn.
- The average time spent off route was greater when there was no visual display than when there was. That is, the Control condition and the Voice Guide only conditions yielded significantly more time off route than conditions in which the TravTek visual displays were used.

- Given that a wrong turn was made, navigation errors were detected more quickly when TravTek was used for navigation than when it was not.

Nature of Wrong Turns. To provide additional insight as to how navigating with TravTek differs from conventional navigation, and to better understand how each type of navigation fails, navigation errors were characterized. For each O/D where the driver made at least one wrong turn, the action that led to that first wrong turn was classified. Because multiple wrong turns on an O/D were infrequent, and because subsequent wrong turns may not be independent of the first wrong turn, only the first wrong turn was examined. The wrong turn actions were classified into five categories:

Missed Turn: Passed the planned turn location,

Turned too Early: Turned before, but in the vicinity of, the planned location.

Turned in Wrong Direction: Turned the wrong way at the planned location.

Other Wrong Turns: Includes getting trapped in a turn only lane, turning when not in the vicinity of a planned turn location, and intentional short-cuts.

Missing Data: Insufficient information to enable classification.

Table 11 shows the distribution of wrong turn classifications. The most common error was to miss the turn. Time of Day appeared to have no effect on the nature of wrong turns. Turning too soon was common only with the Guidance Display. Turning in the wrong direction was common only in the Control condition. Without the Voice Guide, wrong turns made by drivers using the Route Map were almost exclusively of the turning too late (missed turn) variety.

Table 11. Distribution of the navigation errors for first wrong turns as a function of Visual Display and Voice Guide.

Voice	*Display*	*Missed Turn*	*Too Early*	*Wrong Direction*	*Other*	*Missing*
On	Guidance	**62.7%**	**32.2%**	**1.7%**	**3.4%**	**0.0%**
	Route Map	**76.6%**	**12.5%**	**6.3%**	**4.7%**	**0.0%**
	No Visual	**66.7%**	**16.7%**	**9.7%**	**5.6%**	**1.4%**
Off	Guidance	**63.8%**	**29.8%**	**4.3%**	**2.1%**	**0.0%**
	Route Map	**91.2%**	**2.9%**	**2.9%**	**0.0%**	**2.9%**
	No Visual (Control)	**60.8%**	**7.8%**	**23.5%**	**2.0%**	**5.9%**

Recovering from a Wrong Turn. Not only did the experimental conditions differ with respect to the types of navigation errors drivers made, they also differed in the ways that drivers recovered from those errors. The descriptions of how drivers recovered from navigation errors were sorted into six general categories:

Pressed OK New Route: Pressed the TravTek OK New Route button for a new route.

Reprogrammed Route: Parked the vehicle and re-entered the trip into the TravTek computer (usually because of a computer malfunction).

Returned to a Planned Route: Drove back onto a planned route without stopping to replan or seek help.[3]

Looked at Map: Stopped to consult a paper map.

Called Help Desk: Called the TravTek Help Desk for navigation assistance.

Missing Data: Observer notes were inadequate to allow classification of the recovery method.

Consistent with preceding analyses, only drivers who completed all three O/D's were included in this analysis. Only a driver's first wrong turn on an O/D was included. In table 12 the distribution of recovery classifications is shown as a function of Visual Display and Voice Guide. Regardless of configuration, drivers were most likely to recover from a wrong turn by returning to the (previously) planned route. When TravTek was available, drivers pressed the OK New Route button to replan the route to the destination almost as frequently as they elected to return to the old route on their own. In the control condition, for which the OK New Route alternative was not available, the majority returned to a planned route on their own, but nearly 10 percent stopped to consult a paper map and a few elected to call the TISC help desk for assistance.

Table 12. How drivers got back onto a planned route.

Voice	*Display*	Returned *to a Planned Route*	*Pressed OK New Route*	*Reprogrammed*	*Consulted Paper Map*	*Called Help Desk*	*Missing*
On	Guidance	42.4%	32.2%	3.4%	0.0%	0.0%	22.0%
	Route Map	46.9%	40.6%	0.0%	0.0%	0.0%	12.5%
	No Visual	47.2%	37.5%	0.0%	0.0%	0.0%	15.3%
Off	Guidance	57.4%	31.9%	0.0%	0.0%	0.0%	10.6%
	Route Map	39.7%	35.3%	0.0%	0.0%	1.5%	23.5%
No Visual (Control)		74.5%	NA	NA	9.8%	5.9%	9.8%

[3] Most often the driver made a u-turn back to the previously planned route. However this classification includes instances where the driver chose another route (without stopping to replan), or took a more complex route back onto the previously planned route.

Issue 2: Does TravTek improve overall driver performance?

Driver performance was assessed using three measures:

- Maneuver abruptness.
- Number of accidents and near accidents (close calls).
- Subjective workload.

To the extent practical, these measures were examined as a function of Visual Display, Voice Guide, and Time of Day.

Maneuver Abruptness. The maneuver abruptness analyses included data from 246 drivers that completed all three O/D's and had valid (non-missing) abrupt maneuver data.

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

- Abrupt turns.
- Turn signal use.
- Turn lane entry.

For these variables, the observers were instructed not to rate a driver's performance per se, but rather, to rate maneuvers: (1) relative to how the driver normally performs the action, and (2) with respect to whether, in the observer's opinion, that action was related to the driver's navigational awareness. For example, abrupt maneuvers that might fit the above criteria included: turning suddenly and without warning; turning at higher than usual speed; and, veering across several lanes of traffic in order to stay on the planned route. Similarly, for signal use or preparing to turn, the actions were not rated on an absolute scale but (1) relative to how the driver normally performed each action, and (2) whether a deviation from the norm appeared to be 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 the turn signal, the observer recorded none.

Out of 738 trips (3 O/D's driven by 246 drivers), there were 102 trips on which at least one abrupt turn was recorded for a total of 13 1 abrupt turns. The incidence of wrong turns was not reliably related to Visual Display, Voice Guide, or Time of Day.

When examined separately, early or late turn lane entry, and early or late application of turn signals showed no statistically reliable relationship to the independent variables. To increase the sample size for abrupt maneuver events, abrupt turns events, early and late turn signal application events, and early or late turn lane entry events were combined into a composite "abrupt maneuver" variable. This was done by adding the frequency of these events. Thus, the abrupt turn, turn signal, and turn lane variables were given equal weight.

Also note that normal use of a turn signal and non-use are treated as equivalent — only early or late application were counted.

A four-way multiway frequency analysis (MFA) was again performed to examine the association of Visual Display, Voice Guide, Time of Day, and frequency of abrupt maneuvers.(‘) To meet the assumptions of the analysis technique, trips with 5 or more abrupt maneuver events (abrupt turns + early or late signal application + early or late turn preparation) were treated as a group. That is, frequency of abrupt maneuvers had six levels: 0, 1,2,3,4, and 5 or more. The data submitted to the MFA are shown in table 13.

Table 13. The frequency of abrupt maneuvers as a function of Visual Display, Voice Guide, and Time of Day.

Frequency Voice ***Guide***	***Time of Day***	***Guidance***	***No Visual***	***Route Map***
0	*off*	**Day**	25	22	15
		Night	18	13	13
	On	Day	25	19	30
		Night	20	20	17
1	Off	Day	9	10	10
		Night	7	6	7
	On	Day	19	17	11
		Night	12	8	9
2	Off	Day	9	6	11
		Night	6	7	5
	On	Day	8	12	5
		Night	5	10	9
3	off	Day	3	4	4
		Night	5	6	6
	On	Day	9	11	7
		Night	5	4	3
4	off	Day	5	6	4
		Night	2	2	4
	On	Day	5	8	9
		Night	3	5	5
5	off	Day	4	7	11
		Night	14	18	17
	On	Day	8	7	12
		Night	20	18	22

The only statistically reliable result of the MFA was the finding that the frequency of abrupt maneuvers was greater at night than during the day, $X2\ (5) = 39.27$, $p < 0.0001$.

The Time of Day effect is due to a significantly higher frequency in the “5 or more” abrupt maneuvers at night. For the nighttime drivers, 31 percent were in the 5 or more category versus 13 percent for the daytime drivers. The daytime drivers averaged 1.9 abrupt maneuvers versus 3.2 abrupt maneuvers for the nighttime group.

Because abrupt maneuver effect was unrelated to the method of navigation, it appears most likely to be attributable to reduced visibility outside the vehicle. However, attribu-

tion of the cause of this effect cannot be made with certainty because any difference between night and day conditions, or the drivers who volunteered to be tested at those times, could potentially be the cause of the effect. Higher average speeds at night, or reduced traffic at night, could also be contributory factors.

Accidents. There were no traffic accidents that involved any Orlando Test Network Study participants. Given that study participants logged fewer than 15 000 km, this finding is not particularly revealing. It does suggest that no aspect of the TravTek in-vehicle system was inherently unsafe. However, 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.

Near Accidents. Whereas there were no accidents involving study participants, there were events that the observers logged as near accidents or "close calls." Even the number of these events was too small to support statistical analysis. Overall, the observers recorded 11 close calls that involved 8 Orlando Test Network Study drivers. Table 14 shows a breakdown of the close calls by Visual Display and Voice Guide conditions. Whereas the number of close calls was too small to support any causal analysis, these results suggest no relationship between the probability of a close call and the experimental conditions of the Orlando Test Network Study. Not shown in table 14 are the distributions of close calls by Time of Day. Seven of the eleven recorded close calls occurred during the day. Because the observers in this study kept written logs and had numerous observations to record, they were not able to observe all close call events that may have occurred. In the Camera Car Study, the observer did not maintain a written log, and a videotape record was available for review. Therefore readers interested in a more fine grained analysis of close calls should refer to the Camera Car Study final report's analysis of what are refered to there as "near misses."(3)

Table 14. Close call statistics as a function of Voice Guide and Visual Display.

Voice Guide	*Visual Display*	*Number of Drivers*	*Number of Close Calls*	*Drivers Contributing to Close Calls*
On		170		4
	Guidance		2	
	Route Map		2	
	No Visual		2	
Off		152		4
	Guidance		1	
	Route Map		2	
	No Visual			

Subjective Workload. Subjective workload measures were obtained by asking drivers to rate their level of effort. In this context, effort refered to mental effort, not physical effort. Generally, subjective measures of workload are used to express differences in effort at levels for which no reliable degradation in performance is expected. Thus, subjective

workload measures may be sensitive to task differences that observable performance measures are not.

