TravTek Global Evaluation and Executive Summary

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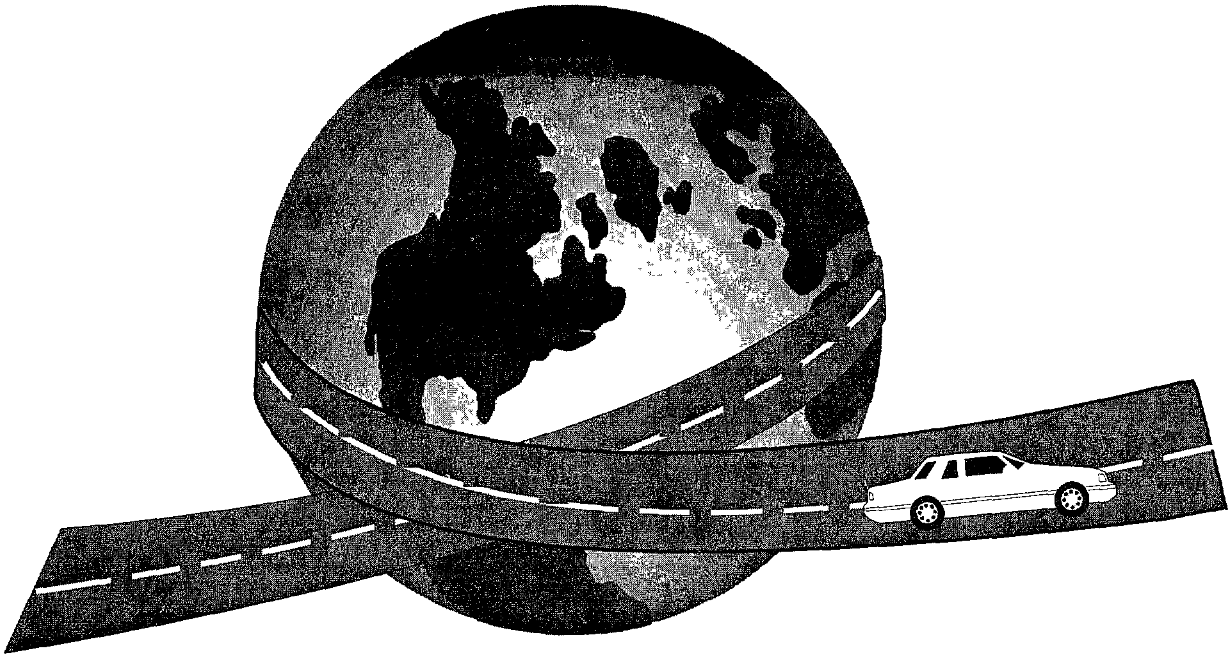

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Federal Highway Administration

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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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Acting Director, Office of Safety and Traffic Operations Research and Development

NOTICE

Technical Report Documentation Page

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16. Abstract

TravTek was an operational field test of an advanced traveler information systems (ATIS) and advanced traffic management systems (ATMS) technologies. This paper summarizess the findings from the series of studies that constituted the TravTek evaluation. Two field studies, three field experiments, and four analytical studies are summarized. The Rental User Study and Local User Study were naturalistic field studies of the use of the TravTek system by rental drivers and high-mileage local area residents respectively. The Yoked Driver Study, Orlando Test Network Study, and Camera Car Study were field experiments that empirically assessed the in-vehicle TravTek subsystem with respect to measures of performance that included trip planning time, travel time, subjective workload, wrong turns, glance location, and glance duration. The Modeling Study extrapolated expected system performance from field studies and experiments for various levels of market penetration, traffic conditions not observed in the field, and measures of performance not directly measured in the field. The Modeling Study projected effects on fuel consumption, vehicle emissions, accident risk, and other measures for market penetration levels of 1 to 100 percent. The Safety Study reviewed and integrated safety-related statistics across all TravTek studies and expanded on Modeling Study methods to project safety benefits. The Architecture Study thoroughly documented the TravTek system and evaluated system components that included: communications, data bases, hardware, software, and system staffing.

Study results showed that the TravTek system was reliable. The distributed information processing system was found to be viable. The system helped drivers save substantial trip planning and travel time. It also was effective in helping drivers avoid congestion. Both visitors and local users used the system frequently, and provided a median estimate of the value of the system in a new car of about $1000. The turn-by-turn Guidance Display and Voice Guide were very well received. Visitors and local users used these features for the majority of their trips, and results of field experiments suggest that the Guidance Display and Voice Guide yielded improved driving and navigation performance over navigating to unfamiliar destinations by conventional means. The Safety Study showed that the system was safe, and suggested a small safety benefit for a fully deployed system. The Modeling Study findings suggest that a TravTek system would benefit not only system users, but also non-equipped vehicles that share the road with system users. The TravTek operational test was a success. The TravTek evaluation demonstrated that users found the system useful, easy to use, and safe. Field experiments showed that the system reduced trip planning and travel time, and improved driving and navigation performance. System users indicated that they were willing to pay for a system such as the one they drove during the operational test.

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)

1 foot (ft) = 30 centimeters (cm)

1 yard (yd □ 0.9 meter (m)

1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2 = 6.5 square centimeters (cm^2)

1 square foot (sq ft, ft^2 = 0.09 square meter (m^2)

1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)

1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)

1 acre = 0.4 hectares (he) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gr)

1 pound (lb) = .45 kilogram (kg)

1 short ton = 2,000 pounds (Lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)

1 tablespoon (tbsp □ 15 milliliters (ml)

1 fluid ounce (fl oz) = 30 milliliters (ml)

1 cup (c) = 0.24 liter (l)

1 pint (pt) = 0.47 liter (l)

1 quart (qt) = 0.96 liter (l)

1 gallon (gal) = 3.8 liters (l)

1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)

1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] ^{o}F □ y ^{o}C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)

1 centimeter (cm) = 0.4 inch (in)

1 meter (m) = 3.3 feet (ft)

1 meter (m) = 1.1 yards (yd)

1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)

1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)

1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)

1 hectare (he) = 10,000 square meters (m^2) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gr) = 0.036 ounce (oz)

1 kilogram (kg) = 2.2 pounds (lb)

1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons

VOLUME (APPROXIMATE)

1 milliliters (ml) □ 0.03 fluid ounce (fl oz)

1 liter (1) = 2.1 pints (pt)

1 liter (l) = 1.06 quarts (qt)

1 liter (l) = 0.26 gallon (gal)

1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)

1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

[(9/5) y + 32] ^{o}C □ x ^{o}F

QUICK INCH-CENTIMETER LENGTH CONVERSION

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

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

QUICK FAHRENHEIT-CELSIUS TEMPERATURE CONVERSION

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

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

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EXECUTIVE SUMMARY

INTRODUCTION

TravTek, short for "Travel Technology," was an Intelligent Transportation Systems (ITS) operational field test. The purpose of TravTek was to perform research, development, test, and evaluation of advanced traveler information systems (ATIS) and advanced traffic management systems (ATMS) concepts.

The TravTek Partnership

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 (FHWA), and the Florida Department of Transportation. The American Automobile Association and General Motors were the private sector participants.

The TravTek System

TravTek consisted of three major subsystems:

1. One-hundred TravTek vehicles.
2. The Orlando Traffic Management Center (TMC).
3. The TravTek Information and Services Center (TISC).

An overview of the relationships between TravTek subsystems is shown in figure 1. The *TravTek System Architecture Evaluation* and reports by Sumner provide detailed descriptions of the TravTek system.[1,2,3] An inherent feature of each subsystem was automated data recording for evaluation purposes. These evaluation features are discussed in later sections of the report. Each of the TravTek partners was responsible for providing and maintaining specific sub-systems. The responsibilities of General Motors included providing the vehicles, the interface between the TMC and test vehicles, a data base, and systems engineering. FHWA provided for the TravTek evaluation, the system manager for the TMC, leasing of the radio subsystem, support for the Florida Department of Transportation's freeway management center, and assisted the City of Orlando in operating and maintaining the TMC. The American Automobile Association provided a TravTek Information and Services Center that maintained the rental reservation system, the navigation data base, the local information data base, and 24-hour help desk services. The City of Orlando provided coordination of the TMC with other traffic management facilities, space, hardware, and software for the TMC, and an interface with the city's traffic signal system. The Florida Department of Transportation provided the freeway surveillance system on I-4, the interface of the surveillance system with the TMC, and maintenance of the TravTek traffic link-node data base.

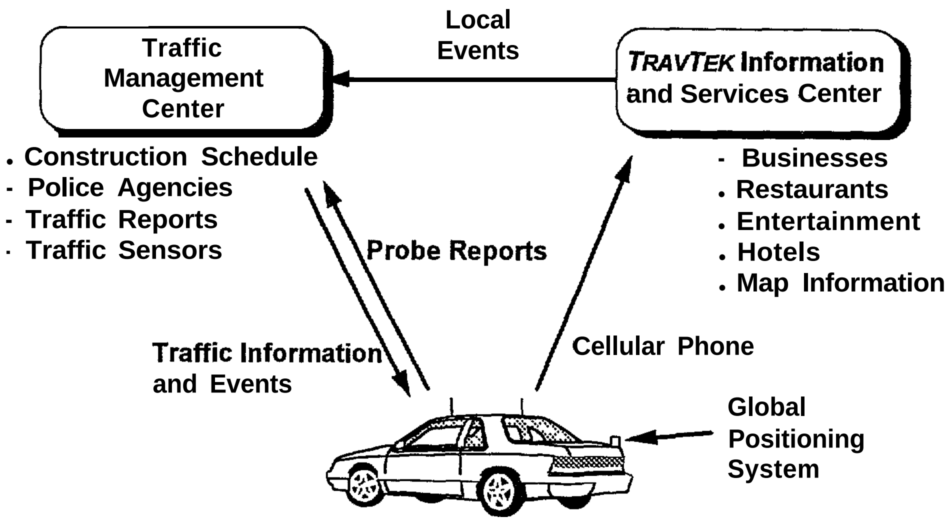

Figure 1. An overview of the TravTek system.

The TravTek In-Vehicle System

Each TravTek vehicle had a two-way communications link with the TMC and communicated with the TISC via hands-free cellular phone. Once each minute, the TravTek vehicles received a broadcast of information from the TMC, and broadcast to the TMC their locations and travel times across TravTek traffic links they had recently traversed. The TravTek in-vehicle system provided a wealth of information to drivers. This information included a local information data base, route planning, route guidance, and real-time traffic information.

As were the other TravTek subsystems, the vehicles were specially designed to collect evaluation data. Data stored on board for later analysis included vehicle speed, vehicle position, driver interactions with all system controls, all TravTek system messages displayed to the driver, and radio messages sent to the Traffic Management Center. In addition, the vehicles could be configured to any of three configurations.

The Services configuration provided drivers with access to the local information data base and integrated cellular phone functions. The local information data base included detailed information on local services (e.g., shopping, eating, hotels, entertainment), and attractions. The detailed information included address, phone number, the ability to auto-dial via the integrated cellular phone, and a pre-drive map that showed the relative location of the selected service or attraction.

The Navigation configuration added route planning and route guidance capabilities to the Services functions. Routes could be planned to destinations based on entered addresses, street names, or selection from the services and attractions data base. Routes were selected based on the shortest travel time and could be constrained to avoid toll roads or Interstate. Travel time estimates were based on nominal travel times that were keyed to road class and did not vary as a function of time of day or current conditions.

The Navigation Plus configuration included all Services and Navigation configuration features plus the display of traffic information and route planning around congestion based on real-time traffic information.

Three configurations, rather than just the Navigation Plus configuration, were included to support research and evaluation. By providing different features to different drivers, or more than one configuration to the same drivers, the evaluators were better able to evaluate the features with respect to driver behaviors and perceptions.

The Traffic Management Center

The TMC received traffic information from a number of sources, processed these data, and transmitted current traffic conditions to the TravTek vehicles. Data sources included the Florida Department of Transportation Freeway Management Center, Orlando's traffic control system, a network of public and private sector reporting stations, and, most importantly, the TravTek vehicles. Information cleared through the system included link travel times, incident status, and the location of congestion. Link travel times were broadcast once each minute for any of 1,488 traffic links for which travel times were greater than nominal. Evaluation data collection functions included the logging of all communications between the vehicles and the TMC. These communications included a record that was updated each minute of the locations of all TravTek vehicles,

The TravTek Information and Services Center

The American Automobile Association operated the TISC. The most visible function of the TISC was to provide help desk services to TravTek users. The TISC also provided and maintained the navigable map data base used in the vehicles. The data base represented a 3 100 km^2 area of metropolitan Orlando and consisted of approximately 74,000 navigable roadway links. The data base was updated and corrected at intervals throughout the operational test. The TISC also managed the local information directory data base and reservation data base. Evaluation data collection functions of the TISC included reservations and help desk contact logs.

The TravTek Network

In the coverage area, two types of data base links were defined: TravTek links, and TravTek Traffic Network links. TravTek links were defined in the navigable data base maintained by the TISC. There were approximately 74,000 of these navigable links representing approximately 16 000 km of roadway. TravTek Traffic Network links represented sections of roadways for which real-time traffic information could be transmitted. There were 1,488 TravTek Traffic Network links that covered a distance of 1 854 km.

THE TRAVTEK EVALUATION

Proponents of ITS technologies such as vehicle navigation, ATIS, and ATMS envision the widespread application of these technologies to improve transportation efficiency, safety, driver satisfaction, and driver security. The TravTek partners identified and tailored their TravTek operational test goals and objectives in light of the overall ITS goals. The purpose of the TravTek evaluation was to determine how well TravTek fulfilled the partners' goals for TravTek and ITS.

Goals and Objectives

The TravTek Partners identified goals and objectives for the TravTek system that could be evaluated by answering the following questions:

1. Did the TravTek system work?
2. Did drivers save time and avoid congestion?
3. Will drivers use the system?
4. How effective were the visual turn-by-turn and moving map displays?
5. How effective was voice guidance?
6. Was TravTek safe?
7. Could TravTek benefit travelers who do not have the TravTek System?
8. Will people be willing to pay for TravTek features?

Approach

The TravTek evaluation consisted of a series of related studies. These studies tended to focus either on the in-vehicle system, primarily from the perspective of individual drivers, or on the functioning of the system external to the vehicles. The studies capitalized on the vast data collection capabilities that were designed into each TravTek sub-system to support the evaluation effort.

THE TRAVTEK STUDIES

There were four classes of studies in the TravTek evaluation: field studies, field experiments, analytical studies, and the integration of the studies that is represented by the present work. The relationships among the TravTek evaluation studies is depicted in figure 2.