The drivers were asked to rate their workload on three dimensions: time stress, visual effort, and psychological stress. On each dimension, the ratings were expressed on a three point scale: "low," "moderate," or "high." 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 that visual scanning necessary for driving and navigating could be accomplished comfortably, but that there was no spare visual capacity. It was suggested that a driver under high visual effort might feel it necessary to delay looking at things necessary for driving or navigation. As an example, it was suggested that under high visual effort, the driver might ignore signs in order to 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 10 workload ratings on each O/D. For analysis, the 10 ratings were averaged into four categories based on the segment of the trip from which the ratings were obtained:

Planning: The first rating was given as soon as possible after the car was put into gear, and assessed driver workload "when you were planning the trip."

Beginning: These ratings were requested when the vehicle left the residential neighborhood in which the trip began. The drivers were asked to rate their workload "since beginning the trip."

En Route: This category included all subsequent workload ratings, except the last. These ratings were obtained for portions of the O/D's that included arterials and limited access roadways. Because the O/D's ran along a north/south axis, the prompts for workload ratings were associated with latitudes rather than particular landmarks. Landmarks alone were insufficient because, in the control condition, the driver selected the route; when TravTek planned the route, the driver might have deviated from the plan.

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.

The workload ratings from 163 drivers with complete records for all 4 trip segments were submitted to analysis of variance. The independent variables in the analysis were Trip Segment (planning, beginning, en route, and finish), Visual Display, Voice Guide, Time of Day, and Type of Stress (i.e., time stress, visual effort, psychological stress). Five significant two-way interactions were identified

- Voice Guide by Visual Display, $F(2,318) = 10.07$, $p < 0.005$
- Segment by Stress, $F(6,954) = 4.79$, $p < 0.005$
- Segment by Time of Day, $F(3,477) = 4.74$, $p < 0.005$
- Segment by Voice Guide, $F(3,477) = 5.01$, $p < 0.005$
- Time of Day by Stress, $F(2, 318) = 9.42$, $p < 0.005$

Table 15 shows the mean workload ratings (averaged over Type of Stress) as a function of Voice Guide condition and Visual Display. The Voice Guide by Visual Display interaction results from higher workload ratings in the Control condition. Post-hoc tests indicated that the No Visual Display condition with Voice Off (i.e., the Control condition) resulted in higher workload ratings than with the Voice On, $F(2, 322) = 30.34$, $p < 0.001$.

Table 15. Workload ratings as a function of Voice Condition and Display Type.

	Visual Display		
Voice Guide	Guidance	Route Map	No Visual
Off	1.12	1.12	1.31
On	1.11	1.12	1.16

Table 16 shows the workload ratings as a function of Trip Segment and Type of Stress. The Trip Segment interaction with Type of Stress is complex. There were no significant differences in workload as a function of Type of Stress during trip planning. For the latter three trip segments the effect of Type of Stress was statistically reliable, but the nature of the effect was not the same for all three segments. At the beginning of the trip, psychological stress was reported to be higher than visual effort or time stress. On the last two segments, visual effort ratings were significantly higher than time stress ratings. The ap-

parent difference between psychological stress and times stress for the en route segment is not statistically reliable.

Table 16. Workload ratings as a function of Trip Segment and Workload Type.

	Type of Stress		
Trip Segment	*Time*	*Visual Effort*	*Psychological*
Planning	1.14	1.16	1.16
Beginning	1.13	1.12	1.17
En Route	1.13	1.22	1.16
Finish	1.10	1.19	1.10

The Trip Segment by Time of Day interaction can be seen in table 17 where mean workload (averaged over Type of Stress) is shown as a function of Trip Segment and Time of Day. During the day, planning and finish workload ratings were slightly lower than start and en route ratings. At night, overall workload was, on average, higher than during the day and did not vary as a function of Trip Segment.

Table 17. Workload ratings as a function of Time of Day and Category.

	Trip Segment			
Time of Day	Planning	Beginning	En Route	Finish
Day	1.14	1.16	1.17	1.08
Night	1.16	1.18	1.17	1.19

The Voice Guide by Trip Segment interaction may be seen in table 18 where mean workload (averaged over Type of Stress) is shown as a function of Trip Segment and Voice Guide. The post-hoc analyses indicated that with the Voice Guide On there was no Trip Segment effect. With the Voice Guide Off, the Trip Segment effect was significant. With Voice Guide Off, workload dropped precipitously for the last rating.

Table 18. Workload ratings as a function of Voice Guide and Trip Segment.

	Trip Segment			
Voice Guide	Planning	Beginning	En Route	Finish
Off	1.19	1.23	1.20	1.11
On	1.12	1.12	1.14	1.14

Although the Voice Guide by Trip Segment by Visual Display interaction was not significant, we suspected that the difference between Voice Guide On and Off as a function of Trip Segment, might be attributable to higher workload in the Control (Voice Guide Off, No Visual Display) condition. This suspicion is at least partly confirmed by the data shown in table 19 where the No Visual Display condition was excluded from the averages. That is, workload is shown only for the Guidance Display and Route Map visual displays. When the No Visual Display condition is excluded, the Voice Guide by Trip Segment in-

teraction is not statistically reliable ($p > 0.12$). Note that the means with Voice Guide On are little affected by the presence or absence of the No Visual Display condition.

Table 19. Workload ratings as a function of Voice Guide and Trip Segment excluding the No Visual Display conditions (i.e., Control and Voice Guide only).

	Trip Segment			
Voice Guide	Planning	Beginning	En Route	Finish
Off	1.09	1.13	1.14	1.06
On	1.12	1.12	1.15	1.11

It can be seen in table 20 that visual effort and psychological stress workload ratings were slightly higher at night than during the day. The day versus night contrast was statistically reliable for visual effort, $F(1, 159) = 7.09$, $p < 0.01$. It appears that the visual effort measure was sensitive to the reduction in visibility normally associated with driving at night.

Table 20. Workload ratings as a function of Time of Day and Type of Stress.

	Type of Stress		
Time of Day	Time Stress	Visual Effort	Psychological Stress
Day	1.13	1.15	1.14
Night	1.12	1.24	1.16

The above data were for 163 drivers with complete records across all four trip segments. However, the en route segment provided more data points than the other segments, and because it included all travel on higher class roadways (arterials and Interstate), the en route segment probably provides the best insight from a safety perspective. Therefore, further analyses of the workload ratings were conducted for the en route segment. Data from 243 drivers, 104 who drove with the Voice Guide off, and 139 who drove with the Voice Guide on, were available for this analysis. The mean workload ratings examined in this analysis are shown in table 21. A three-way interaction of Voice Guidance, Visual Display, and Type of Stress was obtained, $F = (4,956) = 3.72$, $p < 0.01$. Three-way interactions are difficult to interpret, however this interaction was the result of two trends: (1) The interaction of Voice Guidance and Visual Display was only present for the visual effort and psychological stress ratings, and (2) the interaction of Voice Guidance and Visual Display was primarily the result of the difference between Voice Guidance alone (No Visual Display) and the Control configuration. With the Route Map display, the Voice Guide also reduced visual effort ratings somewhat. In other words, the visual effort workload rating tended to be most sensitive to the variables in the research design, and Voice Guide had no effect on workload ratings with the Guidance Display, and yielded only a small rating reduction with the Route Map. It is interesting that participants judged the visual effort to be reduced with Voice Guidance alone relative to the control condition, These findings demonstrate that all of the TravTek configurations, including Voice Guide

alone, reduced perceived visual effort relative to traditional methods of navigating to unfamiliar destinations.

Table 21. Mean subjective workload ratings for the en route trip segment (N = 243).

Visual Display	Voice *Guide*	*Time of Day*	*Time Stress*	*Visual Effort*	*Psychological Stress*
Guidance Display					
	Off	***Day***	***1.09***	1.11	1.11
		Night	1.09	1.19	1.12
	On	Day	1.16	1.15	1.12
		Night	1.07	1.18	1.09
Route Map					
	Off	***Day***	1.13	1.23	1.16
		Night	1.12	1.24	1.15
	On	Day	1.15	1.17	1.15
		Night	1.12	1.21	1.18
No Visual Display					
(control)	Off	Day	1.19	1.31	1.26
(control)		Night	1.19	1.44	1.28
	On	Day	1.20	1.20	1.18
		Night	1.09	1.17	1.14

In summary:

- Workload was higher in the control condition than in any of the conditions that utilized the TravTek system.
- Where the Type of Stress varied as a function of the Trip Segment, drivers rated stress *related to visual effort higher than time or psychological stress.
- Workload was generally rated lower during the day than at night, but this varied with Trip Segment
- Workload was generally rated higher with Voice Guide Off than with Voice Guide On, but this also varied with trip segment and was largely attributable to higher workload ratings from the Control condition.
- Workload attributable to visual effort was higher at night than during the day.
- Overall, workload was relatively low. No mean approached 2, moderate workload.

In conclusion, the TravTek system appears to have reduced workload for drivers navigating to unfamiliar destinations.

Issue 3: Does driver interface usability vary with display configuration?

Because most participants who used TravTek reached their destinations, it is clear that the TravTek system can be learned and was usable. Therefore, this section focuses on the ease with which participants learned to use the TravTek system, and participants' understanding of the system.