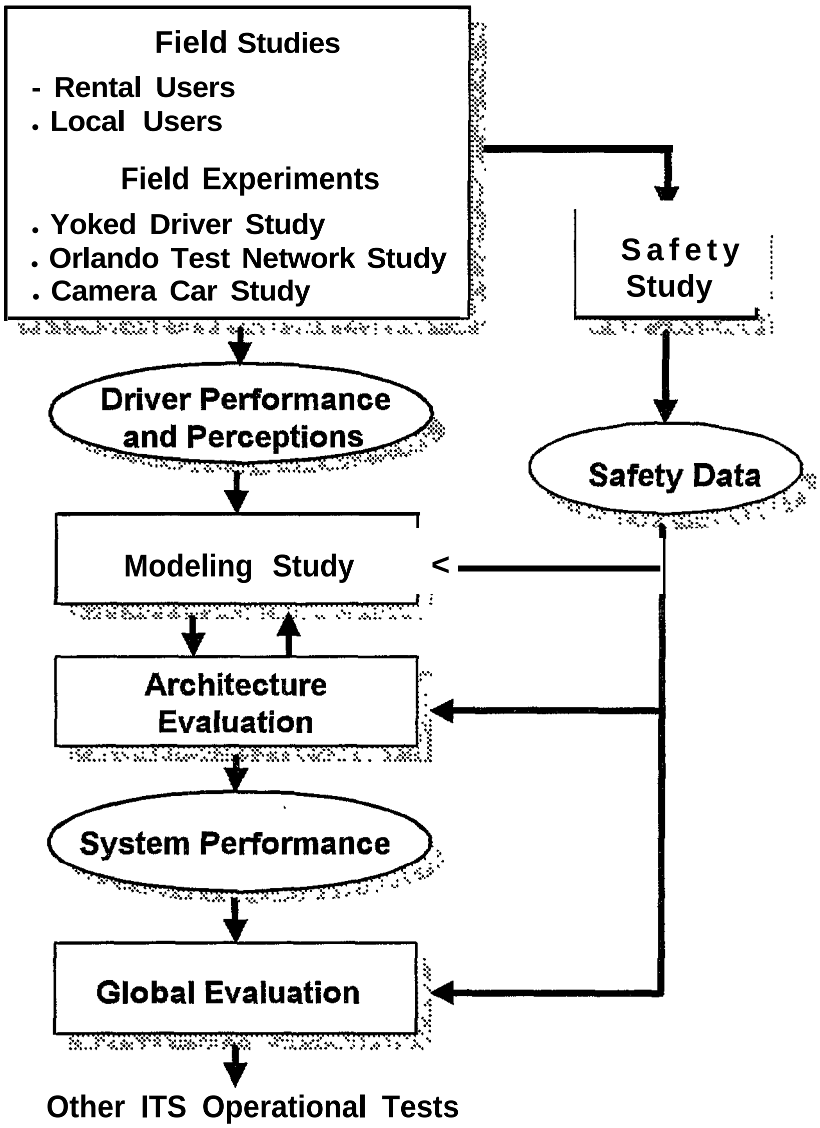

Figure 2. Relationships among TravTek evaluation studies (boxes) and the data they yield (ellipses).

Field Studies

There were two TravTek field studies: the Rental User Study and the Local User Study.[4] In both of these studies, volunteers were provided TravTek vehicles to use freely. The studies provided an opportunity to observe how individuals would use TravTek vehicles when they were not constrained by experimental procedures — as they would be likely to use the TravTek system were it fully deployed.

In the Rental User Study, TravTek vehicles were rented to 4,354 drivers who were primarily Orlando visitors. The drivers were recruited by the American Automobile Association and the vehicles were rented to the recruits by Avis. Rental users provided questionnaire and debriefing assessments of TravTek, and their use of the vehicles was recorded in electronic data logs in the vehicle, at the TMC, and at the TISC.

The Local User Study recruited 53 Orlando residents to drive TravTek vehicles for a period of 6 to 8 weeks. For this study, residents were selected because they drove more frequently than the average driver. To provide an adequate sampling of the driving population, other driver selection criteria included age and gender. In addition to examining how local residents would use the system, this study enabled an examination of how use changed over time. It was anticipated that after 2 months, usage would approximate that which might be seen with a mature system — after the novelty wore off.

Field Experiments

Whereas the Rental User Study and Local User Study examined how drivers would use the system when free of constraints, the field experiments were tightly focused on specific behavioral and system issues. In these studies, drivers were asked to drive from specified origins to specified destinations. Origins and destinations were in residential neighborhoods such that all drivers, even local drivers, needed some kind of assistance (i.e., TravTek, a paper map, or other instructions) to plan the routes. In these studies, observers rode along with the drivers to record data that could not easily be captured by the on-board electronic systems.

The Yoked Driver Study focused on the benefits of real-time information.(5) In this study, sets of three vehicles left the same origin for the same destination, with one vehicle in each set configured to one of the three vehicle configurations: Services, Navigation, and Navigation Plus. Trips in this study were made during the evening peak travel period. In the Services configuration, drivers planned and drove their routes as they normally would without TravTek. With the Navigation configuration, drivers planned and drove routes using TravTek, but without the benefit of real-time traffic information. With the Navigation Plus configuration, drivers planned and drove routes using the default TravTek display configuration, and the routes were optimized (to minimize travel time) by the incorporation of real-time traffic information.

The Orlando Test Network Study examined driving and navigation performance as a function of the display alternatives offered by the TravTek system.(6) Two visual route guidance displays were evaluated: a turn-by-turn *Guidance Display* that minimized information content to that required to navigate, and a moving *Route Map* that displayed planned routes over an electronic version of a traditional map. A supplemental synthesized speech Voice *Guide* was evaluated both by itself and in combination with the two visual displays. The study examined performance both in day and night driving environments.

The Camera Car Study focused on safety and human factors issues related to the use of ATIS displays.(7) The design of the Camera Car Study was similar to that of the Orlando Test Network Study. What made the Camera Car Study unique were changes necessary to focus on age and experience with use of the TravTek system and additional data collection instrumentation. Four video cameras were installed. One camera was focused on the driver's eyes and enabled detailed examination of glance patterns. Another camera focused on the forward roadway and enabled detailed analysis of the traffic environment. A third camera looked over the driver's shoulder to enable recording of hand and foot movements. A fourth camera was attached outside the left side of the car and recorded lane position and lane excursions. Additional sensors in the camera car recorded lateral and longitudinal acceleration, steering wheel position, and vehicle speed.

Analytical Studies

The field studies and experiments focused on data collection to support the evaluation of TravTek. The four analytical studies that are described below used data from the field studies, field experiments, and other sources to extend the system evaluation.

Modeling Study. This study had three main objectives:

1. To extrapolate from the available field data the expected performance of a TravTek type system for levels of market penetration ranging from 1 percent to 100 percent,
2. To extrapolate the expected performance of a TravTek system in terms of measures such as vehicle stops, fuel consumption, vehicle emissions, and accident risk, that were not always directly observed during the field test.
3. To estimate the potential impact on the benefits of the TravTek system for conditions not necessarily encountered in Orlando during the field test, such as different levels of traffic congestion, different incident durations, and different levels of routing quality for either the TravTek or the non-TravTek vehicles.[8]

Computer modeling was employed to extrapolate from the available data. The model that was employed, INTEGRATION, was capable of simulating the behavior of both TravTek equipped and non-equipped vehicles such that numerous scenarios could be evaluated. Data from the other TravTek studies, as well as data collected as part of the modeling study, were used to calibrate the computer model. Of particular importance, was the ability of the model to handle driver behaviors that were affected by TravTek, such as the propensity for making wrong turns and the propensity to choose roads of a particular class.

Safety Study. The objectives of this study were to determine:

- If the users of the TravTek system as deployed in Orlando, experienced a different level of safety than drivers of comparable vehicles without the TravTek system.
- How the different TravTek configurations affected the safety experience of the drivers.
- How the safety experience as observed in Orlando for the 100 vehicles deployed in the operational field test would change as a function of the level of market penetration — as the system was more widely deployed.[9]

In order to meet the objectives, a methodology was developed that included the following four analytical steps:

- Establishment of facility and traffic volume effects on base accident rate.
- Evaluation of incidents and accidents that involved TravTek vehicles.
- Estimation of potential safety impacts of TravTek in-vehicle devices.
- Modeling the potential safety impacts of TravTek.

The Safety Study cataloged the TravTek accident experience. However, because of the relatively few kilometers logged by the 100 vehicles over the 12-month test (fewer than 1.7 million km), modeling played a significant role in the analysis. The TravTek Safety Study broke new ground in exploring safety analysis methodologies for ITS evaluations.

TravTek Architecture Evaluation Study. This study had the following purposes: (1) analyze the hardware, software, and data base triad as a system, (2) verify system accuracy, (3) establish reliability, (4) assess system design alternatives, and (5) examine system staffing and operation requirements .[1]

Major topics associated with the architecture evaluation included:

- A comprehensive description of the system design, implementation, and operation.
- Measures of the quality and timeliness of information conveyed to drivers.
- An evaluation of the sources of information to the system.
- Evaluation of the accuracy of the system data bases.
- Evaluation of the reliability of equipment and the communication systems.
- Evaluation of system personnel and facility requirements.
- Description and critique of the system architecture.
- Assessment of the human interface for the TMC portion of the system.
- Documentation of lessons learned from the TravTek architecture implementation.

Global Evaluation Study. The purpose of this study was to integrate results from among the other TravTek evaluation studies to provide a unified picture of the success of TravTek in meeting its goals. In addition, this study addressed more global issues associated with the success of TravTek as a public/private partnership and its strengths and weaknesses.

RESULTS

TravTek results are presented from the perspective of the eight questions detailed earlier. A summary of the projected benefits of TravTek, from the Modeling Study, is provided in figure 3.[8]

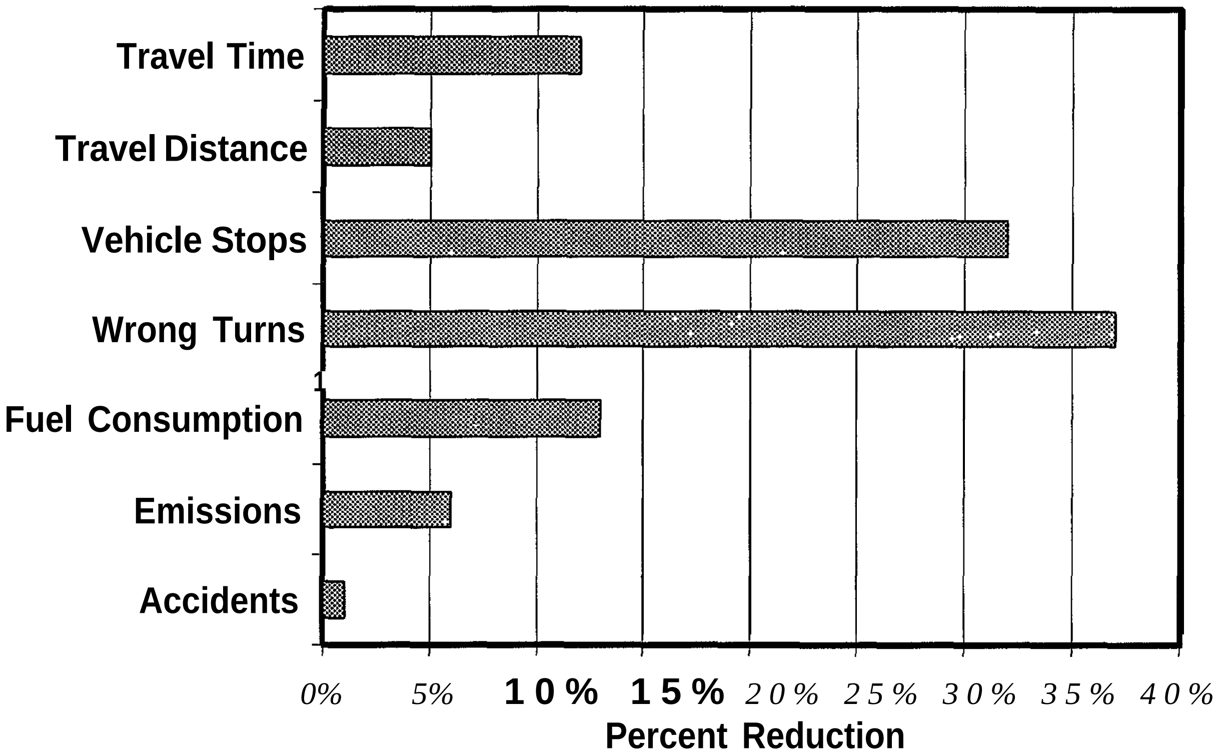

Figure 3. Some of the projected benefits of the TravTek system.

Did the System Work?

The TravTek system was very reliable. System up-time exceeded 96 percent. Vehicle-to-TMC and TMC-to-vehicle communications were reliable enough to meet system requirements. The probe vehicle concept worked very well. The TravTek vehicles distributed themselves across the network very well, such that with a greater number of vehicles deployed, very good network coverage would be achieved for obtaining probe vehicle travel times. The distributed architecture performed well. System reliability and the perception of reliability resulted, in great measure, from the ability of the vehicles to perform their own route planning. Centralized route planning, the alternative to a distributed system, would have placed far more demands on TMC infrastructure while at the same time increased the vulnerability of the system to single point failures.

Although the map data bases posed formidable maintenance challenges, the overall accuracy of all TravTek data bases was high. The fuzzy logic algorithm for fusing traffic data at the TMC worked well. The TMC operator interface functioned properly, but recommendations for improvement were made in the *TravTek System Architecture Evaluation* report.(‘) The TravTek system provided a very high level of automation: travel time data were collected, processed, and distributed to the vehicles without the need for operator intervention. Incident data did require operator intervention, and changes in operator training and the operator interface were recommended in the *TravTek System Architecture Evaluation* report.“)

A need for better incident reporting was identified. The TravTek system did not have enough active incident data sources. Although a sufficient number of sources were identified, not all sources were on line during the test. A need for procedural changes to increase incident reporting timeliness was also identified.

Drivers found the system to be easy to learn, easy to use, and useful. Aside from the reliability of traffic information, users perceived the system to work well.

Did Drivers Save Time and Avoid Congestion?

TravTek was found to save trip planning time and to reduce travel time. Real-time traffic information did not further reduce TravTek users' travel times, but the modeling results indicate that when using real-time traffic information, TravTek reduced network congestion and therefore reduced overall network travel times.

In all three field experiments the results were uniformly positive: for trips to unfamiliar destinations, both visitors and local users saved considerable time in planning trips when they used the TravTek system. The savings using TravTek were measured against two alternative trip planning methods: (1) phone calls to request directions, and (2) consulting an AAA paper map. During the day, the majority of drivers not using TravTek chose to use the map, whereas at night the majority chose to call the TravTek help desk for instructions. In all cases, TravTek saved considerable planning time. Both visitors and local users saved time planning trips with TravTek: For planning a nominal 20 minute trip, visitors saved, on average, over 7 minutes and locals saved more than 4 minutes.

The TravTek route guidance system was found to reduce travel time in all three field experiments, regardless of the TravTek display configuration used to communicate routes to drivers. The TravTek Navigation Plus configuration was shown, in the Yoked Driver Study, to successfully avoid congestion. Although the TravTek system helped vehicles avoid congestion, there were no observed travel time savings associated with congestion avoidance. To avoid congestion, vehicles took slightly longer routes on lower class roadways and, as a result, travel time remained about the same.

Will Drivers Use the System?

Those rental users who drove with the Navigation Plus and Navigation configurations used the TravTek system on approximately 80 percent of all their trips. At the end of 2 months experience with the system, local users were still using TravTek to plan routes for over 40 percent of all their trips. Both actual usage and questionnaire responses indicated that people will use TravTek-like systems for route planning and route guidance. Services users utilized TravTek on 37 percent of their trips — an indication that there is a demand for in-vehicle data bases of local services and attractions even when not integrated with a navigation and route guidance system.

How Effective were the Turn-By-Turn, Moving Map, and Voice Guidance Displays?

There were remarkably few differences in driving performance among the alternative display configurations. Overall, workload measures indicated that any TravTek configuration was preferable to the control configurations Among TravTek displays, the Route Map without supplemental

Voice Guide instructions yielded slightly higher workload and marginally lower performance compared to: the Guidance Display (with or without Voice Guide); the Route Map with Voice Guide; or, the Voice Guide alone.

Drivers generally reported that the TravTek route guidance options helped them pay more attention to their driving and helped them find their way. Among the TravTek display combinations, the field experiments showed the Guidance Display with Voice Guide yielded the best safety-related driving performance.

Rental users, who were largely visitors to Orlando, used the simplified turn-by-turn Guidance Display far more than the more information-dense Route Map. Rental users also tended to leave the Voice Guide on while they were driving — they drove with the Voice Guide on over 85 percent of the time.

Local users also used the Guidance Display more than the Route Map, and kept the Voice Guide on more than off, but local users used the Route Map more than renters (about a third of the time) and drove with the Voice Guide on approximately 70 percent of the time.

For route guidance, the TravTek results strongly support the use of supplemental voice instructions as they yielded better performance than visual displays alone. In designing future systems, if a decision must be made between moving map and turn-by-turn displays, the TravTek results — both performance and user preference — favor the turn-by-turn display. It should be noted however, that only one example of each type of display was evaluated in TravTek. Therefore this recommendation should not be applied uncritically to all implementations of turn-by-turn or map displays.

Was TravTek Safe?

The TravTek field studies and safety evaluation showed that ATIS can be employed under normal operating conditions without degrading safety. There was no evidence that TravTek was the cause of any accidents, and the number of accidents involving TravTek vehicles did not appear to be greater than that which would be expected based on national averages.

The TravTek Safety Study contains an extensive discussion of the problems involved in interpretation of ITS operational test accident experience. With accident probabilities measured in millions of vehicle kilometers per year, and ITS evaluations typically compiling fewer than 2 million kilometers a year, techniques other than accident and incident tabulations and accident investigations must be employed to meaningfully evaluate safety.

The TravTek Safety Study made extensive use of modeling to project safety impacts of the TravTek system for both TravTek-equipped vehicles and for non-equipped vehicles sharing a network with equipped vehicles. The results projected that, under levels of market penetration higher than 30 percent, or on networks with traffic demand no higher than that observed in Orlando, there would be no increase in safety risk. In the absence of congestion, the TravTek system results in a net safety benefit regardless of level of market penetration because its routing algorithm has a bias towards safer (i.e., higher class) roadways. A TravTek-like system was projected to present a slight increase in risk to users under conditions of high traffic demand and low levels of ATIS market oenetration. Under these conditions, TravTek vehicles divert to lower class (less safe) roadways when higher class roadways are congested, and with low market penetration, a high percentage of TravTek vehicles would divert under high traffic demand. With higher levels of market penetration, only a small percentage of TravTek vehicles need to divert and the overall reduction in congestion results in a net safety benefit. The Modeling Study findings apply to conditions similar to those in Orlando, and to systems equipped similarly to the TravTek Navigation Plus configuration.

Could TravTek Benefit Travelers Who Do Not Have the System?

Modeling Study findings suggest that traffic network users, both those equipped with the systems and those not equipped, would derive numerous benefits fi-om deployment of TravTek-like systems. Largely because TravTek equipped vehicles avoid congestion and thereby avoid increasing congestion, benefits are seen to grow directly with market penetration for most measures of effectiveness. As market penetration increases, non-users will experience substantial benefits in reductions to travel time, number of stops, fuel consumption, hydrocarbon emissions, and CO emissions. Non-users should experience a small safety benefit. Non-users should experience no effect on travel distance, or number of wrong turns. Non-users and users can expect to experience an increase in NO, emissions, as these emissions increase with speed, and reduced congestion should result in increased speed.

Will People be Willing to Pay for TravTek Features?

Across all field studies and experiments, users indicated that they would be willing to pay more than $900 for a TravTek system. Fifty percent of the Navigation and Navigation Plus renters indicated that they would be willing to pay $1000 or more. Fifty percent of the Services configuration users indicated that they would be willing to pay $500 or more for a system with a data base of local services and attractions such as was featured in the system they drove. The median willingness to pay estimate from local users was slightly under $1000. Across the field studies, median estimates of the added value of the full TravTek system in a rental car ranged from $28 to $35 per week. There appears to be a strong market for TravTek-like systems if they can be priced close to, or less than $1000.

CONCLUSIONS AND RECOMMENDATIONS

Overall, the TravTek operational test was a success. All of the goals and objectives that the partners identified were addressed. Furthermore, in most cases the system was found to perform at or above expectations. The system saved users time. The system avoided congestion and with full-scale deployment is projected to reduce congestion. Drivers demonstrated in words and behavior that they would use a TravTek-like system. A great deal of information was learned about the display alternatives available in the vehicle and recommendations for implementation were derived. The TravTek system was safe. The human factors effort that went into the design of the driver interface appears to have paid off. Design features that were of particular benefit to system safety were: the turn-by-turn Guidance Display that presented only necessary information in an easy to use format; the Voice Guide that minimized the need for the driver to consult the visual displays; and the restrictions on access to features that could be used while the vehicle was in motion. Modeling suggests that non-users will experience substantial benefits if TravTek-like systems reach even modest levels (i.e., approximately 30 percent) of market penetration. Participants who used the system said they would pay for the TravTek system if it were available.

A considerable amount of effort went into the development and maintenance of the map data bases that were the heart of the TravTek navigation system. This effort might have been greatly facilitated by automation and standards for public and private agency cooperation in the exchange of geographic information systems (GIS) data. Whereas private agencies are unlikely to share such information, public agencies could, and should, improve inter-jurisdictional infrastructures for updating and disseminating GIS data.

Although the TravTek operational test was successful, there were areas where improvements could be made. The TravTek operational test could have benefited from the presence of a system manager whose till-time responsibility was to monitor the functioning of the entire system. There were instances when system failures went undetected for more than a day, and these failures would likely have been detected sooner by a full-time manager. To be effective, this manager would require spending authority to fix problems that were detected.

The TravTek partners successfully addressed the evaluation requirement for a stable system with the institution of a Configuration Control Board. Because of the importance of the data bases and software to the overall performance of the TravTek system, the partners wished to keep these critical components up to date. For example, they did not want to delay updating the data bases to reflect changes in the direction of flow on streets. However, changes to a system undergoing evaluation create problems of their own. One problem that arose in TravTek was incompatibilities between software versions of various components. A problem specific to the evaluation was the difficulty in maintaining a stable system as data bases and operating software were upgraded. The TravTek partners addressed these problems with a Configuration Control Board that was composed of Evaluation and Technical working group members. This board evaluated the need for changes, scheduled and coordinated the changes, and documented the changes. It is recommended that future operational tests strongly consider implementing a similar functional organization. Other observations and recommendations are included in the body of the report.

Implications for Deployment

The success of the TravTek Operational Test has wide implications for ATIS and ATMS. TravTek has shown that such systems can be deployed safely, that they have measurable benefits, and that there is a demand for them. TravTek has shown that drivers want in-vehicle navigation and route planning systems, and the data bases associated with these systems. It showed that with improvements to traffic information infrastructure, in-vehicle route guidance systems have the potential to measurably improve traffic network performance, in part because drivers will use such systems.

INTRODUCTION

TravTek, short for "Travel Technology," was an operational field test under the Intelligent Vehicle Highway Systems (IVHS) program. IVHS has been re-named the Intelligent Transportation Systems (ITS) program. Consistent with the thrust of IVHS and ITS operational test programs, TravTek was built by a partnership of private and public sector participants.

The primary purpose of TravTek was to perform research, development, test, and evaluation of advanced traveler information systems (ATIS) alternatives. To evaluate alternative navigation and route guidance system configurations and driver interfaces, alternative in-vehicle system configurations were field tested. Volunteer drivers were recruited from American Automobile Association membership and the general public to systematically test the configurations.

Another purpose of TravTek was to perform research, development, test, and evaluation of advanced traffic management systems (ATMS) concepts. The Orlando Traffic Management Center (TMC) was expanded and modified to support the TravTek operational test. The TravTek evaluation included evaluation of the TMC and the architecture that integrated the TMC into the TravTek system.

THE TRAVTEK PARTNERSHIP

The TravTek system was built by a public-private partnership of the American Automobile Association (AAA), the City of Orlando, the Federal Highway Administration (FHWA), Florida's Department of Transportation (FDOT), and General Motors (GM). In addition to the TravTek Partners, a large number of organizations played a significant role toward the realization of TravTek and its evaluation. Table 1 lists the major TravTek participants.

THE TRAVTEK SYSTEM

TravTek consisted of three major subsystems:

1. One-hundred TravTek vehicles.
2. The Orlando Traffic Management Center (TMC).
3. The TravTek Information and Services Center (TISC).

Figure 4 presents an overview of the TravTek system architecture. The *TravTek System Architecture Evaluation* and reports by Sumner provide detailed descriptions of the TravTek system.[1,2,3] All three components of the system were specially designed to support data collection for the operational test evaluation. The special provisions for evaluation data collection and other features of each system component are described in the sections that follow.

Table 1. Major TravTek operational field test participants.

TravTek Partners

American Automobile Association (AAA)
The City of Orlando
The Federal Highway Administration (FHWA)
Florida's Department of Transportation (FDOT)
General Motors (GM).

Additional Participants

Avis Pent-A-Car System, Inc.
The Central Florida Phone Book™
Etak, Inc.
Magnavox Marine & Survey Systems
Motorola, Inc.
National Highway Traffic Safety Administration
Navigation Technologies Corp.

TravTek Partners' Technical Support Teams

Farradyne Systems, Inc.
SEI Information Technology

The TravTek Evaluation Contractor Team

Science Applications International Corporation
Center for Applied Research
Performance and Safety Sciences, Inc.
Queen's University, Kingston, Ontario
Texas Transportation Institute
University of Central Florida
University of South Florida's Center for Urban Transportation Research

Special Thanks To:

A&J Computer Consultants, Inc.
Delta Airlines
East Central Florida Regional Planning Council
Kissimmee-St. Cloud Convention/Visitors Bureau
Orlando Metropolitan Planning Organization

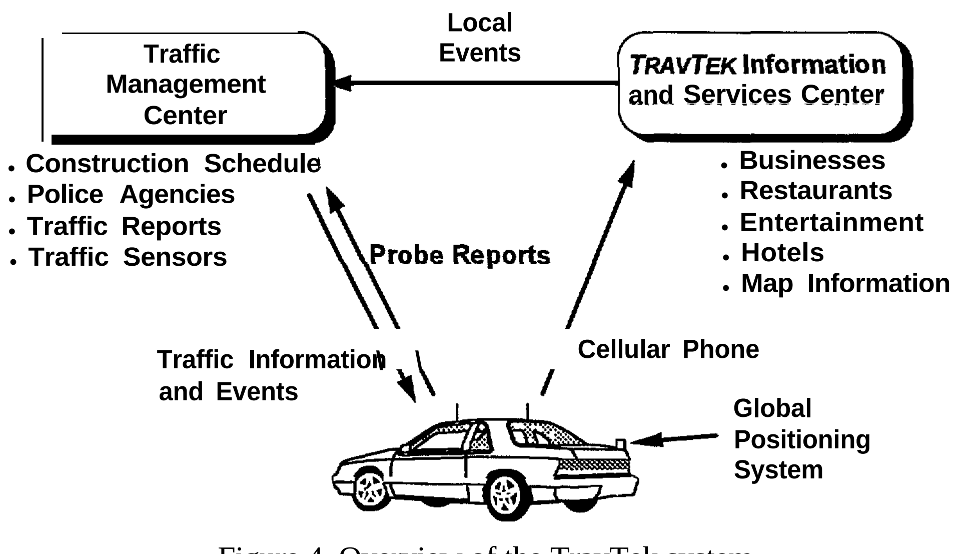

Figure 4. Overview of the TravTek system.

Each of the TravTek partners was responsible for providing and maintaining specific sub-systems. General Motors provided the vehicles, in-vehicle radios, the interface between the TMC and test vehicles, the Etak map data base, system level engineering, operational readiness review, and system test. FHWA provided the TMC system manager and leasing of the radio subsystem, assisted the City of Orlando in operating and maintaining the TMC, and supported upgrades to the TMC and FDOT's freeway management center. FHWA, with additional support from the National Highway Traffic Safety Administration, provided the TravTek operational test evaluation. The American Automobile Association provided the TravTek Information and Services Center that supplied a help desk, the Navigation technology map data base, a local information data base, renter reservations, and publicity. The City of Orlando provided coordination of the TMC with other traffic management facilities, space, and hardware and software for the TMC and an interface with the city's traffic signal system. The Florida Department of Transportation provided the freeway surveillance system on I-4, the interface of the surveillance system with the TMC, and maintenance of the TravTek Traffic Link network map and link-node listing.

THE TRAVTEK IN-VEHICLE SYSTEM

The TravTek vehicles had a two-way communications link with the TMC and communicated with the TISC via hands-free cellular phone. Once each minute, the TravTek vehicles received broadcasts of information from the TMC and broadcast to the TMC their location and travel times for any TravTek traffic links they had recently traversed. [1] The TravTek in-vehicle system provided a wealth of information to drivers.(") This information included:

- A data base of local information (e.g., hotels, restaurants, electronic teller machines).
- Navigation assistance.
- Route planning.
- Route guidance.
- Real-time traffic information.
- Location assistance.
- Built in tutorial and help.

As part of the TravTek design, the vehicles were specially equipped to support evaluation data collection. For evaluation purposes, the vehicles recorded their position and speed at frequent intervals. All driver interactions with the TravTek system were recorded. Furthermore, each vehicle could be set to one of three configurations: Services, Navigation, or Navigation Plus. The configurations varied in the number of TravTek features that were enabled, and thus provided the evaluators a way of identifying the contributions of sets of features to the value and effectiveness of the system. All three configurations made available the data base of local information, location assistance, tutorials, and help. The Navigation and Navigation Plus configuration added navigation assistance, route planning, and route guidance to the basic capabilities. Only the Navigation

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1 Traffic links are discussed in **THE TRAVTEK TRAFFIC NETWORK** section that begins on page **26.**

Plus configuration presented the user with real-time traffic information and used real-time travel times in route planning.

Data Base of Local Information

TravTek vehicles carried an on-board data base of local information. The data base included accommodations, restaurants, attractions, the locations of bank automatic teller machines, and a variety of other services. Once selected, any service or attraction in the data base could be located on an electronic map, one-touch dialed on the cellular phone, and, (if the vehicle was in the Navigation Plus or Navigation configuration) made a destination for route planning and guidance. For the Navigation Plus configuration, the data base included timely information such as weather and local events that was regularly updated from the TMC. Figure 5 shows an example of a local information data base screen.

Figure 5. An example of a screen from the local information data base.