Ease of learning was assessed by observing how many trips participants planned before they could use the system without hesitation or prompting. At the beginning of each training O/D, the observer recorded the driver's proficiency at entering a destination. The eight steps required to enter an intersection as a destination were used to evaluate ease of learning. Those steps were:

1. **Press NAVIG.** This was 1 of 10 bezel buttons that surrounded the Oldsmobile Toronado's vehicle information center screen. The NAVIG button accessed the TravTek system screen displays.
2. **Select ENTER DESTINATION.** This was one of six menu selections on the TravTek system's main screen and accessed another menu that offered a variety of destination entry options.
3. **Select INTERSECTION.** Other choices included complete address, street name, services/attractions, and saved destinations.
4. **Enter first street name,** After choosing to enter an intersection, the user was prompted to enter the first of two street names. The process involved typing all or part of a street name and pressing a done button to bring up a list of matches to the entered name. The user then picked the correct match.
5. **Enter second street name.** After entering and selecting the first street name, the same process described in the preceding paragraph was repeated for the intersection's second street name.
6. **Confirm the intersection.** Once both street names were entered, a confirmation screen with the complete intersection name was presented. If the user indicated that the selection was correct, the save destination screen was presented. Otherwise, the user was returned to step 4.
7. **Choose not to SAVE DESTINATION.** The TravTek system offered to save destinations for easy selection the next time the user wished navigation assistance to the same destination. Participants in this experiment were instructed not to save the destination, as they would not be returning to it.
8. **Choose the routing method.** The TravTek system offered three routing methods: FASTEST, AVOID TOLLS, and AVOID INTERSTATES. Participants in this experiment were instructed to select FASTEST.

An example of the checklist used by the research assistants is shown in figure 14. Drivers were rated as proficient, hesitant, or requiring a prompt from the observer.

Task	Proficient						Hesitant						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 14. This is 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 lowest possible score (1) could be attained by performing without hesitation on the first two trials Means were computed by averaging over scores for the 8 intersection entry steps. There were 303 drivers with valid proficiency data. Table 22 shows the mean number of trials needed to achieve proficiency as a function of Time of Day, Gender, and Age Group. The sample size for each cell is shown in parentheses. The number of trials required to reach proficiency was greater at night than during the day, $F(1,291) = 7.11$, $p < 0.01$. The number of trials required to reach proficiency also increased with age, $F(2,291) = 11.74$, $p < 0.001$.

Because interior lighting in the vehicle was adequate both during the day and at night, the reason for the Time of Day effect is not clear. The age effect was substantial, but the reason for this effect also requires further research. The age effect might be attributable to such diverse sources as prior experience with computer interfaces or interactions between the age of the trainers and the age of the trainees.

Table 22. Mean number of training runs to achieve proficiency at entering a destination by Gender, Age Group, and Time of Day.

	Time of Day					
	Day			Night		
Age	Female	Male	Total	Female	Male	Total
25 through 34	1.96 (6)	1.99 (33)	1.98 (39)	2.43 (16)	2.01 (38)	2.13 (54)
35 through 54	2.12 (22)	2.17 (61)	2.16 (83)	2.60 (25)	2.38 (52)	2.45 (77)
55 and above	3.06 (11)	2.47 (25)	2.65 (36)	3.12 (4)	3.52 (10)	3.41 (14)
Total	2.36 (39)	2.18 (119)	2.23 (158)	2.59 (45)	2.35 (100)	2.42 (145)

Several TravTek functions were controlled by buttons on the steering wheel hub. Use of four steering wheel buttons tested was examined. These buttons were:

SWAP MAP	Toggled the visual display between the Route Map and the guidance display
REPEAT VOICE	Replays the last voice message if that message is less than 40 S old.
WHERE AM I	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.

Understanding of how to use these steering wheel button functions, as well as adjustment of Voice Guide volume, was assessed by asking the driver to exercise them on training O/D's. The synthesized voice volume could be adjusted with the radio volume control whenever the synthesized voice was delivering a message. The driver was rated proficient with a function when it was performed correctly on two consecutive training trials. The mean number of errors per driver, averaged over all five functions, is shown in table 23. Sample size is shown in parentheses. For this assessment, there were 303 drivers with valid data. There were no significant effects for age or gender. Overall, fewer than one in seven drivers made an error in performing any of the five tasks (the four steering wheel button functions or adjusting the voice volume). The average driver made far fewer than one error in performing these functions during training, and errors were unrelated to Age Group, Time of Day, or Gender.

Table 23. Average number of errors in performing each of five system manipulation tasks as a function of Gender, Age Group, and Time of Day.

	Dar		*Night*	
Age Group	***Female***	***Male***	***Female***	***Male***
25 through 34	0.04 (5)	0.12 (33)	0.09 (17)	0.07 (38)
35 through 54	0.08 (22)	0.08 (61)	0.11 (23)	0.11 (51)
55 and above	0.10 (12)	0.32 (26)	0.12 (5)	0.04 (10)

While on training runs, the observers asked a series of questions that probed drivers' understanding of the TravTek system. These 11 questions are shown in the left column of table 24. Each question was asked five times or until the driver answered correctly two consecutive times. The observer provided an explanation of the correct answer if the driver answered incorrectly. The information required to answer the questions had been presented earlier in the training. The number of trials until drivers answered a question correctly can be interpreted as a measure of ease of learning.

Table 24. The percentage of drivers, broken out by age group, who answered system information questions correctly the first time they were asked.

	Question	*Age Group*		
		25 through 34	***35 through 54***	***55 and older***
†	If you type a wrong letter when entering a street name, how can you correct the mistake?	***90.3***	82.0	73.6
	How do you enter a space in a street name? For example, how do you enter the space in "Orange Blossom?'	88.2	95.0	92.5
†	How do you return to the previous menu?	73.9	68.9	50.9
	How can you return to the main menu?	56.0	56.5	54.7
	Is it necessary to enter all the letters of a street name?	92.5	95.7	88.7
†	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?	81.3	77.5	61.5
†	If an "OFF ROUTE" message occurs, what should you do?	63.7	70.0	49.1
†	On the TravTek Route Map, when can you zoom in or out?	71.4	61.0	48.1
	How long can you wait before pressing "OK New Route" for a new route?	86.8	79.4	75.5
	To hear the last message again, how long can you wait before pressing "REPEAT VOICE"	89.0	80.0	75.5
†	What TravTek functions can be accessed while the car is moving?	72.5	68.1	52.8

t Significant age group difference ($p < 0.05$)

On average, each question was answered correctly on the first occasion 74.8 percent of the time. For the question "On the TravTek Route Map, when can you zoom in or out?' males answered correctly significantly more often than females, $X2\ (1) = 7.58$, $p < 0.01$. Otherwise, there were no statistically reliable gender differences in the responses.

Table 24 shows the percentage of drivers who answered the questions correctly on the first occasion summarized by age group. Chi-square tests indicated a significant ($p < 0.05$) age group effect for 6 of 11 questions. The questions for which significant age effects were obtained are marked with daggers (t). For those 6 questions, fewer than expected 55 and older drivers answered the questions correctly. [4] For 5 of the 6 questions, the younger age group answered correctly more often than expected. These results suggest that additional attention directed towards training methods for middle-aged and older

[4] For this test, the expected frequency was calculated such that each age group would have a frequency of correct responses proportional to the number of individuals in the group.

adults might be worthwhile. Almost all drivers answered all the questions correctly on their second opportunity, and all drivers were required to answer correctly before the training was ended.

In conclusion, the system was comprehensible by drivers of all ages, and was easily comprehended.

Issue 4: Do drivers perceive TravTek as useful, usable, and safe?

Participants' perceptions of TravTek usefulness, usability, and safety were assessed with a questionnaire. The questionnaire was given to the participants after the driving portion of their TravTek experience was complete. Many of the participants who drove during the day completed their questionnaires in the room where their initial briefing had been conducted. All of the evening participants returned the questionnaires by mail in a stamped envelope provided by the evaluator.

The questionnaire data included here were obtained not only from Orlando Test Network Study participants, but also from participants in the Yoked Driver Study.(5) Participants in both studies received the same briefing and in-vehicle training. Thus, participants in both studies experienced the six experimental configurations of the Orlando Test Network Study. Participants in the Yoked Driver Study drove only one test O/D and may have experienced real-time traffic information updates and routing that reflected real-time traffic conditions. The questionnaire was the same for both studies. No differences in questionnaire response trends were detected between Orlando Test Network Study and Yoked Driver Study participants. The merging of the data from these two groups considerably enhanced reliability for multivariate data analyses that rely on stability of the correlation matrix of questionnaire items.

Readers who have read the Yoked Driver Study final report may want to skip the rest of this section and proceed to the next (Issue 5: Do drivers prefer particular TravTek display configurations?) as the analyses reported here are the same as those included in the Yoked Driver Study report.

Usability. One measure of the perception of usability is the effect drivers thought the system had on their navigation and driving performance. The questionnaire provided one source of these perceptions. There were 23 1 items in the questionnaire. From those items, 14 were selected that seemed most strongly related to driving performance or driver navigation performance.5 For all of these items, ratings were on a six-point Likert scale

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5 There were 190 questions in the 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 was a subjective process. It was particularly subjective because these decisions were made after design of the questionnaire.

on which one represented “strongly disagree” and six represented “strongly agree.” Figure 15 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 15. Questionnaire items related to driving performance were rated on a six point Likert scale.

Table 25 shows the 14 questions and the mean ratings from 393 drivers, 189 from the Yoked Driver Study and 204 from the Orlando Test Network Study. It can be seen that for most of the items in table 25, “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 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, the 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 transformed items. Before submitting item scores to factor analysis, a log transformation was applied to compensate for a positive skew in the distribution.

Table 25. Items from the Yoked Driver Study and Orlando Test Network Study questionnaire selected to represent driver opinion on the effect of the TravTek system on driver performance.

Question	*Abbre-viation*	Mean[6]
The TravTek system's Guidance Display helped me pay more attention to my driving.	G ATTN	D4.8
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 ATIN	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 26. 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 27.

[6] The displayed means were computed prior to reflection or transformation of the scores.

Table 26. Correlation matrix of 14 driving performance variables in the auestionnaire.

	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 Al-TN	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						
VG INTF	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 27 are the result of the analyst's interpretation. A cutoff of 0.50 was used to determine which items loaded on which factors. The factor loadings of items and factors that are shown in bold face indicate that the item loaded on the respective factor. The five "interfered with..." items loaded on the first factor, and it was therefore 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, and therefore 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 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 27. Factor structure for the four factor solution with quartimax rotation.

Item	*Factors*			
	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 Guide 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**

*Boldface indicates item has significant loading on factor.

Usefulness. Although the TravTek system has potential utility in areas other than for navigation guidance, such as for congestion avoidance, for this analysis only those questions that pertained to the utility of TravTek for navigation guidance are examined. Pertinent questions queried users about the following TravTek features:

- Routing method.
- Guidance display.
- Route Map.
- OK New Route.
- Voice Guide.

Only two questionnaire items specifically asked if a feature "was useful." However, because this analysis focused on navigation guidance, the "helped me find my way" question could serve as a surrogate for "was useful."

One questionnaire item included both the "was useful" and "helped me find my way" ratings. That item asked 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. Thus, "Helped me find my way" appeared to be an acceptable surrogate for "was useful."

The questions used to evaluate driver ratings of the utility of TravTek as a routing and navigation aid, are shown in table 28. All of the questions were rated on a scale from one to six, with one representing "strongly disagree" and six representing "strongly agree." The mean ratings for each question are given in the right column of the table. 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 ($p > 0.05$). It can reasonably be concluded that users perceived TravTek as useful for navigation.

Table 28. The questionnaire items used to assess TravTek's utility as a routing and navigation aid and the obtained mean ratings.

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 useful.	5.49 (1.01)
The TravTek system's Voice Guide feature helped me find my way.	*5.47* (1.00)

The participants were largely visitors to the Orlando area. Given that they were unfamiliar with the Orlando area, it is reasonable to wonder how useful they would feel the system was for use in an area with which they were more familiar. 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." 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 29 shows the frequency of drivers' responses to the useful for at home driving as a function of age group and gender. The at home finding was similar regardless of gender. However, driv-

ers in the youngest age group were most likely to say that TravTek would be useful at home, and drivers in the oldest age group were least likely to say that TravTek would be useful for at home driving.

Table 29. The frequency of responses to the question of 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

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 thought that TravTek would be useful for out-of-town vacation driving, no one said TravTek would not be useful for out-of-town vacation driving, and 1 percent did not answer.

Thus, whereas their TravTek experience convinced most participants that TravTek was a useful navigation device for out-of-town driving, less than half thought that it would be useful for trips in their home area. This finding may have implications for the marketing of systems similar to TravTek. It should be noted however, that another TravTek Evaluation study, the Local User Study, provided extended use of TravTek vehicles to Orlando residents who logged above average distances (over 64.4 km per day) in the local area. Those drivers reported the TravTek navigation system to be very useful for "at home" driving.(6) It should also be noted that the Orlando Test Network Study did not present drivers with real-time traffic information, and the availability of quality traffic information may also have influenced judgments of utility for at home driving.

Safety. In the questionnaire, participants were asked "Do you think TravTek helped you drive more safely?" The response was rated on a scale from one to six, where one was anchored with the label "didn't help me drive safely" and six was anchored with the label "helped me drive more safely." Of 242 Orlando Test Network Study respondents, 61 percent selected either 5 or 6, and 7 percent selected 1 or 2. Thus, the majority of participants indicated they perceived TravTek to be an aid to safe driving. In addition, participants' responses to the "interfered with my driving" and "helped me pay attention to my driving" questions also support the perception of TravTek as a benefit to safer driving.

Issue 5: Do drivers prefer particular TravTek display configurations?

In the questionnaire, participants were asked how well they liked the five TravTek configurations. That is, they were asked to rate on a scale from one to six, where one represented "disliked" and six represented "liked" each of the TravTek visual and aural display combinations. A summary of Orlando Test Network Study participants' responses to the five display configuration questions is shown in table 30. It can be seen that both the Guidance Display and Route Map were rated as "liked" when they were accompanied by the Voice Guide. The median response to these two display combinations was 6. Without the Voice Guide, the Guidance Display and Route Map were significantly less liked. Furthermore, the Route Map without Voice Guide was significantly less liked than the Guidance Display without voice guidance. The median ratings for the Guidance Display and Route Map without Voice Guide were 5 and 4 respectively. The Voice Guide alone was significantly less liked than any of the other TravTek configurations, but still received a mildly positive rating. The median rating for Voice Guide alone was 4. A neutral response, which was not possible given the scale used in the questionnaire, would have been 3.5.

Table 30. Display configuration preference rating means and confidence intervals.

Display Configuration	*Mean*	*Median*	*Confidence Interval (p = 0.95)*	*Number of Respondents*
Guidance Display with Voice Guide	5.55	6	5.43 to 5.67	246
Route Map with Voice Guide	5.47	5	5.33 to 5.59	245
Guidance Display without Voice	4.38	5	4.18 to 4.58	245
Route Map without Voice Guide	4.16	4	3.95 to 4.36	244
Voice Guide alone	3.62	4	3.38 to 3.86	223

In summary, study participants were mildly to strongly positive towards the various display configurations:

- There was a strong preference for the visual display with voice guidance combination.
- Without voice guidance, the Guidance Display is preferred over the Route Map.
- Voice guidance alone is the least preferred display configuration, and was the only configuration for which a substantial number of participants expressed dislike.

It should be noted again, that the Voice Guide, as implemented in TravTek, was designed to be used as a supplement to the visual displays.

Another source of preferences for TravTek configuration alternatives comes from the debriefings that were conducted by the observers after completion of the test O/D's 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 that were asked of all debriefing participants 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 3 11 Orlando Test Network Study participants: 16 1 from the Day condition, 150 from the Night condition; 147 from the Voice Off condition, 164 from the Voice On condition. Some interesting differences in preferences were obtained between those drivers who were tested with Voice Guide Off and those tested with the Voice Guide On, and these differences are reported below. However, all participants experienced all conditions, if only during the training O/D's, and for the most part their debriefing response patterns were similar. Therefore, except where noted, the data that follow pool responses from day, night, Voice Guide On, and Voice Guide Off participants.

Because responses to the debriefing questions were open ended, summarization of the data requires classification of the many responses into far fewer categories, or types, of responses. To this end, analysts read through debriefings from several hundred respondents, and for each debriefing questions created categories into which similar responses could be grouped. The summaries provided below are the work of several analysts, and included categories derived from several TravTek studies. (See references 3,5, and 6) Although, the categories include input from other studies, some categories are unique to the Orlando Test Network Study, and some common in other studies were infrequent in this study and do not appear here.

Overall Impressions of TravTek. Responses to the question "Overall, what impressions do you have about TravTek now that you've had a chance to 'driver the future?"' are summarized in table 3 1. It can be seen that most of the drivers reported favorable overall impressions.

Because responses were open ended, a single participant may be represented in more than one category. That is, the frequency of responses may sum to greater than the number of respondents, and the percent of drivers providing a response may sum to more than 100 percent. The column labeled "percent of responses" does accurately reflect the frequency of a response category as a percent of the responses (but not respondents), that is, it sums to 100 percent.

Table 3 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.	149	**47.3%**	**47.9%**
Liked — stated they liked TravTek.	103	32.7%	33.1%
Awesome — TravTek described as fantastic, amazing, impressive.	26	8.3%	8.4%
Fascinating — described TravTek as intriguing, remarkable.	11	3.5%	3.5%
Other — catch all category for responses that were made by only one driver.	10	3.2%	3.2%
Helpful — described TravTek as providing assistance with navigation in an unfamiliar area.	6	1.9%	1.9%
Friendly — described TravTek as user-friendly.	4	1.3%	1.3%
Decreases stress — commented that TravTek reduced anxiety.	3	1.0%	1 .0%
Needs improvement — commented that they liked TravTek but thought it needed **some** revision.	3	1.0%	1 .0%

Favorite Features. Table 32 summarizes driver responses to the debriefing question "What was your favorite feature?" The Guidance Display and Route Map were the first and third most cited favorite features. It is clear that route guidance in a visual format was highly appreciated.

Voice Guide was cited second most as a 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 quality of the synthesized voice. That drivers did not like the sound of the voice, but still rated voice guidance favorably in the questionnaire and debriefings, suggests a 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 favorite feature.

"Easy to use" and "Easy to learn" ratings should be regarded with skepticism as the observers offered "easy to use or easy to learn" as an example of a favorite feature in prompting responses.

Table 32. What was vour favorite feature?

Response	*Frequency*	*Percent of Responses*	*Percent of Drivers*
Guidance display — liked the turn-by-turn display. Some said that the guidance display was straightforward and provided cleal instruction.	102	**25.9%**	32.8%
Voice Guide — liked aural turn-by-turn instructions. Some said that the voice enables them to concentrate on driving without having to look at the screen.	77	**19.5%**	24.8%
Route Map — liked the detail the Route Map provided.	43	10.9%	13.8%
Route guidance — liked the complete TravTek system, which included the voice guidance, guidance display, and the Route Map.	26	6.6%	8.4%
Helped me find my way — liked how TravTek helped them navigate.	25	6.3%	8.0%
Easy to use — liked the user-friendliness of TravTek.	20	5.1%	6.4%
Saved time — said TravTek saved time over traditional methods.	17	4.3%	5.5%
OK New Route — liked the OK New Route function.	16	4.1%	5.1%
Other — catch all category for responses that were made by only one driver.	16	4.1%	5.1%
Swap map — liked how the swap map button enabled switching between the Guidance Display and Route Map.	12	3.0%	3.9%
Zoom in/zoom out — liked the ability to change the Route Map scale.	8	2.0%	2.6%
Easy to learn - liked how easy the TravTek system was to learn.	8	2.0%	2.6%
Next turn warning — liked the advance warning of the next turn that TravTek provided.	6	1.5%	1.9%
Planning destination — liked the ease of planning a route with TravTek.	4	1 .0%	1.3%
Where Am I — liked the Where Am I function. Some said that it provided comfort.	3	0.8%	1.0%
Repeat Voice — found this feature to be useful if the last message was forgotten or not understood.	3	0.8%	1 .0%
Cellular phone — liked the hands free cellular phone.	2	0.5%	0.6%
Help desk — liked being able to communicate with someone at the help desk if needed.	2	0.5%	0.6%
Makes you feel more confident — liked the added sense of security TravTek provided.	2	0.5%	0.6%
The accuracy of TravTek — was impressed by the accuracy of TravTek.	2	0.5%	0.6%

Least Favorite Features. The features cited by drivers as their least favorite are shown in table 33. The most frequently cited least favorite feature was the synthesized voice. The Route Map was cited as a most favorite feature by 43 drivers and as a least favorite feature by 33 drivers. Both the Guidance Display and Route Map were frequently cited as a most favorite feature. However the Route Map alone was frequently cited 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 in general. Many drivers suggested that the Route Map would be more usable if they could zoom it in or out while driving. Also, in the TravTek Route Map implementation, the current street narne and next street name were not always displayed. Whereas the Route Map display was disliked by a non-trivial minority of participants, it cannot be assumed from these data that moving map displays in general would have been disliked by these respondents.