Navigation Assistance

In Navigation and Navigation Plus configurations, a variable-scale color map was displayed on the vehicle's 127-mm (5-in) video display. The video display, an option on the Oldsmobile Toronado, was positioned high on the dashboard and to the driver's right. The navigation system used a combination of dead-reckoning, map-matching, and Global Positioning System information to indicate the vehicle's position on the map. The vehicle's position was indicated by a horizontally-centered icon that was three-fourths of the distance from the top of the screen. When the vehicle was in DRIVE the map was displayed in a heading-up format. Figure 6 provides an example of a navigation display with congestion and incident traffic information. Only the Navigation Plus configuration displayed traffic congestion and incident information. When the vehicle was in PARK, soft (touch sensitive) buttons on the display provided optional heading-up and north-up selections.

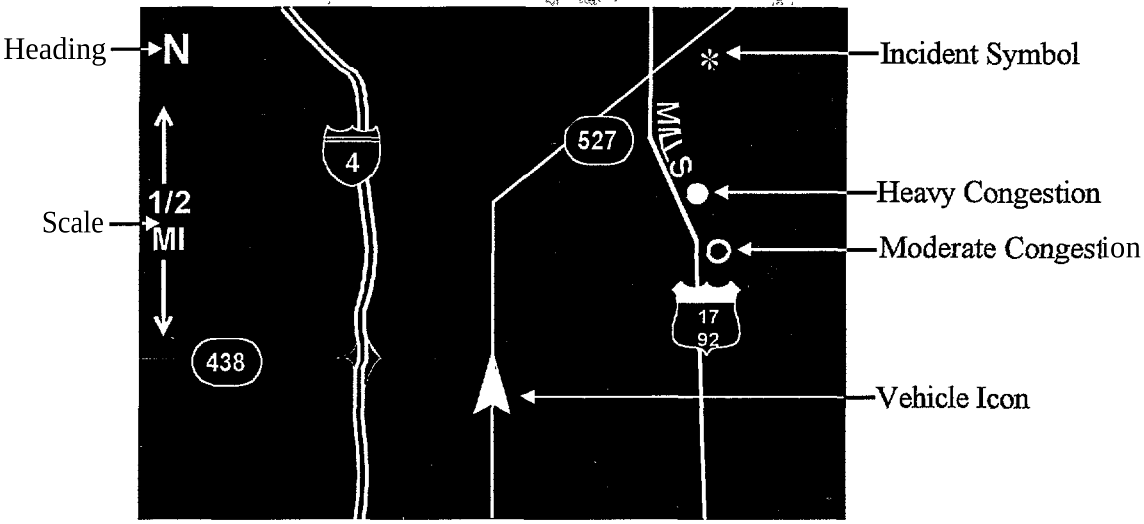

Figure 6. TravTek Navigation Plus display.

Route Planning

With the Navigation and Navigation Plus configurations, users could input a destination into the system and a route would be planned automatically. Intersections, street addresses, street names, or selections from the local information data base could be entered as destinations. An in-vehicle routing computer calculated 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 class roadways, and avoidance of short-cuts through residential areas. The Navigation Plus configuration used real-time travel time information in calculating routes. The Navigation configuration used nominal travel times based on road class information in the map data base. Users could influence the routing by selecting among three route planning criteria: fastest, avoid Interstates, or avoid tolls.

Route Guidance

With Navigation and Navigation Plus configurations, a sequence of guidance displays provided maneuver-by-maneuver driving instructions for following routes planned by the system. The *Guidance Display,* one of two route guidance visual displays, is illustrated in figure 7. The driver could switch between the maneuver-by-maneuver Guidance Display and a Route *Map.* The Route Map showed the planned route as a magenta line traced over a map display such as that illustrated in figure 6. The visual guidance displays were augmented by a synthesized speech *Voice Guide* that provided aural instructions for the next turn direction, distance to the turn, and the name of the street on which to turn. Buttons on the steering wheel hub were used to swap between the Guidance Display and the Route Map and to turn the Voice Guide off or on.

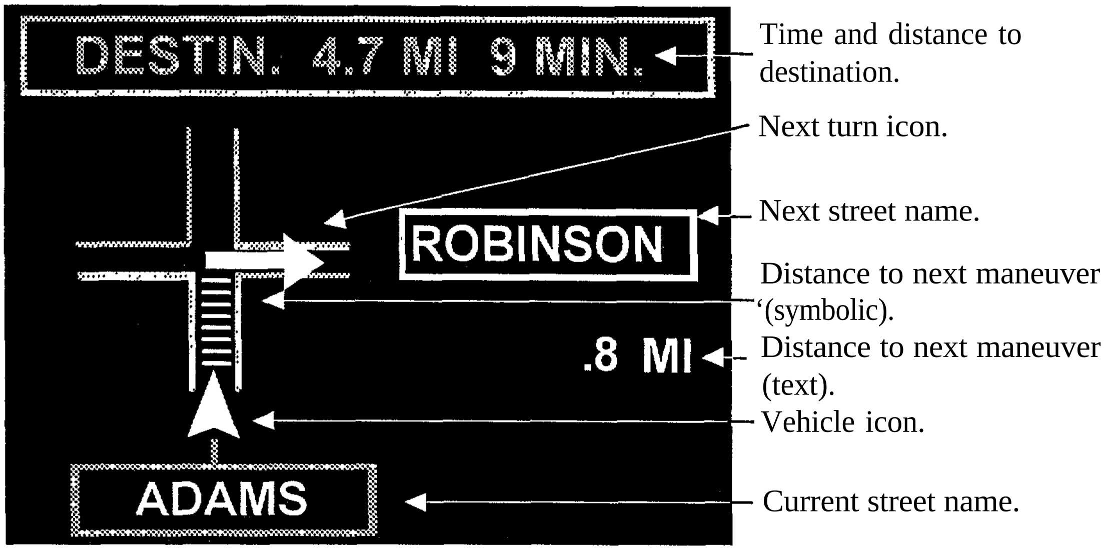

Figure 7. The TravTek Guidance Display.

Real-Time Traffic Information

Real-time traffic information from the TMC was broadcast to TravTek vehicles once every minute. To limit the quantity of information broadcast, only exceptions to normal traffic flow were reported. In the Navigation Plus configured vehicle, real-time information was used in route planning and to represent congestion and incidents on the navigation display. If traffic conditions changed while a Navigation Plus vehicle was en route, a new, faster route could be offered to the driver. Conditions available to the Navigation Plus configured system via broadcasts from the TMC included:

- Historical travel times as a function of time of day and day of week.
- Travel times computed from roadway sensor data (e.g., from roadway loop detectors).
- Police reports.
- City reports of maintenance and road closures.
- Other TravTek Information Network users (see TMC description below).
- Travel times based on probe reports from other TravTek vehicles that had recently traversed TravTek traffic links (roadway segments).

When a route was planned in a Navigation Plus vehicle, the routing computer made a continual search for a significantly faster route. If a faster route was identified, it was offered to the driver for acceptance or rejection. Traffic congestion and incidents were represented on the Route Map. On the Guidance Display, the Navigation Plus configuration displayed a yellow dot and the words "caution ahead" if there was traffic congestion or incidents ahead on the planned route. Synthesized voice announcements of traffic information could be turned on and back off (the default) with a TRAFFIC REPORT button on the steering wheel hub.

Location Assistance

When a TravTek car was in PARIS, a "HELP" button was displayed in the upper left comer of all TravTek screens (with the exception of the main help menu screen). A HELP button is illustrated in figure 5. The main help screen is illustrated in figure 8. Selection of emergency help led, through one or two intermediate screens, to one of the screens illustrated in figure 9.

As illustrated in figure 9, the computed location of the vehicle was provided on the emergency screens to aid the driver in communicating the vehicle's location. While any TravTek vehicle was in PARK, the driver could use the system to contact emergency services — either emergency road services from AAA, or 911 emergency services. These services were accessed using the touch screen video display. Also, when a user called the TravTek help desk, the help desk operator had access, through a data link to the TMC, to the current computed location of the user's vehicle.

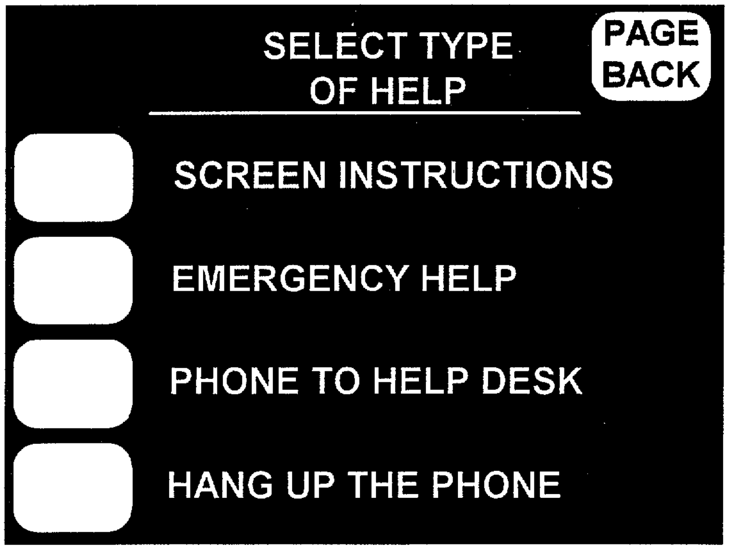

Figure 8. The main help screen from which emergency and road service help could be accessed.

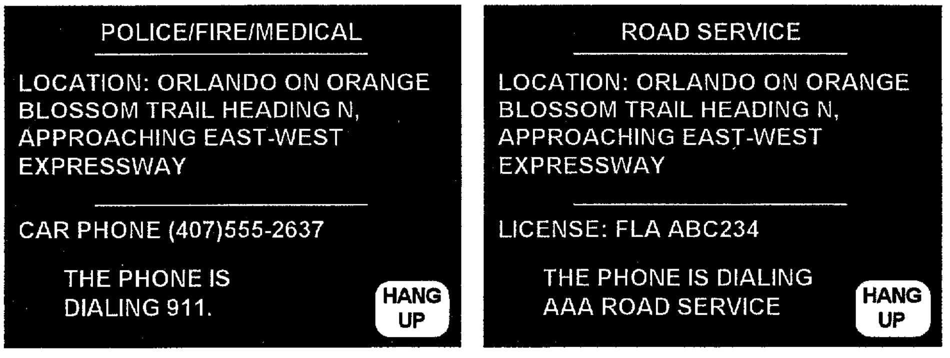

Figure 9. Emergency service and road service screens accessible in all TravTek vehicle configurations.

Built in tutorial and help

A complete tutorial system was built into the TravTek in-vehicle system. Anytime the car was in PARK the driver could select tutorial instructions from the main menu. Also, most of the TravTek menu and information screens had a "HELP" button that, when touched, provided access to screen-specific instructions.

TRAFFIC MANAGEMENT CENTER

The Traffic Management Center was the focal point of data and information flow in the TravTek system. It was located at the City of Orlando Traffic Engineering offices in downtown Orlando. Traffic related information from a variety of sources throughout the Orlando metropolitan area was combined and sorted. This traffic information included link travel times (probe data) from the TravTek vehicles. Once each minute, the TMC coded and sent updates of best estimate link travel time information to TravTek vehicles. An FM data radio system provided bi-directional links between the TMC and the TravTek vehicles. The communications computer at the TMC handled all radio communications with the vehicles via telephone land-line link with a base station.

The TMC received traffic information from a number of sources, processed these data, and transmitted current traffic conditions to the TravTek vehicles. TMC traffic information sources were collectively referred to as the TIN (Traffic Information Network). This network included the Florida Department of Transportation Freeway Management Center (FMC), the City of Orlando Urban Traffic Control System (UTCS), and a network of public and private sector reporting stations. A schematic depiction of the TMC architecture and its relation to the rest of the TravTek system is shown in figure 10. A more indepth description of the TMC architecture from both functional and process perspectives is provided in the *TravTek System Architecture Evaluation* report.[1]

The TMC served as the network hub for TIN reporting stations. There were three types of TIN reporting station connections: telephone (voice), data terminal, and graphic workstations. Except for the graphic workstation located at the TMC, data terminal and workstation connections used telephone modem links. The reporting stations contributed traffic incident reports to the system and, in turn, had access to TravTek data from all sources. Public and private sector TIN users included:

1. Ace Expeditors.
2. American Automobile Association.
3. City of Casselberry Department of Public Safety (DPS).
4. City of Lake Mary DPS.
5. City of Maitland DPS.
6. City of Ocoee DPS.
7. City of Sanford DPS.
8. City of Winter Park DPS.
9. Emery Worldwide.

10. Florida Department of Transportation (DeLand).
11. Florida Department of Transportation FMC.
12. Mears Transportation Croup.
13. Metro Traffic Control.
14. Post, Buckley, Schuh & Jernigan (PBS&J).
15. Prestige Delivery Service.

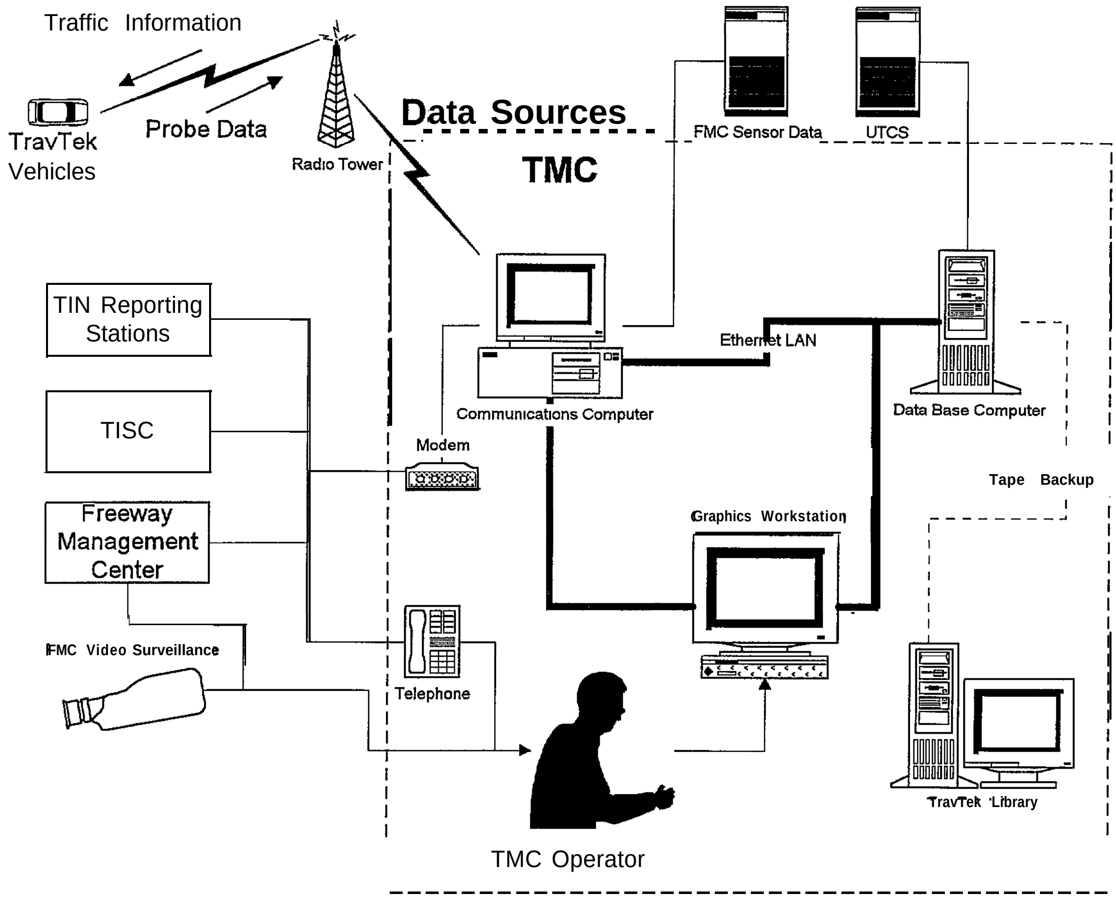

Figure 10. Schematic representation of the TravTek TMC and its relation to the TravTek system.

During the operational test, the TMC was operated 24 hours per day, 7 days per week. The TravTek system was automated to the extent practical. However, the handling of incoming TIN information ultimately rested with a human operator. Incident data, in particular, required operator input for confirmation and categorization. UTCS and FMC loop detector data input was entirely automated. Nonetheless, even the automated sources required monitoring to ensure that the system was operating normally.

The TMC served as a clearinghouse for traffic information. Information cleared through the system included:

- Link travel times.
- Incident status.
- Congestion locations.

Travel times on selected TravTek traffic links were broadcast once each minute. Incident and congestion locations were broadcast for display on the navigation map or Route Map in Navigation Plus configured vehicles. Other messages transmitted for display in Navigation Plus vehicles included parking lot status, weather status, and special event information.

All TravTek vehicle configurations broadcast the following information to the TMC each minute after they (1) were turned on, and (2) received an initial TMC message:

- Vehicle ID.
- Latitude, longitude, and heading.
- Last link traversed and travel time on that link.
- Second to last link traversed and travel time on that link.
- Third to last link traversed and travel time on that link.
- Equipment status.

To support the operational test evaluation, the TMC maintained extensive data logs that included all broadcasts received from TravTek vehicles and all travel time estimates for TravTek traffic links.

TRAVTEK INFORMATION AND SERVICES CENTER

The motorist assistance services help desk, operated by the American Automobile Association, was the nerve center of TISC operations. In the TravTek vehicles, users could call the help desk, toll-free, from the main help screen menu (illustrated in figure 8). The help desk could also be reached from any phone by dialing 444-HELP. This number was prominently displayed in all TravTek vehicles, The help desk was operated 24 hours per day, 7 days per week, by specially trained motorist assistance counselors. A simulator of the TravTek in-vehicle display system was available to the motorist assistance counselors. The simulator had a serial link to a computer that in-turn had a serial modem connection to the TMC Through this connection, the simulator could obtain the location of a caller's vehicle so that the counselor could replicate the navigation display as seen by the driver. The simulator contained the full TravTek in-vehicle data bases and functions so that the counselor could replicate any TravTek interactions with the system that a caller might describe. The simulator also received radio transmissions from the TMC. Calls from TravTek users were logged in a TISC data base to support evaluation of the TISC.

In addition to providing the help desk function, the TISC provided and maintained the navigable map data base that the TravTek vehicles used for route planning and route guidance.[2] Maintenance of the navigable data base was a major TISC function. The data base represented a 3 100 km^2 area of metropolitan Orlando and consisted of approximately 74,000 navigable roadway links. The data base was updated and corrected at intervals throughout the operational test. Other information associated with network link records included:

- Attributes separately defined for each side of the link.
  - Zip code.
  - Lowest address.
  - Highest address.
  - City.
- Street name.
  - Prefix, e.g., North or South.
  - Type, e.g., street or avenue.
  - Suffix.
- Ramp sign text.
- Road or lane restriction information.
- Link type, e.g., freeway, local.
- Turn restrictions.
- Latitude and longitude.
- Points of interest.
  - Name and address.
  - Phone number.
  - Hours of operation.
  - City code.

The TISC also managed the local information directory data base that was presented in the vehicles when the driver accessed SERVICES/ATTRACTIONS from the main menu. The Local information directory included:

- Where to stay.
  - Orlando area hotels and motels.
  - Site information, e.g., credit cards accepted or recreational facilities available.

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2 Two map data bases were maintained in the vehicles. One was used to generate the map display, and the other, the one maintained by the TISC, was used for computing routes and the vehicle's position.

- Where to eat.
  - Orlando area restaurants.
  - Site information, e.g., cuisine type and price range.
- Yellow page listings.
  - Central Florida Phone Book Yellow Pages selected listings.
  - Sub-categories.
  - Name, address, telephone number.

Other TISC responsibilities were driver recruitment and orientation for the Rental User Study, and (through agreement with Avis) diagnostic maintenance for the in-vehicle system at the end of each rental period.

THE TRAVTEK TRAFFIC NETWORK

The TravTek system functioned within the TravTek network. The approximately 3 100 km^2 area of that network comprised the area indicated by the shaded box in figure 11. Within this area, destinations could be selected, routes could be planned, route guidance was provided, and information was available on local services and attractions. Whereas map displays in the vehicle extended well beyond the shaded area indicated in figure **11** (e.g., Daytona, and Cocoa Beach), other TravTek functions were available only for the area within the coverage area.

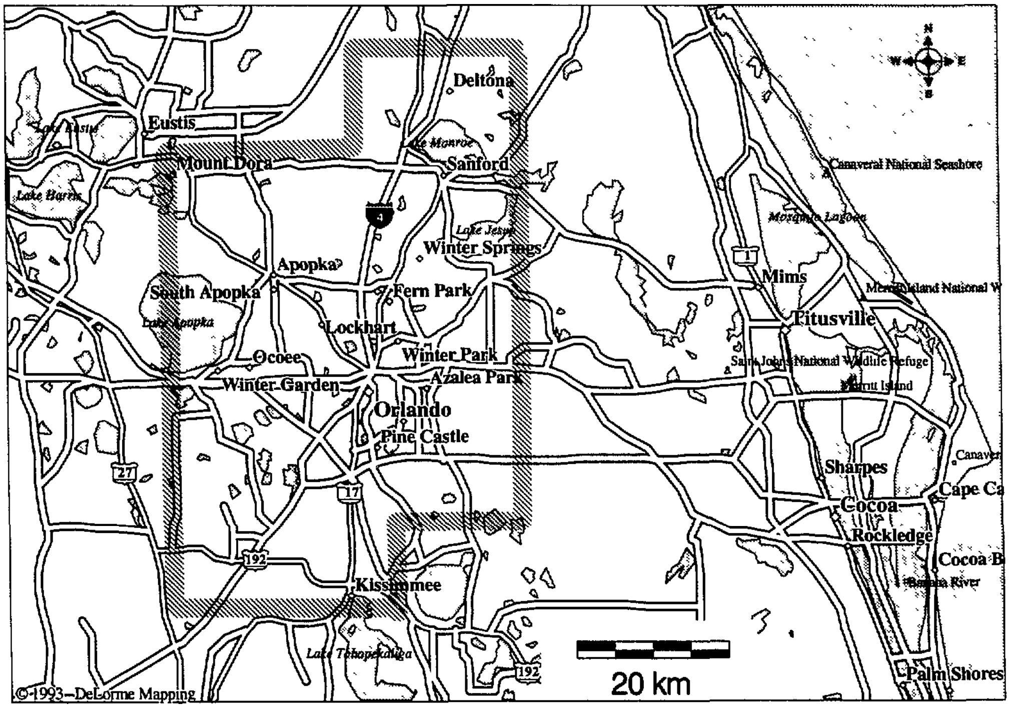

Figure 11. The TravTek coverage area extended beyond Deltona on the North: Winter Springs on the East: Orlando International Airport, Kissimmee and Walt Disney World on the South: and Winter Garden on the West.

In the coverage area, two types of data base links were defined: TravTek links, and TravTek Traffic Network links. TravTek links were defined in the navigable data base maintained by the TISC. There were approximately 74000 of these navigable links representing approximately 16 000 km of roadway. TravTek Traffic Network links represented sections of roadways for which real-time traffic information could be transmitted. There were 1,488 TravTek Traffic Network links that covered a distance of 1 854 km. All traffic network links were either Interstate, expressway, or arterial. The percent total distance of each TravTek Traffic Network link type is depicted in figure 12.

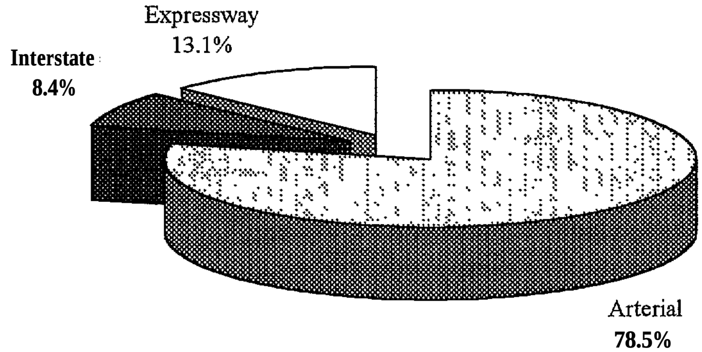

Figure 12. Percent of traffic network link distance as a function of road class.

Sources of real-time information on the network links were:

- Twenty-five loop-detector stations and 3 8 directional links on 18 km of Interstate 4.
- UTCS traffic control detectors on 185 directional arterial links, most of which were in the vicinity of the Orlando central business district.
- Probe times from the TravTek vehicles.
- Historical times.
- Operator input.
- Model-derived time estimates.

The link travel times broadcast to cars were the product of a data fusion process that used a fuzzy logic algorithm to select the best travel time estimate for each link from among available estimates.(r)

Historical times were determined from the other available sources and were continuously refined by software running on the TMC data base computer. Operator inputs, probe vehicle times, and historical times were the only sources that applied to all 1,488 links. Model (FREFLO) estimates were available only for Interstate links. As only 15 percent of the Traffic Network links were detectorized, the system depended heavily on TIN user and TravTek probe reports for real-time information.

Navigation Plus vehicles used the real-time information for the 1,488 TravTek Traffic Network links in route planning around congestion. Navigation vehicles used nominal travel times for route planning. Those times were based on the road class of the links. For the TravTek links that were not contiguous with TravTek Traffic Network links, both Navigation Plus and Navigation configured vehicles used nominal travel times.

TRAVTEK EVALUATION

Proponents of the ITS technologies of vehicle navigation, ATIS, and ATMS envision the widespread application of advance computer and communication technology to improve transportation efficiency, safety, driver satisfaction, and driver security.[11] These are the goals of ITS technologies. It is the purpose of any ITS operational test evaluation to assess how well selected technologies measure up to the goals appropriate to the technologies employed in the test, This section discusses the TravTek goals, the testable hypotheses derived from those goals, and how the tests of those hypotheses were operationalized.

OPERATIONAL FIELD TEST OBJECTIVES AND EVALUATION GOALS

In describing the process of planning TravTek's comprehensive research program, *Research and Evaluation Plans for the TravTek IVHS Operational Field Test* provides the initial definition of TravTek objectives and evaluation goals.[11] This definition of objectives was the product of focused discussions among TravTek Partner representatives. The partners worked together not only to identify objectives and evaluation goals, but also to place priorities for accomplishing them. This process served as a fundamental pre-condition for enabling the development of evaluation plans and clarifying respective partner roles for the operational field test. Table 2 provides a summary of the partner-derived objectives and evaluation goals for TravTek as they were originally stated.

The Partners' prioritization of goals and objectives enabled further refinement, such that achievement of the major objectives could be attained through answering 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 were the visual turn-by-turn and moving map displays?
5. How effective was voice guidance?
6. Was TravTek safe?
7. Could TravTek benefit travelers who do not have the TravTek System?
8. Will people be willing to pay for TravTek features?

The sections that follow describe how the TravTek evaluation was implemented to answer the eight basic questions as well as address most of the remaining partner goals and objectives. The subjects of the evaluation — the hypotheses to be tested — are presented first, followed by a discussion of the criterion variables against which hypotheses were evaluated. Finally, the design of nine studies conducted to collect and analyze the necessary data are summarized.

Table 2. TravTek objectives and evaluation goals as set forth by the TravTek partners.[11]

- I. **Trip/Network efficiency**
  - A. Congestion Avoidance
  - B. Time Savings
  - C. Pollution Reductions
  - D. Fuel Savings
  - E. Reduced Vehicle Operation Cost
- II. Benefits to Non-TravTek Users
- III. Driver Performance/Behavior/Satisfaction
- IV. Safety
- V. System and Subsystem Performance
  - A. Hardware
    - 1. Reliability
    - 2. Compatibility
  - B. Software
    - 1, Reliability
    - 2. Compatibility
  - C. Data
    - 1. Accuracy (map, local information, etc.)
    - 2. Timeliness
  - D. Operations/Procedures
    - 1. Data Collection (map, traffic, events, local information)
    - 2. Data Input: TMC, TISC
    - 3. Driver Recruitment, Training, Debriefing
    - 4. Help Desk Management
    - 5. Vehicle Management
    - 6. Vehicle Maintenance
- VI. Image
- VII. Impact on Future Transportation/Travel
  - A. Generalizable/Transportable
  - B. Technology Transfer
- VIII. Feature Preferences
- Ix. Price/Cost
  - A. Willingness, Personal vehicle
  - B. Willingness, Rental Vehicle
  - C. Infrastructure (TMC, TISC)
- X. Local Area Impact
  - A. Improvements Beyond TravTek Operating Period
  - B. Routing through Sensitive Areas (neighborhoods, hospitals, etc.)
  - C. Local Driver Usage
  - D. Local Jurisdiction Policy Issues
  - E. Macroeconomic Benefits

VARIABLES OF INTEREST

The TravTek evaluation consisted of a series of related studies. These studies tended to focus either on the in-vehicle system, primarily from the perspective of individual drivers, or on the functioning of the entire system. Thus, in the paragraphs that follow, the variables of interest are presented separately from the vehicle subsystem perspective and from the perspective of the system as a whole.

Vehicle Subsystem Variables

Modeling, field studies, and field experiments were conducted to evaluate:

- The types of information TravTek offered.
- The alternative navigation displays.
- Environmental factors.
- Individual difference factors.

Types of Information. TravTek made a wealth of information available to drivers, The information categories included:

- ***Local Services and Attractions Information.*** The evaluation examined user perceptions of usefulness, ease of use, and willingness to pay for TravTek's services and attractions feature. The frequency of use of this feature for selecting destinations was also examined.

- ***Navigation functions.*** In TravTek, the navigation functions, and the information they provided, were distinguished from route planning and route guidance functions. Under this distinction, the display of a map, and the present location of the vehicle were considered navigation features. Congestion and incident information displayed on the moving map display were also considered navigation features. Automated route selection and turn-by-turn guidance to a destination were not called navigation functions, but rather, route guidance functions. The evaluation of navigation functions focused on user perceptions of utility and willingness to pay.

- ***Emergency/Help.*** The TravTek system provided simplified access to 9 11 emergency services as well as AAA roadside assistance. In addition, the system had a built in tutorial and on-screen instructions. If the on-screen instructions were insufficient, the user had round-the-clock access to trained motorist assistance counselors at the TravTek help desk. The evaluation examined users' perceptions of the emergency and help systems as well as the frequency of use of those systems.

- ***Route planning and route guidance.*** The evaluation examined route planning and route guidance features from diverse perspectives that included measured performance, perceptions of performance, frequency of use, and willingness to pay.