Table 33. What was your least fa orite feature?

Response	*Frequency*	*Percent of Responses*	*Percent of Drivers*
Voice quality — sound or intelligibility of the Voice Guide.	**97**	**29.8%**	31.2%
None — declined to name least favorite feature.	83	25.5%	26.7%
Route Map — Some said the Route Map required more effort tc use than the Guidance Display.	33	10.2%	10.6%
Keyboard interface — the awkwardness of the keyboard. Some said the keyboard interface was not user-friendly.	29	8.9%	9.3%
Other — catch all category for responses that were made by only one driver.	27	8.3%	8.7%
Inability to zoom in or out while moving — the inability to change the scale of the Route Map while moving.	11	3.4%	3.5%
Location of function buttons — reported difficulty finding the appropriate function button on the steering wheel hub.	5	1.5%	1.6%
Tracking problem — how TravTek would misrepresent the vehicle's position.	4	1.2%	1.3%
No response — did not answer this question.	4	1.2%	1.3%
Hard to learn — found TravTek a little difficult to learn.	4	1.2%	1.3%
Voice without Visual display — did not like using the voice guidance without a visual display.	4	1.2%	1.3%
Destination entry — the time required to input a destination into the TravTek system.	3	0.9%	1.0%
System can be distracting — the system could be distracting under certain conditions such as heavy traffic or bad weather.	3	0.9%	1.0%
Using Maps without the Voice — did not like using either visual display without the voice guidance.	3	0.9%	1.0%
Route Map without Voice — did not like using the Route Map display without the voice guidance.	3	0.9%	1.0%
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	0.6%	0.6%
Having to be in park to program — the requirement to be in park to program a destination.	2	0.6%	0.6%
Need more warning before turns — how TravTek did not instruct them to turn soon enough.	2	0.6%	0.6%
TravTek Malfunction — when a feature of TravTek did not function correctly.	2	0.6%	0.6%
New route planning delay — found the delay between the press of the OK New Route button and TravTek's delivery of a new route too long.	2	0.6%	0.6%
Help Desk — found the help desk confusing.	2	0.6%	0.6%

How TravTek Helped Drivers. Responses to the question "While driving with TravTek, were there any situations where TravTek was especially helpful?" are shown in table 34. The OK New Route function was most frequently cited as being especially helpful in particular situations.

Table 34. 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.	107	32.7%	34.4%
Finding specific destination — TravTek was helpful locating a particular destination.	78	23.9%	25.1%
Other — catch all category for responses that were made by only one driver.	20	6.1%	6.4%
Distance to next maneuver -the advanced warning TravTek provided for the next turn.	18	5.5%	5.8%
TravTek was helpful all the time — TravTek was helpfui in all cases.	17	5.2%	5.5%
Instruction to turn — the information TravTek provided as to exactly where to turn.	16	4.9%	5.1%
None — in no instance was TravTek especially helpful.	12	3.7%	3.9%
Driving in residential areas — the detailed directions TravTek provided were helpful when driving in residential areas.	12	3.7%	3.9%
Guidance display — the clear instruction of the turn-by-turn display.	9	2.8%	2.9%
Route guidance -the Voice Guide, Guidance Display, and Route Map.	6	1.8%	1.9%
Close proximity maneuvers — TravTek was helpful when two consecutive turns were in close proximity.	6	1.8%	1.9%
TravTek was generally helpful — TravTek was helpful in most cases.	5	1.5%	1.6%
Route Map — the detail the Route Map provided was helpful.	3	0.9%	1.0%
No response — driver did not answer this question.	3	0.9%	1.0%
Saved time — the time savings TravTek provided over using a paper map.	3	0.9%	1.0%
Helped navigate through downtown — found TravTek more helpful navigating through the city as opposed to driving on the Interstate.	3	0.9%	**1.0%**
Voice Guide — by following the aural instructions of the voice guidance, drivers were not required to take their eyes off of the road way.	3	0.9%	1.0%
Help desk — the ability to call the help desk for assistance.	2	0.6%	0.6%
REPEAT VOICE — in cases where the voice message was not understood the REPEAT VOICE function was very helpful.	2	0.6%	0.6%
Zoom in / zoom out — Zoom in / zoom out function allowed the scale of the Route Map to be changed.	2	0.6%	0.6%

When TravTek Did Not Help. Table 35 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." Twenty drivers mentioned that they had problems with the Voice Guide, and some drivers stated that the Voice Guide caused them to make a wrong turn. Route Map was mentioned by 18 drivers. Drivers stated that it was difficult to see where to turn with the Route Map display, especially when exiting from the Interstate onto an exit ramp. Drivers stated that part of the difficulty was due to the fact that the Route Map display contained too many streets close together and that they were unable to read some of the street names.

Table 35. 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.	168	53.2%	54.0%
Other — catch all category for responses that were made by only one driver.	29	9.2%	9.3%
Problems with voice — Some said the voice was difficult to understand. Some said that this caused them to make a wrong turn.	20	6.3%	6.4%
Route Map — Some said that it was difficult to see where to turn with the Route Map.	18	5.7%	5.8%
Tracking problems — it was confusing when TravTek incorrectly displayed the car's current location.	12	3.8%	3.9%
Weird routing — sometimes TravTek suggested a maneuver that was not intuitive, legal, or possible.	11	3.5%	3.5%
Bear right / left confusing — TravTek's instruction to bear right/left was confusing. Some said when TravTek instructed them to bear they mistakenly turned.	8	2.5%	2.6%
No response — driver did not answer this question.	7	2.2%	2.3%
Street names not consistent with street signs — conflicts between street signs and street names used by TravTek.	7	2.2%	2.3%
Inability to zoom while driving — sometimes the scale of the Route Map needed to be adjusted while the car was moving.	6	1.9%	1.9%
Using TravTek in parking lots — initial instructions from TravTek were unclear as to how to exit parking lots.	5	1.6%	1.6%
TravTek not specific enough when reaching destination — upon nearing the planned destination, TravTek announced that "you are in the vicinity of your destination." At that point, route guidance ends.	5	1.6%	1.6%
Need more warning before turns — there was not enough advanced warning of upcoming turns.	5	1.6%	1.6%
System can be distracting — the system could be distracting under certain conditions.	3	0.9%	1.0%
Guidance Display — some said the guidance display did not provide enough warning as to which lane to be in for an upcoming turn.	3	0.9%	1.0%
Not needed on long stretches of Interstate — route guidance is not needed on long stretches of the Interstate.	3	0.9%	1.0%
In heavy traffic — TravTek was distracting in heavy traffic.	2	0.6%	0.6%
Instructed to turn too early — the instruction to turn was delivered prematurely.	2	0.6%	0.6%
New route planning delay — the delay between press of OK New Route button and delivery of new route was too long.	2	0.6%	0.6%

The Orlando Test Network Study Orientation. 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. Nonetheless, driver comments on the training they received are reported in table 36.

Table 36. Did the orientation you were given prepare you for driving with TravTek?

Response	*Frequency*	*Percent of Responses*	*Percent of Drivers*
Yes	268	84.5%	86.2%
No response — driver did not answer this question.	29	9.1%	9.3%
No	14	4.4%	4.5%
Other — catch all category for responses that were made by only one driver.	6	1.9%	1.9%

Suggestions for Improvement. Suggestions for improvements to the TravTek system are shown in table 37. The quality of the synthesized voice was most frequently cited as needing improvement. It should be stressed that these comments were referred to the ease of intelligibility and the naturalness of the voice and not to the usability of the Voice Guide. The performance data showed that the Voice Guide was intelligible. The fact that the Voice Guide was also frequently mentioned by the same individuals as a "favorite" feature also stresses that this is a feature participants wanted improved, not eliminated.

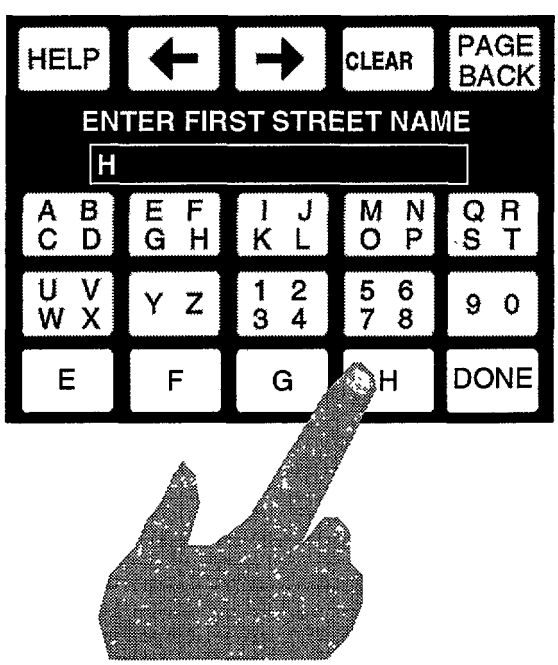


Figure 16. An example of the TravTek "keyboard" interface.

The second most requested improvement was for easier input of text into the system. Participants entered at least nine different destinations into the system. Each destination required the entering of two street names on a touch keypad. An example of the touch keypad, as it was presented on the TravTek video display, is shown in figure 16. Four letters or numbers were displayed on each of the keys on the top two rows of buttons. Entering a letter or number was a two step process. First, the key that included the target in the top two rows was pressed. This caused presentation of four additional keys in a third (bottom) row. Second, the desired number or letter was 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 brought up a list of streets beginning with those let-

entry of streets without the requirement for a dedicated keyboard. However many users found the implementation somewhat awkward.