Alternative Display Formats. TravTek drivers could push a button to select one of two alternative visual route guidance displays: a turn-by-turn display that was designed to easily communicate the most important information about upcoming maneuvers, and a moving map display that communicated routing information in a more traditional format. The TravTek system supplemented the visual displays with the Voice Guide, turn-by-turn instructions presented using synthesized-speech. The Voice Guide, which could be turned on and off by the driver, was intended to minimize the need to look at the visual displays but was also examined as a stand-alone guidance feature. Performance with paper maps and transcribed turn-by-turn instructions was also examined to enable comparisons with how drivers performed without TravTek features.

Environmental Factors. Driving and navigation performance were examined under day and night driving conditions, on trips that utilized diverse levels of road class, and under varying traffic conditions.

User Variables. Various TravTek studies examined the effects of individual difference variables on driving and navigation performance, user preference, and willingness to pay. Individual difference variables included gender, length of experience with the TravTek system, age, and familiarity with the Orlando area.

System Variables

The evaluation examined the quality of TravTek information data sources, the extent to which TravTek satisfied the needs of its information users, the quality of system data bases, the adequacy of TravTek system personnel staffing and training, the adequacy of equipment, the appropriateness of the overall system architecture to system goals and objectives, and the adequacy of the TMC user interface.

CRITERION MEASURES

A series of modeling, experimental-, and quasi-experimental field studies contributed data to the evaluation of the TravTek system and the in-vehicle subsystem. Additional analyses of system logs contributed data for the system-wide evaluation.

In-Vehicle Systems

Time. The TravTek system was designed to save time. The route planning function was designed to save planning time and to save travel time by selecting the fastest available route. The navigation and route guidance functions were intended to reduce travel time by reducing the navigational waste that results from wrong turns or inadequate understanding of alternative routes. Thus, three of the field studies measured trip planning time and travel time with and without TravTek as well as with various alternative system and display configurations.

Speed. Vehicle speed can be used as an indicator of congestion. Speeds less than free flow speed may indicate congestion, and as congestion increases, speed decreases. Vehicle speed was used as an indicator of congestion in a field study conducted during peak traffic periods. Speed variability was used as an indicator of driver workload in another field study conducted during off-peak travel periods.

Travel Distance. The TravTek system was designed to save time and did not necessarily choose the shortest distance route. However, because the navigation and route guidance features were intended to reduce navigational waste, it was anticipated that travel distance would be reduced compared to trips between the same origins and destinations made without the system. Several field studies examined this hypothesis.

Because TravTek eased the burden of trip planning and navigation, it was anticipated that visitors using the TravTek Navigation and Navigation Plus configurations might be encouraged to travel further, or travel more often. The field studies examined the effect of trip planning and navigation assistance on the travel patterns of both visitors and users familiar with the Orlando area.

Distance traveled on different class roads was also examined. The TravTek system was designed with a bias toward selection of higher class roadways, e.g., Interstates were preferred to arterials, and arterials were preferred over local roads. Higher class roadways are generally associated with reduced accident risk and higher fuel economy. Therefore, several studies examined the impact of TravTek use on travel distance and travel time as a function of road class.

Driver Perceptions. Regardless of how well the TravTek system performed relative to the performance criteria measures, if individual users did not perceive the benefits, then in the future, we might expect that similar systems might not be purchased or used, and the potential for benefits would be lost. Thus, all of the field studies examined user perceptions of time savings, ease of use, utility, value, driver workload, and safety. In addition to user perceptions of the system as a whole, user perceptions of many of the individual TravTek features and functions were examined.

Driver Behavior. Several of the TravTek field studies examined driver use of particular features and functions in addition to examining driving and navigation performance at the trip level.

Display/Control Usage. Two of the field studies examined which functions and features drivers chose to use. In these studies, local users and visitors were allowed free use of a TravTek system for periods up to 2 months. The choice of displays, and the use of controls such as the WHERE AM I and TRAFFIC REPORT buttons were recorded.

Route Choices. In three field experiments, drivers were asked to drive from pre-selected origins to pre-selected destinations. Route choices of drivers using TravTek were compared to the choices of drivers using their usual trip planning and route following techniques. In two of the field studies where users were given free use of the TravTek system, route choices — and choices of routing criteria (i.e., fastest, avoid Interstate, and avoid tolls) were recorded. Together these studies provided insights into how ITS may influence routing choices and hence levels of safety and congestion on entire roadway networks.

Visual Scanning Patterns. One of the TravTek studies recorded drivers' eye glance behavior as they drove with various TravTek and control vehicle configurations. This study provided detailed information on how drivers are likely to use ITS devices while driving, and what effects that use may have on driving safety.

Accidents. Detailed records were kept on accidents involving TravTek vehicles. Whereas the million plus miles compiled by TravTek users during the l-year operational test were insufficient to statistically confirm a safety benefit from the TravTek system, accident records were examined to ensure that the system was not exposing users to higher than expected risk.

Near Accidents. In field experiments where observers were present, the occurrence of near accidents (also referred to as close calls or near misses) were recorded. As near accidents are presumed to be more frequent than reported accidents, it was hoped that near accident frequency would provide more information on TravTek system use than would actual accidents.

Safety Surrogates. In addition to near accidents, a number of other driver behaviors were recorded that might logically be related to safety. These measures included lane excursions, abrupt turns, abrupt stops, steering wheel reversals, and extended gaze time at instruments.

TravTek System Measures

The TravTek system was evaluated from a number of perspectives. These perspectives included:

- Examination of system performance relative to design specifications,
- Examination of system performance relative to user requirements.
- Effects on network safety.
- Effects on network performance.
- Environmental impacts.

Examination of system performance included analysis of the reliability and timeliness of information in the various data bases. Evaluation of the adequacy of the system data sources to support user requirements included examination of the adequacy of link travel time estimates to support efficient routing by the TravTek vehicles, the adequacy of TravTek data to support other TIN users, and an examination of the accuracy of the navigation data bases. The implications of TravTek for traffic management center design were also investigated.

Network performance, and the effects of TravTek on network-wide safety were extrapolated through modeling from measures obtained in the various field studies.

Environmental impacts of TravTek use were assessed both through direct measurement and through modeling. Fuel consumption of the TravTek vehicle, a 1992 Oldsmobile Toronado, was measured under various driving patterns. Field study data were used to determine under what conditions drivers most closely followed those patterns. These findings were then used as inputs to a traffic micro-model, INTEGRATION, to extrapolate both fuel consumption and emissions for all vehicles on a mixed network of TravTek equipped and non-equipped vehicles.

TRAVTEK EVALUATION DATA SOURCES

A halhnark of the partners' operational test planning was the emphasis on designing evaluation data collection into all aspects of the TravTek system. This emphasis has resulted in a rich data base that supported the TravTek evaluation, and that can continue to support ITS research for years to come.

Data sources included:

- Questionnaires (field studies).
- Debriefings (field studies).
- In-vehicle data logs.
- TISC logs.
- TMC logs.

- FMC logs.
- Observer logs (field experiments).
- Camera Car video.
- Camera Car data log.

Questionnaires

A common format and set of core questions were included in questionnaires that were used in five TravTek field studies. In some studies, the questionnaires were tailored for the vehicle configuration the user experienced. In other studies, the questionnaires were tailored to be appropriate either for visitors or local residents. Nonetheless, the core set of questions and common format permitted comparability of results across all studies. Drivers in all configurations were asked to judge general statements about the system such as, "The TravTek system helped me avoid congestion," or "The TravTek system helped me find my way," even when their configuration might not be expected to confer a particular benefit because it lacked a specific feature.

The return rate for the questionnaires was quite high. A total of 1,733 questionnaires were returned by renters in the largest of the studies, the Rental User Study.[4] The number returned and the percent of questionnaires returned are shown as a function of vehicle configuration in table 3.

Table 3. Questionnaires returned by Rental User Study participants shown as a function of vehicle configuration.

Configuration	*Number Returned*	*Return Rate*
~~Services~~	~~154~~	~~42 Percent~~
Navigation	644	70 Percent
Navigation Plus	935	73 Percent

Debriefings

In addition to completing formal questionnaires, drivers in four of five field studies were asked to participate in semi-structured debriefings in which they were free to say whatever they liked about the TravTek system. Whereas drivers were free to say whatever they liked, the following questions were always asked to elicit open ended responses:

- 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?
- While driving with TravTek, were there any situations where TravTek was not helpful?
- 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?

Renters were debriefed at the Orlando International Airport at the time they were scheduled to depart. Because of the large number of renters, and the fact that they could return the vehicles at all hours, and because not all renters departed at the scheduled time, it was never intended that all renters be debriefed. However, 486 of the renters were debriefed: 42 from the Services configuration, 2 16 from the Navigation configuration, and 228 from the Navigation Plus configuration. All participants in the other field studies were debriefed at least once.

In-vehicle data logs

In each TravTek vehicle, one of two TravTek on-board 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. Extensive data were recorded in this log and the current description is not intended to be exhaustive. In-vehicle log data included:

- All messages received from the Traffic Management Center.
- The identity and travel time for every TravTek traffic link that was traversed.
- Vehicle latitudes and longitudes from both the Global Positioning System and the dead reckoning/map matching system (every 15 seconds).
- Vehicle speed once per second.
- All synthetic voice messages that were generated.
- All Guidance Display text messages that alerted the driver to upcoming maneuvers or off-route status.
- The start and end times for each trip and trip distance (regardless of whether the TravTek system was accessed).

The in-vehicle data log could store more than 1 month's data under normal usage. However, when the hard disk holding the data log filled, the vehicle transmitted a disk full message. This message was monitored by the TISC and the driver of the vehicle (almost always a local user) was asked to bring the vehicle in for service.

The in-vehicle log data base provided a rich source of information about how, when, and where users traveled.

TravTek Information and Services Center (TISC) logs

The TISC maintained several data bases. TISC data bases that served as sources of evaluation data included:

- The reservations data base.
- The call management data base.
- The vehicle information data base.

The reservation data base, held data about individual rentals and the rental users. Because this data base contained information about AAA customers, it was not directly accessible to the evaluation team. However, AAA representatives provided appropriate information from that data base. The call management data base contained records of TravTek user calls to the help desk, and help desk calls to users. The vehicle information data base provided vehicle maintenance records,

Traffic Management Center (TMC) logs

The TMC maintained extensive logs. These logs included:

- All radio transmissions to the vehicles.
- Probe reports received from the vehicles.
- Communications status reports.
- Workstation logs.
- TIN reports.
- TIN requests.
- Incident Reports.
- One minute summaries of speed and volume reports from the FMC.
- One minute summaries from the arterial signal control system (UTCS).
- Operator interactions with the TMC system.

Transmissions to the vehicles included current link travel time ratios, incident information, special event data, and weather conditions.

For each active vehicle in the network, probe reports were logged once per minute. These reports included: (1) vehicle ID, (2) latitude, longitude, and heading, (3) link travel times for the last three TravTek traffic network links traversed and not previously transmitted, (4) equipment status.

Communications status reports were used to determine the up time of the various TMC communications subsystems (e.g., the UTCS, FMC, and TIN's). Workstation logs were used to track the reliability of the computers on the TMC network.

Freeway Management Center (FMC) Logs

The FMC maintained a manual log of all observed I-4 incidents and a computerized log of loop detector data from the 24 stations. For each lane at each station, speed, volume, and occupancy were recorded every 30 seconds. Loop detector data from January through March 1993 were retained.

Observer Logs

In the field experiments, observers rode with volunteer drivers and recorded a number of behavioral observations. These observers recorded training proficiency as well as the following information during test drives between pre-selected origins and destinations:

- 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.

Camera Car Video

In one of the field experiments, a specially instrumented TravTek car was used. This car was equipped with four reasonably inconspicuous cameras that recorded:

- The driver's eye movements.
- A 60-degree wide view of the roadway through the front windshield.
- Lane markings on the left side of the vehicle.
- An over-the-shoulder view of driver hand and foot movements.

Video data were time stamped so that they could be correlated with data recorded in the camera car data log. The four views were multiplexed on to a single Super VHS tape. Observer and driver comments were recorded on the audio channel of the tape. Meticulous analysis of the video data was recorded in a data base table that has become part of the TravTek data base archive.

Camera Car Data Log

The camera car data log included the following data items sampled at 10 cycles per second:

- Vehicle speed.
- Lateral and longitudinal acceleration.
- Brake light status.
- Steering wheel position in degrees.

In addition, the data log recorded observer inputs to a work station in the back seat of the vehicle. The observer inputs were used to mark events for later video analysis.

TRAVTEK STUDIES

In this section, the nine TravTek studies are described: Two naturalistic field studies, three field experiments, a traffic modeling study, a safety study, a system architecture study, and the global evaluation study.

NATURALISTIC FIELD STUDIES

There were two naturalistic field studies in the TravTek evaluation: the Rental User Study and Local User Study. These studies capitalized on realism to provide generalizations to real-world settings. That is, users in these studies were provided TravTek vehicles to use as they chose. Accordingly, participants in these field studies were unconstrained as to how they would use, or not use, the TravTek system.

The only variable manipulated for these studies was the configuration of the vehicles to which drivers were assigned. No additional constraints were levied upon drivers' daily use of the vehicles. The principal purpose of both studies was to see if, and how, drivers would use the features offered by the configuration they possessed. Voluminous records of driver performance data were collected non-intrusively while the participants drove. Except for the consent form that all participants signed, there was little to remind drivers that their driving and TravTek system use were being recorded for later analysis. An extensive report on the conduct and findings of these studies is provided in the *TravTek Evaluation Rental and Local User Studies Final Report.*[4]

The Rental User Study and Local User Study addressed four major issues:

1. Does TravTek affect driver performance, behavior, and satisfaction?
2. Which in-vehicle features do drivers prefer and what is the frequency of use of those features?
3. How much are drivers willing to pay for TravTek features and capabilities?
4. Does TravTek enhance trip and network efficiency?

Whereas both studies addressed the same issues, each provided a different perspective on those issues. Participants in the Rental User Study were primarily recruited from among individuals planning visits to the Orlando area. Thus rental users were expected to be relatively unfamiliar with the local area, and to drive with TravTek for a relatively short time. Participants in the Local User Study were recruited from among local residents who were selected, in part, because they logged above average mileage in the Orlando area. Thus, the Rental User Study was intended to provide performance and preferences information from drivers who (1) were unfamiliar with the local area, and (2) had limited experience with the TravTek system. The Local User Study was intended to provide performance and preference information from drivers (1) familiar with the local area, and (2) who would acquire extensive experience with the TravTek system.

Besides the differences between rental and local users, the research designs differed in the vehicle configurations that were used. Inaddition to providing information on local area services and attractions, the Services configuration was intended to serve as a control configuration for the navigation, route planning, and route guidance capabilities offered by the other configurations. The Navigation configuration provided the services and attraction data base, a moving map display, route planning, and route guidance. The Navigation Plus configuration provided all the Navigation features plus real-time traffic information and trip planning that was intended to avoid congestion by incorporating real-time estimates of travel time.

Both the rental and the local user studies provided drivers with Navigation and Navigation Plus configurations; however, only the rental study used the Services configuration. The data base of local information was tailored to the needs of tourists. This reduced the utility of evaluating local user perceptions of that data base. The other function of the Services configuration was to serve as a control against which the Navigation Plus and Navigation configurations could be evaluated. To conserve evaluation resources, it was decided that, for local users, the control for Navigation Plus and Navigation configurations would be local user experience with their personal vehicles.

In the Rental User Study, each driver experienced only one vehicle configuration. In the Local User Study, each driver experienced both the Navigation and Navigation Plus configurations. Thus the Local User Study enabled comparisons of differences in the preferences and performance of same drivers as a function of vehicle configuration.

Rental User Study.

Of the 100 TravTek cars, 75 were included in the Avis rental fleet and were rented from March 1992 through March 1993. There was a total of 2,896 TravTek car rentals and a total of 4,354 drivers. However, renters who were employees of partner organizations, partner affiliates, or others with special TravTek interests were excluded from most analyses. This left a total of 2,568 TravTek car rentals with 3,944 drivers qualified for inclusion in evaluation analyses. Of these qualified drivers, 1,332 (34 percent) were female and 2,612 (66 percent) were male.

The participants in this study were recruited by the American Automobile Association, with support from Avis Rental Car, Inc., and the TravTek partners. The minimum requirements for participation were those required of all Avis rental customers: a valid drivers license and a minimum age of 25 years. The rental agency charge for a TravTek vehicle was $29 per day. Through most of the study period this charge was less than the airport rental charge for any model.

In addition to recruitment from among their membership, AAA also recruited from organizations planning conventions in Orlando. The Chamber of Commerce provided lists of upcoming conventions and AAA solicited interest from convention organizers to promote TravTek participation among convention attendees. Avis assisted in recruitment through promotional contests among employees at Avis rental desks at Orlando International Airport. Drivers recruited by Avis were randomly assigned to one of the three vehicle configurations.

Most of the Rental User Study analyses focus on qualified drivers who listed themselves as the primary driver. There were 2,568 primary drivers, 398 (16 percent) female and 2,170 (84 percent) male. Of the primary drivers, 1,278 (50 percent) were assigned to the Navigation Plus configuration, 921 (36 percent) to the Navigation configuration, and 369 (14 percent) to the Services configuration Reservations were made through AAA by 81 percent of the primary drivers and the remaining 19 percent were recruited at the Avis counter. Primary driver ages were evenly distributed across the vehicle configurations: 19 percent of the drivers between the ages of 25 and 34; 64 percent between 35 and 54; and, 17 percent 55 years old or older.

There are a number of AAA affiliates in each major US demographic region, and assignments of drivers to configurations were balanced across major regions. To avoid problems that might arise if acquaintances from the same affiliate received different vehicle configurations, each AAA affiliate recruited drivers for a single vehicle configuration. Whereas drivers recruited through conventions tended to be business travelers, drivers recruited through AAA affiliates were more likely to be traveling for pleasure. Exceptionally strong recruitment efforts by AAA affiliates assigned to the Navigation configuration resulted in a greater proportion of the Navigation configuration drivers falling into the pleasure travel category. Because the purpose of visits was correlated with the length of visits, the average visit length was not equal across vehicle configurations. Business travelers averaged 4 rental days compared to 7 and 6.1 days for pleasure and combined business and pleasure travelers, respectively. Navigation Plus rentals averaged 5.2 days, Navigation rentals averaged 6.1 days, and Service rentals averaged 5.3 days.

Local User Study

A total of 53 (20 female and 33 male) high mileage local users with good driving records were recruited by the evaluation contractor. At the time of recruitment, these drivers reported average daily distances driven ranging from an equivalent of 32 km to 242 km, with a mean of 121 km. Of the 53 drivers, 14 (26 percent) were between 25 and 34 years old, 26 (49 percent) were between 35 and 54, and 13 (25 percent) were 55 or older.

Local users were given TravTek vehicles for an average of 8 weeks. Roughly half began with the Navigation Plus configuration, and half began with the Navigation configuration. Local drivers reported back to the evaluation contractor after 1 week for a debriefing, and again after 4 weeks to fill out a questionnaire and to have their vehicle configuration changed, either from Navigation Plus to Navigation, or vice versa. Upon returning their car at the end of 8 weeks, local users completed another questionnaire that focused on the last 4 weeks.

Not only did this group of local users enable comparisons of feature use with rental users, it was also the only group of drivers that experienced both the Navigation Plus and Navigation configurations, and was the only group for which changes in feature use and attitudes over an 8-week period were assessed.

FIELD EXPERIMENTS

Field experiments were distinguished from other field studies by the greater degree of control over test factors that investigators wield in an experiment. This greater degree of control over variables that might influence test outcomes enables stronger attribution of causal relationships between independent and dependent variables. Three field experiments were performed: the Yoked Driver Study, the Orlando Test Network Study, and the Camera Car Study.

The Yoked Driver Study focused on differences among Navigation Plus, Navigation, and Services configurations as they affected travel time and navigational waste during peak traffic conditions.

The Orlando Test Network Study focused on relative advantages and disadvantages of alternative methods of communicating routes to drivers under day and night driving conditions.

The Camera Car Study investigated the relationship of visual glance and other driving behaviors to methods of communicating routes to drivers. Other areas of investigation included differences among age groups and between TravTek novices and TravTek experts (selected from the Local User Study) in the use of the TravTek system,

All three experiments, but especially the Camera Car Study, were designed to provide data to the Safety Study for further analysis of potential links between driver behavior and safety.

Yoked Driver Study

The Yoked Driver Study was a behavioral and systems study to determine the value of

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

The study examined value with respect to:

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

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

The principal purpose of the Yoked Driver Study was to evaluate relative trip efficiencies provided by the three TravTek vehicle configurations: Navigation Plus, Navigation, and Services. Drivers with the Navigation Plus and Navigation configurations used the TravTek system for route planning and route guidance, whereas those with the Services configuration used conventional methods of route planning and navigation — conventional methods included options to use a paper map or to transcribe verbal instructions before beginning the trip. Drivers desiring a paper map were given a AAA map of the area. Drivers desiring verbal instructions were instructed to call the TravTek help desk and obtained scripted directions from the help desk operator.

An important feature of the Yoked Driver Study was the need to recruit driver "triads." A triad was a set of three drivers, each assigned a different car configuration and each assigned to drive the same origin-destination (O-D) pair Drivers were recruited at a major Orlando tourist attraction. Interested visitors made an appointment to participate, usually for the next day, and were paid $25 upon completion of their participation. Volunteers attended a brief classroom orientation, drove several practice routes, and then drove a designated O-D pair during peak traffic conditions. Each driver departed within 2 minutes of the other, enough time to preclude unwanted car-following behavior, yet close enough in time to ensure consistency in other variables such as prevailing weather and traffic conditions. Instead of assigning all triads to one O-D pair, triplets were randomly assigned to one of three O-D pairs so that results could be more confidently generalized.

A total of 213 volunteers participated in the Yoked Driver Study. Of these 213, 123 (58 percent) of the drivers appeared as scheduled and comprised 41 sets of complete triads (i.e. all three drivers completed their assigned O-D). The conduct and findings of this study are reported in *TravTek Evaluation Yoked Driver Study.*[5]

Orlando Test Network Study

The Orlando Test Network Study addressed five 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 primary purpose of this study was to evaluate driver performance and preferences for six alternative navigation display combinations. Each volunteer drove during off-peak traffic between each of three O-D pairs (the same three O-D pairs used in the Yoked Study). Drivers were assigned to one of four groups. Two groups drove in the mid-morning, half with the Voice Guide on and half with the Voice Guide off. Two groups drove at night, also half with the Voice Guide on and half with the Voice Guide off. Each driver experienced one O-D with the Route Map, one with the Guidance Display, and one with no visual display. The Route Map was the same as the navigation display except that a magenta line overlaid the planned route. An example of the Route Map is shown in figure 13. In the no visual display condition, the group without the Voice Guide constituted a control group that used conventional route planning and navigation techniques. Assignment of conditions to O-D pairs was counterbalanced.

Drivers were recruited in the same manner described for the Yoked Driver study. A total of 3 13 volunteer subjects participated, 161 (5 1 percent) during the day and 152 (49 percent) during the night. During the day, 89 (55 percent) drivers had the Voice Guide on, and 72 (45 percent) had it off; 121 (75 percent) were males and 40 (25 percent) were females. At night, 76 (50 percent) drivers had the Voice Guide on, and 76 (50 percent) had it off, 104 (68 percent) were males and 48 (32 percent) were females.

Two-hundred and forty-two drivers completed all three O-D pairs and were the primary focus of analysis. Although the plan was to recruit equal numbers of drivers from each age category for the day and night sessions, this proved to be difficult in practice. Older drivers were reluctant to volunteer for night sessions. Whereas 21 percent of the day session volunteers were from the older group, only 7 percent of the night session volunteers were from that group. The association between age group and session was statistically reliable, X^2 (2) = 14.3. There was no significant difference between younger and middle age groups in volunteer rates between day and night. The age difference in volunteer rates, and a similar reluctance on the part of females to volunteer to drive at night, led the researchers to minimize the analysis of age and gender differences in this study. The conduct and findings of this study are reported in the *TravTek Evaluation Orlando Test Network Study.* [6]

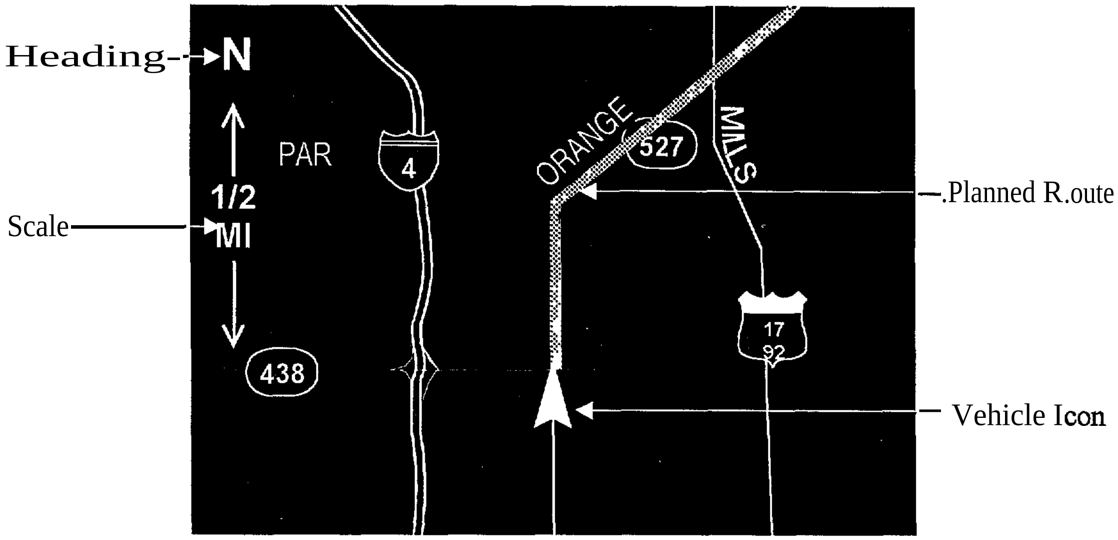

Figure 13. The TravTek Route Map displayed the planned route as an overlay on the heading up map display.

Camera Car Study

The primary purpose of the Camera Car Study was to examine safety issues related to the use of in-vehicle ATIS displays, and especially how driver age and experience with in-vehicle systems may relate to ATIS safety. The instrumentation of the camera car enabled collection of very detailed driver behavior data. Except for the changes necessary to focus on age and experience, the design of the Camera Car Study was similar to that of the Orlando Test Network Study. That is, performance with both route guidance displays was examined with and without the Voice Guide. Two control conditions that used paper lists of instructions were also examined. Under the paper list conditions, drivers drove a route using either (1) an experimenter-provided route, or (2) a route planned by the participant using a paper map. In the case where a paper map was used, participants were instructed to park the vehicle before consulting the map when en route. Performance with the Voice Guide alone was not examined.

There were 30 volunteer test drivers in the Camera Car Study. Of the 30 volunteers, 12 also participated in the Local Users Study, and 18 were visitors to Orlando recruited specifically for the Camera Car Study. The local users were tested twice in the camera car: once before they received their own TravTek vehicles, and again after 5 to 6 weeks experience with their TravTek vehicle. Visitors were tested once. Half of the 12 local users participating in this test were 35 to 45 years old, and half were over 65. Because the camera car was not a rental, rental restrictions that limited participation to those over 24 years of age did not apply. Thus, six very young (16 to 18 years old) visitors were recruited, in addition to six middle aged (35 to 45), and six older (over 65) visiting drivers. The conduct and findings of the Camera Car Study are described *in TravTek Evaluation Task C3 — Camera Car Study.*“’

ANALYTICAL STUDIES

There were four TravTek studies that were primarily analytical: that is, they relied on data from other studies rather than generating data themselves. These were: the Modeling Study, the Safety Study, the Architecture Study, and the Global Evaluation.

Modeling Study

The modeling study had three main objectives:

- To extrapolate from the available field data the expected performance of a TravTek type system for levels of market penetration ranging from 1 percent to 100 percent.
- To extrapolate the expected performance of a TravTek system in terms of measures such as vehicle stops, fuel consumption, vehicle emissions, and accident risk — variables that were not always directly observed during the field test.
- To estimate the potential impact on the benefits of the TravTek system for conditions not necessarily encountered in Orlando during the field test, such as different levels of traffic congestion, different incident durations, and different levels of routing quality for either the TravTek or the non-TravTek vehicles.

The INTEGRATION simulation model was employed as the primary means of deriving modeling estimates. This model is microscopic, in that it considers traffic in terms of individual entities (e.g., vehicles), each with its own unique characteristics. The basic model combines traffic simulation and traffic assignment, and is highly dynamic. In addition to time-varying demands and capacities, dynamic changes in traffic controls can also be considered. Of special interest to the TravTek evaluation was the ability to model different vehicle sub-populations, each with their own unique routing characteristics, and the ability to estimate a wide range of measures of performance, such as travel time and distance, queue sizes, and the expected number of stops per vehicle. In addition, the individual vehicle's fuel consumption and emissions of HC, CO and NO,, and expected accident risk per vehicle trip were estimated.

In order to perform the TravTek modeling evaluation, the basic INTEGRATION simulation model was customized and calibrated to the TravTek architecture and Orlando network in several ways. Specifically, the Orlando road network that was modeled was converted directly from the navigation data base in the TravTek vehicle to a format compatible with the INTEGRATION input files. Subsequently, the speed-flow and capacity characteristics of the freeway links were refined using statistical analyses of the I-4 FMC loop data. These same FMC data were also utilized to derive the link traffic flows from which the dynamic network synthetic O-Ds were estimated.

Abstractions of the actual TravTek routing logic were incorporated in the model, as were abstractions of the data fusion and transmission logic at the TMC. Data fusion is the process by which multiple sources of travel time information are fused into a single travel time estimate.[2] The relative efficiency, in terms of travel time, distance, and number of wrong turns was included in the model, as were the fuel consumption characteristics of the TravTek vehicle based on performance characteristics that were measured directly in Orlando. The modeling approach was novel, and somewhat complex. Therefore, the nature of the flow of data from the various data sources to the INTEGRATION model is illustrated in figure 14.