Table 37. 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 needs to be improved.	98	24.3%	31.5%
Other — catch all category for responses that were made by only one driver.	62	15.3%	19.9%
None -nothing needs to be improved.	55	13.6%	17.7%
Improve keyboard interface -the user-friendliness of the 'keyboard interface needs to be improved. Some said that the time required to enter a destination needed to be shortened.	28	6.9%	9.0%
Ability to zoom in and out while driving — add the capability to change the scale of the Route Map while moving.	24	5.9%	7.7%
Heads-up display -the display needs to be positioned so that drivers can keep their head up while driving.	17	4.2%	5.5%
Improve upon visual display — suggestions included sharper graphics, and improving the resolution of the visual display.	10	2.5%	3.2%
Provide speed limit information -the speed limit should be displayed. Some even suggested that TravTek monitor the car's speed and notify the driver when the speed limit was being surpassed.	9	2.2%	2.9%
No response — driver did not answer this question.	8	2.0%	2.6%
Provide advanced notification of direction of turn — TravTek should notify the driver further in advance as to the direction of the next turn.	8	2.0%	2.6%
Capability of voice input-would like to use voice commands to control TravTek.	7	1.7%	2.3%
Screen glare — reduce the glare on the visual display.	6	1.5%	1.9%
Improve data base -would like the street **names** TravTek uses to match the corresponding street signs.	6	1.5%	1.9%
Improve tracking -the tracking of the car's position needs to be improved.	5	1.2%	1.6%
Choice of voice -would like to be able to select a female voice	5	1.2%	I .6%
Illuminate TravTek system — display screen and steering wheel buttons need to be more effectively lighted.	5	1.2%	1.6%
Legibility of Route Map — hard to read street names on Route Map display.	5	1.2%	1.6%
Add a clock display to the maps -would like to add a clock to both of the visual displays.	4	1.0%	1.3%
Provide exit numbers — display freeway exit numbers.	4	1.0%	1.3%
Add option of foreign languages — system should be available in other languages.	4	1 .0%	1.3%
Repeat Voice — would like to extend time limit allowed to re-**cover** last voice message.	4	1 .0%	1.3%

Table 37. Can you think of anything that could be improved about TravTek to make it better? (continued)

Response	*Frequency*	*Percent of Responses*	*Percent of Drivers*
Screen size — a larger visual display is needed.	3	0.7%	1.0%
Add destination information to Route Map — would like to add ETA and distance to destination to Route Map display.	3	0.7%	1.0%
Earlier instruction to turn -instruction to turn should come sooner.	3	0.7%	1.0%
Warn driver of impending wrong turn -would like TravTek to monitor turn signals and notify driver if a wrong turn is indicated.	3	0.7%	1.0%
New route planning delay — would like faster re-routing after pressing the OK New Route button.	3	0.7%	1.0%
Location of Zoom function — would like the zoom in /zoom out function moved to the steering wheel.	3	0.7%	1.0%
Full compass rose — would like to have a compass for reference.	2	0.5%	0.6%
Programming ability while driving — would like the ability to program a destination while driving.	2	0.5%	0.6%
More advanced warning of next turn **—** increase distance before first announcement of next turn.	2	0.5%	0.6%
Using TravTek in parking lots — when beginning a route provide clear instructions as to how to exit parking lot.	2	0.5%	0.6%
Use metric units — change miles to kilometers.	2	0.5%	0.6%
Provide a TravTek display for orientation -would like to be able to touch and use a TravTek display during orientation.	2	0.5%	0.6%

In the case of the Voice Guide, familiarity does not appear to have reduced dissatisfaction. When asked to name their least favorite feature, 40 percent of the participants who drove the test O/D's with Voice Guide On named "voice quality" compared to 22 percent of the participants who drove with Voice Guide Off. When asked to describe a situation in which TravTek was not helpful, 11 percent of the participants who were tested with Voice Guide On said "problems with the voice" compared to 1 percent who were tested with the Voice Guide Off. When asked what could be improved about TravTek to make it better, 43 percent of the participants who drove with Voice Guide On identified improvements to the voice, whereas only 19 percent of the participants who were tested with Voice Guide Off identified the voice as potentially benefiting from improvement.

Those who were tested with the Voice Guide On also differed from those who drove the test O/D's in the Voice Guide Off condition in their evaluation of the Guidance Display and Route Map. Only 27 percent of those who were tested in the Voice Guide on condition identified the Guidance Display as their favorite feature whereas 39 percent of participants in the Voice Guide off condition named that display as their favorite feature. The Guidance Display and the Voice Guide provided essentially the same information, whereas the Route Map did not consistently show distance to maneuver, current street name, or next street name. Thus, the appreciation for the kind of information that the Guidance

Display provided may have been greater among those who experienced a lack of adequate information when using the Route Map without the supplemental information provided by the Voice Guide. This interpretation is further supported by the finding that when asked to name their least favorite feature, 16 percent of the participants who were tested with the Voice Guide Off named the Route Map; whereas, only 5 percent of the participants who were tested with the Voice Guide On named the Route Map. One driver expressed this interpretation directly by saying that the "…Route Map wasn't clear enough without the voice."

Willingness to Pay

In the questionnaire, participants were asked how much they would be willing to pay for TravTek and various TravTek functions. Four sets of questions addressed willingness-to-Pay:

- 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.

Because patterns were not reliably different between Yoked Driver Study and Orlando Test Network Study respondents, the analyses reported here include participants from both studies. Although the sample size varies slightly for each of the analyses reported below because of occasional failures to respond, the data are drawn on responses from approximately 370 respondents.

Responses to the willingness-to-pay questions were indicated by placing an X on a line that had tick marks representing dollar values at equally spaced intervals. Figure 17 provides an example of a willingness-to-pay scale used in the questionnaire.

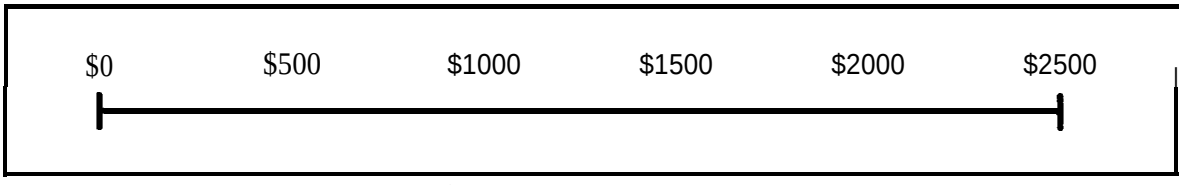


Figure 17. An example of a willingness-to-pay scale in the questionnaire.

Table 38 provides a summary of responses to the willingness-to-pay questions. The range of values from which the participants had to select, and the mean across participants from both the Orlando Test Network Study and the Yoked Driver Study are shown. The participants indicated that they would be willing to pay about $1000 for the TravTek system. Regardless of whether the participants were rating the individual TravTek features as options in a new car, or as add-ons to any car, they were consistent in ranking the relative

value of TravTek features. Participants were willing to pay the most for Route Guidance (i.e., turn-by-turn route planning and instructions), followed by Navigation (i.e., a map with present location without routing information), followed by Traffic Information. It should be noted that Orlando Test Network Study participants did not experience real-time traffic information updates, and only a subset of the Yoked Driver Study participants experienced routing based on real-time information and traffic information messages.

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 38. Summary of responses to the willing less-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 38 (above) 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 39 shows the proportion of drivers, as a function of income, who indicated they would not pay for TravTek or its functions. Generally, the lowest income group had the fewest participants who said they would pay nothing, and the middle income group had the most participants who said they would pay nothing. Very few participants were unwilling to pay for the route guidance feature, with values ranging between 1.4 percent and 8.7 percent. 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 figures 18 through 21, 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 18 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 TravTek Rental User Study provides willingness-to-pay estimates from approximately 2500 drivers who actually rented TravTek vehicles and is probably a better source of data for rental value estimation.'@

Table 39. Proportion of participants who said they 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?	0.031	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	.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[7]	116	185	70

7 The sample size varies slightly (+5 percent) for each question because of occasional failures to respond.

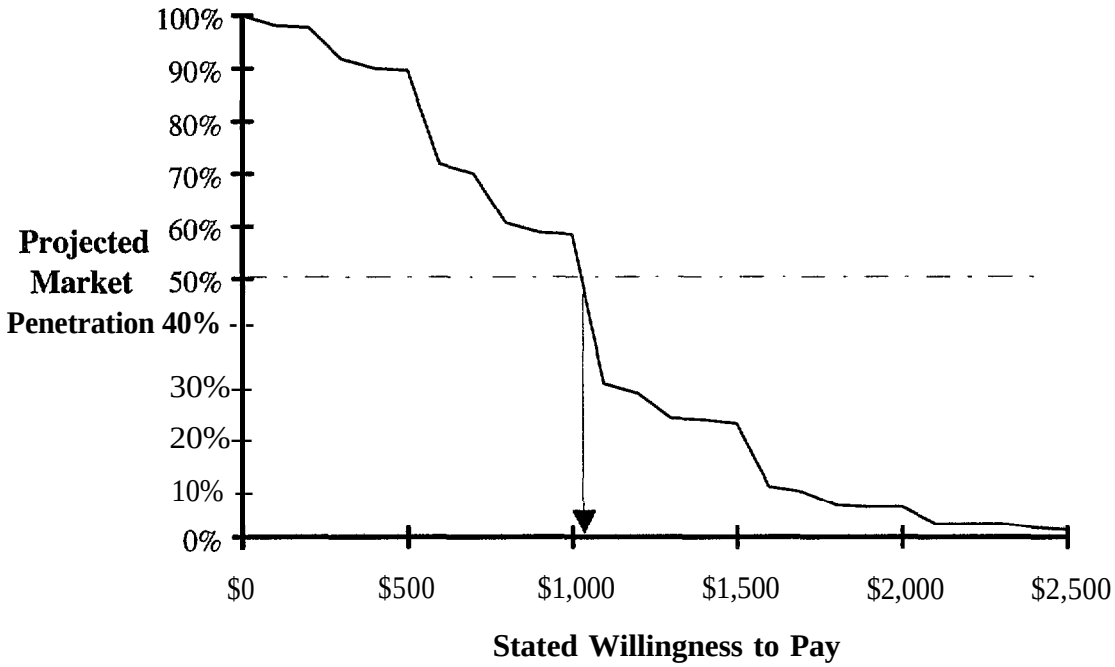


Figure 18. Estimated market penetration for the TravTek system "such as the one you drove."

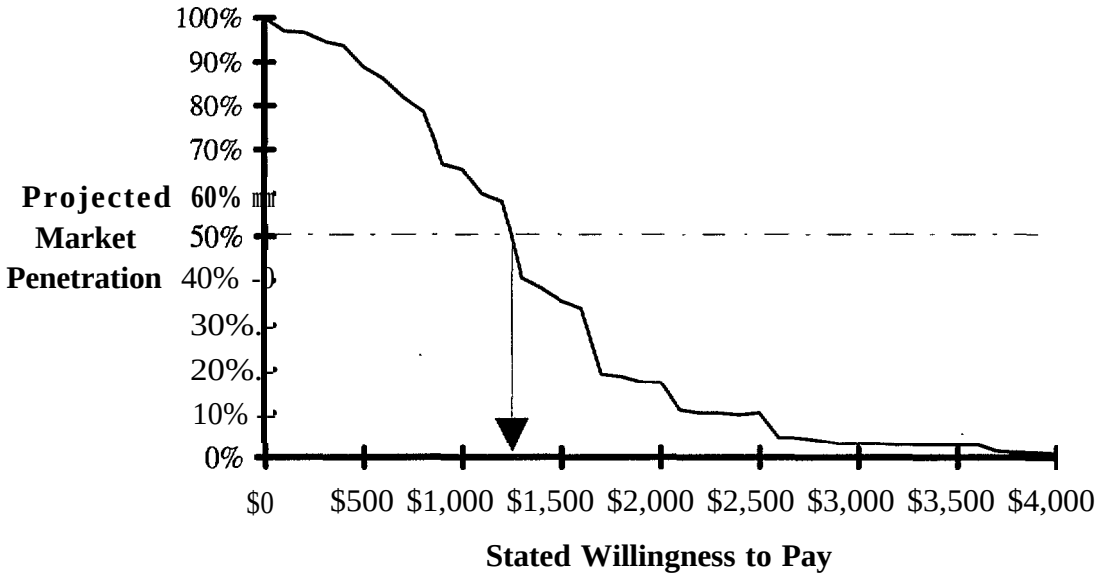


Figure 19. Estimated market penetration for the TravTek system purchased as "options on a new car."

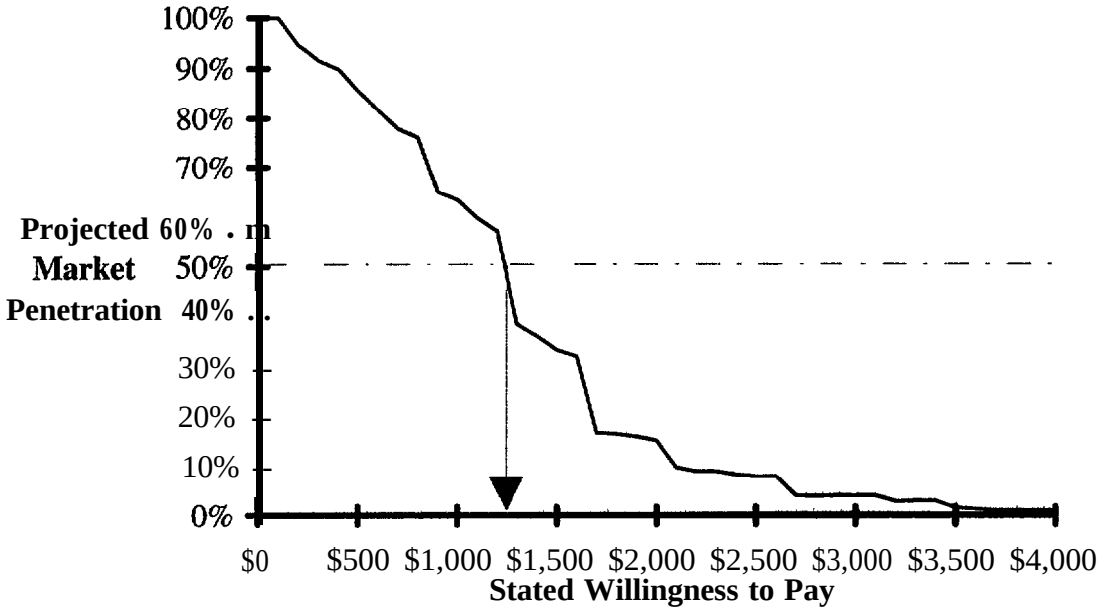


Figure 20. Estimated market penetration for the TravTek system purchased as "an add-on to any car."

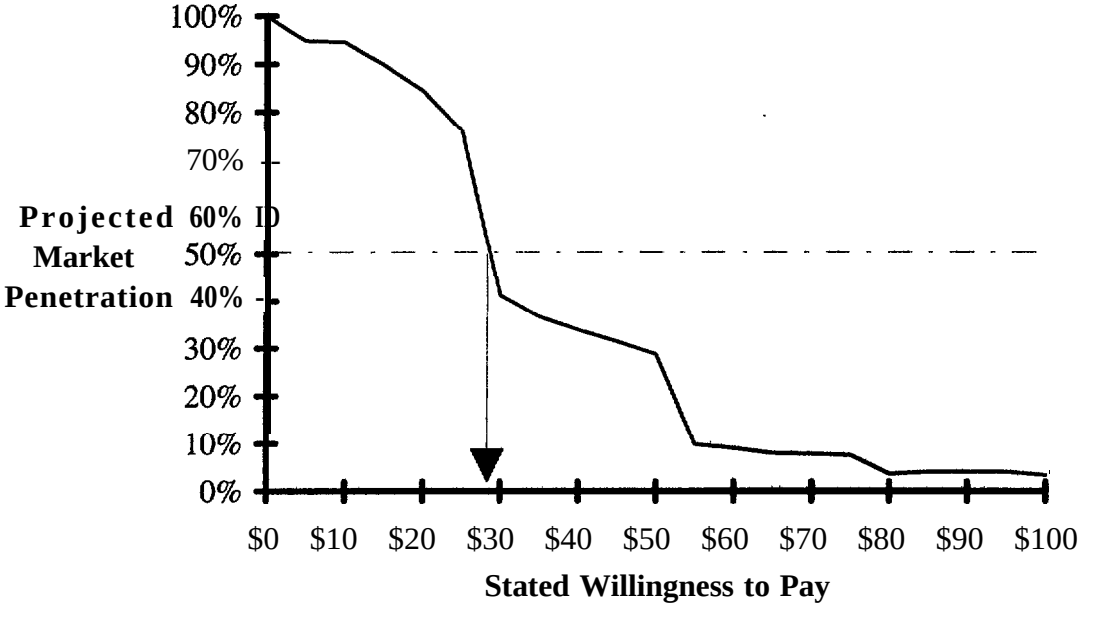


Figure 21. Estimated market penetration for the TravTek system as added cost on a weekly rental rate.

DISCUSSION

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

1. Does TravTek improve driver navigation?
2. Does TravTek improve overall driver performance?
3. Does driver interface usability vary with display configuration?
4. Do drivers perceive TravTek as useful, usable, and safe?
5. Do drivers prefer particular TravTek display configurations?

Issue 1: Does TravTek improve driver navigation?

The influence of TravTek display configurations on driver navigation performance was assessed using trip length and navigation errors as measures of effectiveness. The measures of performance that were used to examine navigation performance were:

- Trip planning time.
- Time en route.
- Trip distance.
- Number of wrong turns.
- Time off planned route.

Drivers using TravTek to plan trips required less time than drivers using conventional route planning means. Participants took less than 1.5 min to complete route planing using TravTek, well under the average of 5.0 min required by those in the control condition.

Average en route travel times were also less for drivers using TravTek. When not using TravTek for route guidance, drivers took 5 min longer to complete trips than when they used the TravTek system to find their way. No travel time differences were observed among the five TravTek route guidance configurations.

No statistically reliable differences in distance traveled were observed for any of the test conditions. That is, drivers using TravTek and those in the Control condition traveled about the same distance, but the drivers using TravTek took significantly less time to travel that distance.

Drivers in all test conditions were equally likely to make wrong turns. However drivers in the Control condition, and those using TravTek with the Voice Guide and without benefit of a visual display spent more time off route. Drivers in the control condition took significantly longer to detect they had made a navigation error than those using TravTek. Thus, whereas drivers were equally likely to make navigation errors in all test conditions, the consequences of those error tended to be more severe when they did not have a TravTek visual display to guide them. However, it should be noted that average time off route in

this experiment was less than 90 s even in the worst conditions. On longer trips the nature and severity of navigation errors could be different.

In summary, TravTek cut trip planning time by about 75 percent and cut driving time by about 25 percent. Drivers made about the same number of navigation errors with TravTek as without, but time off route was longer for drivers navigating by conventional means, or using TravTek with only the Voice Guide.

Issue 2: Does TravTek improve overall driver performance?

Driver performance was assessed using three measures:

- Maneuver abruptness.
- Number of accidents and near accidents.
- Subjective workload.

Maneuver abruptness was defined in terms of three behaviors that were assumed related to preparation for planned turns or navigational awareness: the abruptness of turns, turn lane entry point, and the point at which the turn signal was applied. No differences in maneuver abruptness were observed among any of the six navigation conditions. More abrupt maneuvers occurred at night than during the day, but this was independent of whether TravTek or conventional methods of navigation were used.

There were no accidents involving Orlando Test Network Study participants. Furthermore there were only eight events that the observers classified as close calls, and these were evenly distributed across test conditions.

Whereas the maneuver abruptness, accident, and near accident data suggest no relationship between use of TravTek and driver performance or safety, the subjective workload measures suggest a driving performance or safety benefit when using the TravTek system to navigate. Subjective workload measures are regarded by many as important in the evaluation of relative safety when operators are rarely taxed beyond their limits.(4) Because driving is a relatively safe activity, devices that add or detract from safe performance can rarely be observed to have an effect, as the circumstances under which they might show an effect are rare. However, users may be able to assess whether there is an effect by reporting their relative workload. It is presumed that when workload is high, users are closer to the brink, such that when a rare combination of circumstances does push them close to their performance limits they would be more likely to fail.

Participants in the Orlando Test Network Study reported that their workload, in particular visual effort, was less with TravTek than in the Control condition. If their subjective impressions are accurate, then they would be expected to have additional reserve visual capacity for handling high workload situations when using TravTek. Reduced visual effort may also result in a reduction in fatigue, such that drivers might perform better for longer periods of driving when using TravTek. Subjective workload assessment is built on a

theoretical construct, mental workload, that is not well understood. However the subjective measures reported here are suggestive of a safety benefit.

Issue 3: Does driver interface usability vary with display configuration?

The usability of the TravTek system was evaluated in terms of ease of learning. The navigation and driving performance measures discussed above suggest that once learned, the system was usable.

Participants mastered use of the system rather easily. Number of trials to become proficient at entry of destinations into the system was used as a learning measure. On average, participants entered 2.3 destinations before the observers rated them as proficient, that is before they performed the eight destination entry steps without requiring assistance and without hesitating between steps. However, older adults took more trials, on average, than young adults before reaching proficiency: those 25 to 34 averaged 2.1 trials; those 35 to 54 averaged 2.3 trials, and those 55 and older averaged 2.9 trials.

The above analysis examined ease of learning pre-drive TravTek functions. In another assessment of usability, performance of five TravTek drive functions was assessed. Fewer than one in seven drivers erred in performing the five drive functions when requested to do so. The frequency of errors was unrelated to age or gender.

While on training runs, the participants were also asked 11 questions that probed their understanding of the system. Approximately 75 percent of the participants answered each question correctly the first time it was asked. However, for 5 of the 11 questions, the 55 and older age group answered correctly less often on the first trial than did younger participants. Thus for two of the three usability assessment measures, older adults had somewhat more difficulty mastering the TravTek system. Ease of learning difficulties were relative: all the participants mastered the system in a relatively few trials.

In summary, the TravTek system appeared to be easy to learn and easy to use.

Issue 4: Do drivers perceive TravTek as useful, usable, and safe?

User perceptions of TravTek's usefulness as a navigation aid were explored by analyzing 14 items from the questionnaire. These questions asked either whether the navigation function was useful or helpful.

Users tended to disagree with statements that asserted TravTek, or one of its navigation functions, interfered with their driving. Furthermore, they agreed with statements that asserted TravTek, or one of its navigation functions, helped them pay more attention to their driving and helped them find their way. The Voice Guide was favorably rated, but responses to the Voice Guide tended to be somewhat independent of the favorability responses for other TravTek functions.

The participants were almost unanimous in agreeing that TravTek would be useful for out-of-town business and pleasure trips. Users were not so unanimous about the utility of TravTek for driving near their home: 42 percent thought TravTek would be useful for trips "at home." It should be remembered that the vast majority of participants were tourists on vacation in the Orlando area.

Users tended to agree with the assertion that TravTek helped them drive more safely.

Overall, participants judged TravTek to be useful, usable, and safe.

Issue 5: Do drivers prefer particular TravTek display configurations?

On a scale of one to six, where one represented disliked and six represented liked, Orlando Test Network Study participants gave the TravTek Guidance Display and Route Map with Voice Guide a median rating of 6. The median rating for the Guidance Display without Voice Guide was 5. The Route Map without Voice Guide received a median rating of 4. The Voice Guide alone also received a median rating of 4, but its mean rating was less than that for the Route Map. Thus, participants strongly liked the combination of visual display with voice guidance regardless of whether the visual display was the Route Map or the Guidance Display. When the visual display was used without the Voice Guide to supplement it, the visual displays were not as highly rated, and the Guidance Display was generally favored over the Route Map. Users did not like the Voice Guide alone, although the majority did not express dislike for the Voice Guide alone option.

The debriefings provided additional insights on preferences. Debriefing responses were equally positive about the utility of the navigation functions. Voice Guide, the Guidance Display, and route guidance were the most frequently cited favorite features. During the debriefing, participants selected the OK New Route feature as especially helpful.

Negative impressions expressed during the debriefings often included the Voice Guide's sound quality and the touch keypad interface: these turned up as frequently cited least favorite features.

Whether as an add-on or as a 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 per week additional for a system like TravTek in a rental car.

CONCLUSIONS

The Orlando Test Network Study was designed to evaluate alternative TravTek visual and aural display configurations, and TravTek's route planning and route guidance functions with respect to:

- Trip efficiency.
- Navigation performance.
- Driving performance.
- Driver preference.
- Driver perception.
- Willingness-to-pay.

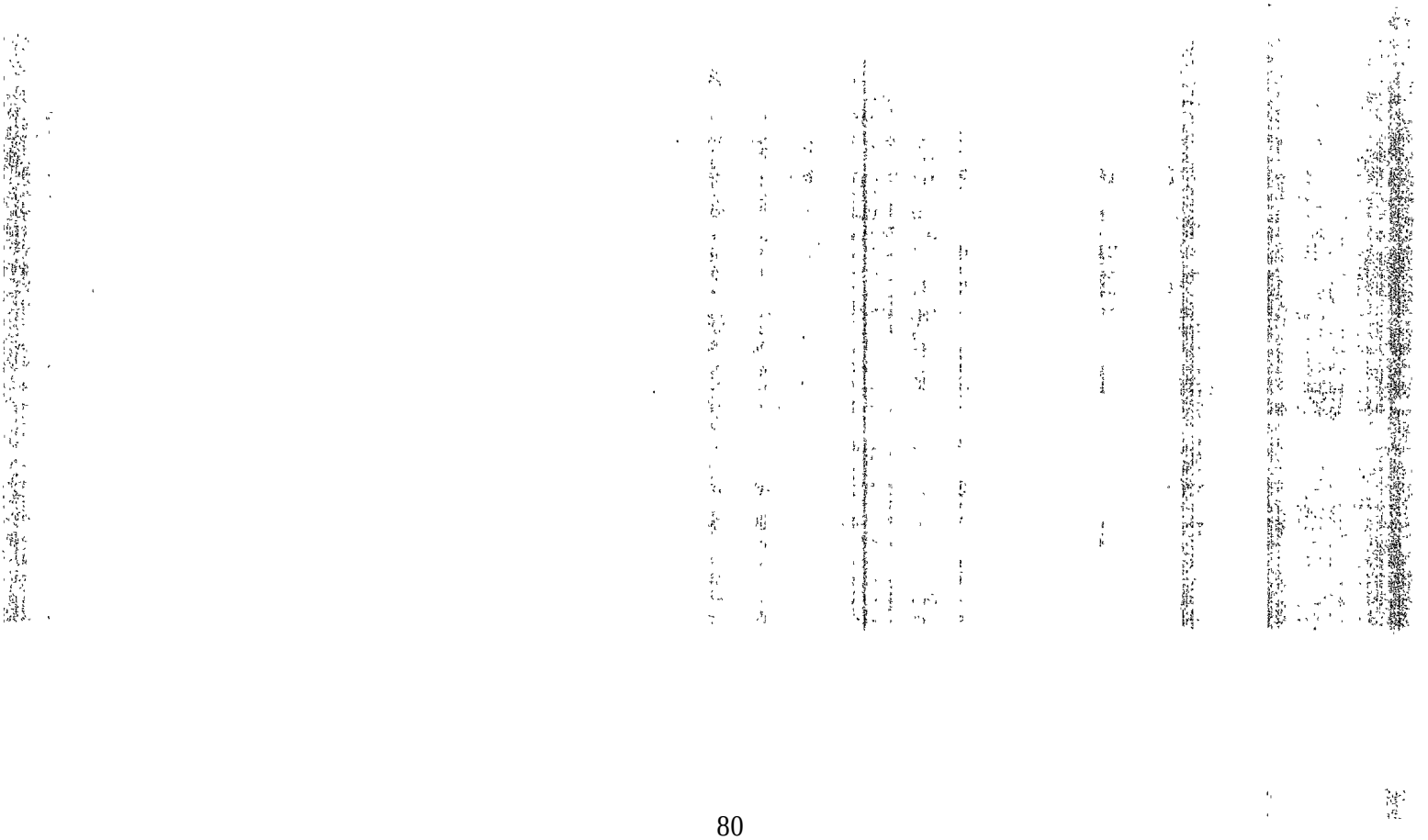
The TravTek system was found to improve the efficiency of trips over trips driven without the system. Tourists unfamiliar with the local area were able to plan trips to nearby unfamiliar destinations in about 75-percent less time using TravTek than using the method they would normally use. On the nominal 16 km trips used in this study, participants reduced their travel time by about 5 min when they navigated with TravTek. There were no differences in travel time among the alternative TravTek configurations that were evaluated.

No differences in driver performance were detected between that obtained when TravTek was used and that obtained when conventional navigation techniques were used. Nor were any performance differences detected as a function of the alternative TravTek configurations. However, drivers did report that their visual effort was reduced when they used TravTek to navigate. This finding suggests their may be a safety benefit with extended use of TravTek-like systems, but this conclusion rests on the assumption that drivers' subjective workload estimates reflect actual mental effort, and that higher levels of required effort reduce safety margins. For a further discussion of the safety benefits of TravTek refer to the *TruvTek Evaluation-Safety Study* final report."" The TravTek Camera Car Study reported glance frequency and glance dwell time data that supported the Orlando Test Network Study drivers' impressions of visual workload.(3)

Drivers prefered navigating with the combination of a visual navigation display and supplemental voice guidance. If voice guidance was not available, drivers prefered TravTek's simplified Guidance Display to the TravTek Route Map. Although voice guidance by itself proved useful, and yielded performance similar to that with the Guidance Display or Route Map by themselves, drivers in this study much preferred visual displays to voice guidance alone.

Both performance measures and drivers' subjective ratings suggest that that TravTek system was easy to learn and easy to use. Younger drivers found the system somewhat easier to learn than older drivers.

Finally, participants in this study expressed a willingness to pay for a TravTek system. In a new car the median dollar amount the participants said they would pay for TravTek was about $1000. In a rental car, they judged that the TravTek system they drove would increase the weekly rental value by about $28.



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