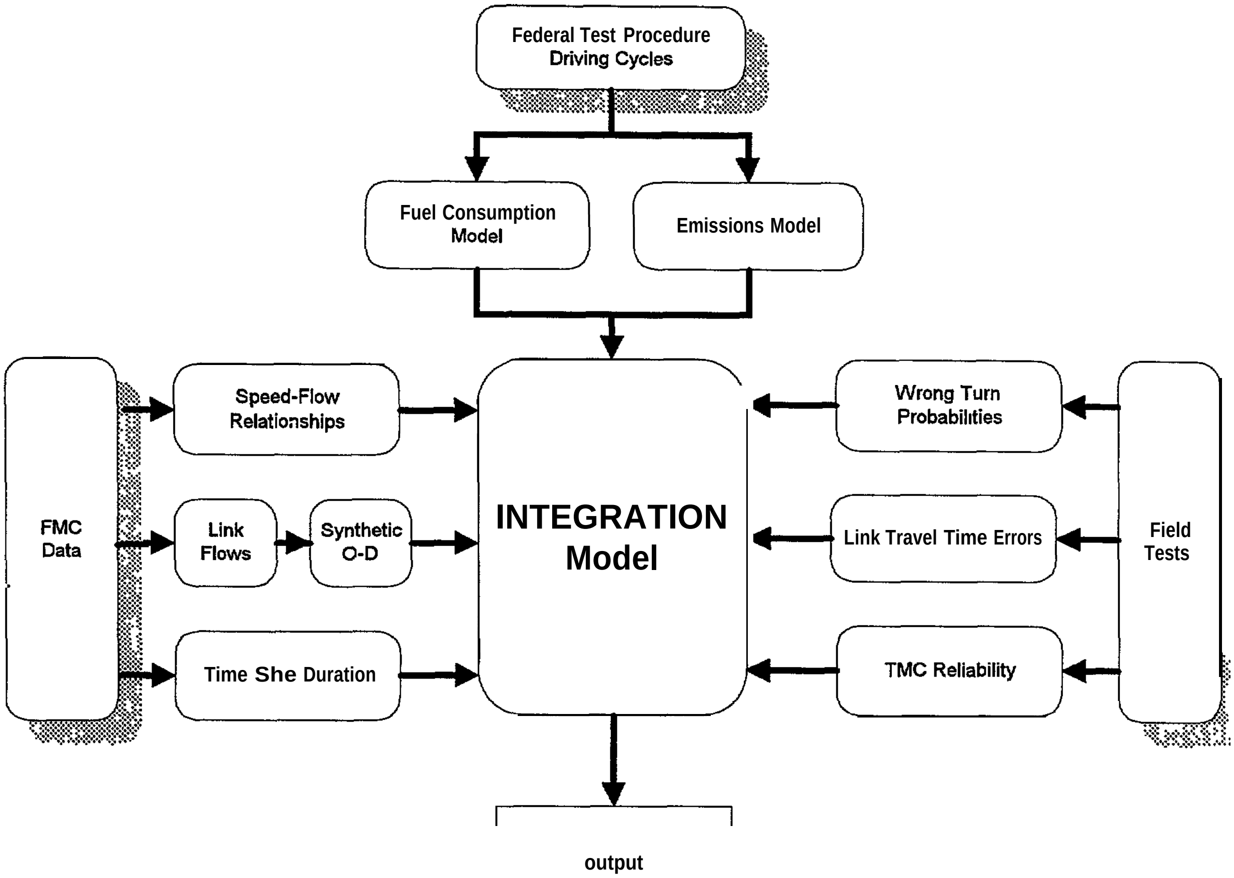

Figure 14. Data flow to and from the INTEGRATION model.

One hundred seventy-five different simulation runs were performed on a combination of a series of PCs and RISC-6000 workstations, where each run required approximately 10 hours of CPU time. During a typical run, the movement of roughly 65,000 vehicles was traced across the network of 2,700 links and 90 Origin-Destination zones. The total network travel distance driven was nearly 700,000 veh-km, corresponding to an average trip length of about 11.3 min. Most of the simulation runs concentrated on the analysis of that portion of Orlando for which real-time loop detector data were available and on the PM peak traffic conditions as observed in Orlando during the winter of 1993. A small number of sensitivity analyses examined increased as well as reduced levels of traffic demand to represent both future and off-peak conditions, respectively. Finally, while most analyses were conducted for recurring congestion scenarios, representative freeway incidents were also analyzed. The conduct and findings of the Modeling Study are presented in *TravTek Evaluation Modeling Study.*(8)

Safety Study

The TravTek Safety Study was a comprehensive analysis of the TravTek Operational Test from a safety perspective. The study entailed the analyses of safety related data from all of the TravTek empirical studies: the Rental User Study, Local User Study, Yoked Driver Study, Orlando Test Network Study, and the Camera Car Study. The empirical studies provided vehicle collision data, driver/vehicle performance measures, observer measures, and drivers' subjective ratings.

The objectives of the safety study were to determine:

- If the users of the TravTek system as deployed in Orlando experienced a different level of safety than drivers of comparable vehicles without the TravTek system.
- How the different TravTek configurations affected the safety experience of the drivers.
- How the safety experience as observed in Orlando for the 100 vehicles deployed in the operational field test would change as a function of the level of market penetration as the system becomes more widely deployed.

In order to meet the objectives, a methodology was developed that included the following four analytical steps:

- Establishment of facility and traffic volume effects on base accident rate.
- Evaluation of incidents and accidents that involved TravTek vehicles.
- Estimation of potential safety impacts of TravTek in-vehicle devices.
- Modeling the potential safety impacts of TravTek. [11,12]

As with the Modeling Study, the technical approach to the Safety Study was both novel and multifaceted. Therefore, to clarify the approach, it is summarized graphically in figure 15.

Establishment of facility and traffic volume effects on base accident rate. An analysis of the impact of traffic congestion on accident rates was performed. The analysis considered the correlation that exists between traffic volume and facility type. The results were used to establish risk factors associated with levels of congestion as a function of facility type for use in modeling the safety impacts of TravTek.

Evaluation of incidents and accidents that involved TravTek vehicles. Incidents and accidents involving TravTek vehicles were described. TravTek accident statistics were compared to statistics for Avis vehicles in the United States and Orlando fleets. Exposure values were estimated for drivers in the empirical field studies and for evaluator personnel who drove TravTek vehicles. [3]

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[3] There were no studies that included evaluator personnel as drivers. However, in the course of conducting the evaluation, evaluation personnel accumulated several thousand miles transporting vehicles, developing research procedures, and trouble shooting.

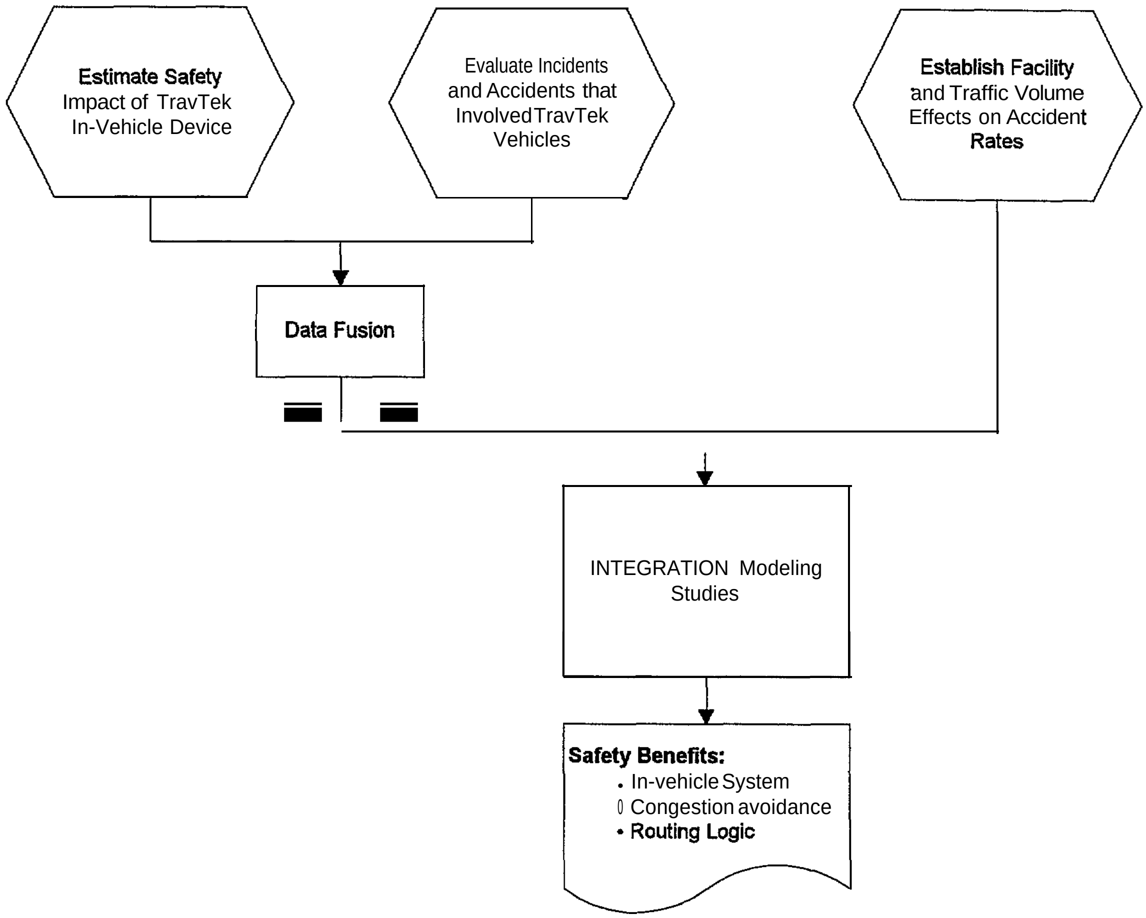

Figure 15. Overview of Safety Study technical approach.

Estimation of potential safety impacts of TravTek in-vehicle devices. This analysis drew on the data collected in the TravTek field studies to estimate the potential impact of TravTek-like in-vehicle systems on safety.

Modeling the potential safety impacts of TravTek. The INTEGRATION model was used to integrate the results of the preceding analytical efforts. The potential safety impacts were investigated under varying levels of market penetration of the TravTek device, and for varying levels of traffic demand. The modeling results attempted to parse the safety effects attributable to use of the in-vehicle system, the congestion avoidance capability of the Navigation Plus configuration, and the route selection characteristics of the TravTek system. The Safety study approach and findings are described in *TravTek Evaluation Safety Study.*[9]

Architecture Evaluation

The purpose of the TravTek Architecture Evaluation Study was to:

- Analyze the hardware, software, and data bases as a system.
- Verify system accuracy.
- Establish reliability.

- Assess system design alternatives.
- Examine system staffing and operation requirements.

The architecture evaluation approached the system analysis from a functional perspective, where a function constituted an action required to achieve a given purpose. Such actions may have been accomplished through the use of equipment, personnel, facilities, software, data, or a combination thereof The functional approach helped to ensure that:

- All facets of the TravTek system development, operation, and support were fully described and documented.
- All elements of the TravTek system were fully recognized and defined.
- A means of relating TravTek equipment concepts and support requirements was provided.

Many diverse aspects of the TravTek system were bridged in the architecture evaluation. To retain the system perspective, evaluation of functions sometimes overlapped with evaluations of other TravTek studies. Where this occurred, the TravTek System Architecture Evaluation final report cross referenced the other studies.(‘)

Major topics associated with the architecture evaluation included:

- A comprehensive description of the system design, implementation, and operation,
- Measures of the quality and timeliness of information conveyed to drivers.
- An evaluation of the sources of information to the system.
- Evaluation of the accuracy of the system data bases.
- Evaluation of the reliability of equipment and the communication systems.
- Evaluation of system personnel and facility requirements.
- Description and critique of the system architecture.
- Assessment of the human interface for the TMC portion of the system.
- Documentation of lessons learned from the TravTek architecture implementation.

In the process of evaluating the TravTek system architecture, the *TravTek System Architecture Evaluation* also provided the most complete description of the TravTek system that is available within a single document.[1]

TravTek was a *distributed system.* That is, route planning and route guidance functions were distributed, with each vehicle planning its own route using on-board software and an on-board database. The Traffic Management Center received travel time information from the TravTek vehicles and broadcast traffic link travel times to the TravTek vehicles. However, the TMC did not direct the vehicles, as is the case with a *centralized* system in which routes for all vehicles are computed by a central traffic management computer system. One function of the Architecture Evaluation Study was to evaluate the effectiveness of TravTek's distributed route planning subsystem against centralized alternatives.

Although the central feature of any system is its composite nature, systems consist of, and are described in terms of, elements. Elements are distinguished by their functions. System operation is determined by the interchange of information among system elements. System properties can be assessed through a study of elements and their interactions. Properties that were assessed in the system architecture evaluation included:

- Reliability.
- Expandability.
- Extensibility.
- Maintainability.
- Performance
- Human engineering.
- cost.
- Complexity.
- Input configuration.
- Processing distribution.
- Channel capacity.
- Processing algorithms.

The TravTek architecture study approach and findings are detailed in the *TravTek System Architecture Evaluation.* [1]

Global Evaluation

The purpose of the Global Evaluation was to integrate results from the other TravTek evaluation studies to provide a unified picture of the success of TravTek in meeting its goals. In addition, more global issues associated with the success of TravTek as a public/private partnership and its strengths and weaknesses are discussed. This report constitutes the *TravTek Global Evaluation and Executive Summary.*

EVALUATION RESULTS

In this section, the evaluation results are presented with respect to the eight basic questions presented earlier:

1. Did the TravTek system work?
2. Did drivers save time and avoid congestion?
3. Will drivers use the system?
4. How effective were the visual turn-by-turn and moving map displays?
5. How effective was voice guidance?
6. Was TravTek safe?
7. Could TravTek benefit travelers who do not have the TravTek System?
8. Will people be willing to pay for TravTek features?

The answers to these questions are based upon an integrated look across all of the TravTek evaluation studies. Because of the design of the TravTek studies and the TravTek system, the effectiveness of visual and voice displays was examined as they interacted with each other. Therefore, the answers with respect to questions 4 and 5 are discussed together under the heading "How effective were the turn-by-turn, moving map, and voice guidance displays?'

DID THE TRAVTEK SYSTEM WORK?

There are two perspectives from which the question of whether the system worked may be addressed: (1) Did it function according to design specification? and (2) Was it perceived to work, especially, was it perceived to work by its end users?

Did the System Function According to Specification?

The *Architecture Evaluation Study* evaluated system function against its design specification. The following are conclusions from the architecture evaluation:

The TravTek system was very reliable. Reliability was largely attributable to the distributed architecture. The availability of the system was in excess of 96 percent throughout the project across all subsystems. The subsystems considered were UTCS, TISC, TIN, FMC, and radio. The TMC/Vehicle communication subsystem was analyzed separately, to measure the two-way radio data error rates. The error rate for TMC-to-vehicle communications was 14.8 percent. The message receipt error rate for vehicle-to-TMC communications was 14.1 percent. Possible explanations for the relatively high vehicle / TMC communications error rates are discussed on pages 182 through *190* of the *TravTek System Architecture Evaluation final* report.(1)

The probe vehicle concept worked very well. The TravTek Traffic Link network had almost total coverage by the TravTek vehicles. There were approximately 45,000 probe reports per month. The probe reports generally provided good representation of actual roadways and their travel times. Figure 16 shows a plot of the TravTek traffic network links with the thickness of a link determined by the extent of probe vehicle activity on that link. Whereas the traffic network links were well covered by the probes, so was the rest of the TravTek network. A plot of latitude and longitudes from which probe vehicles reported during a 10-day period is shown in figure 17. The plot forms an impressive map of the Orlando roadway system.

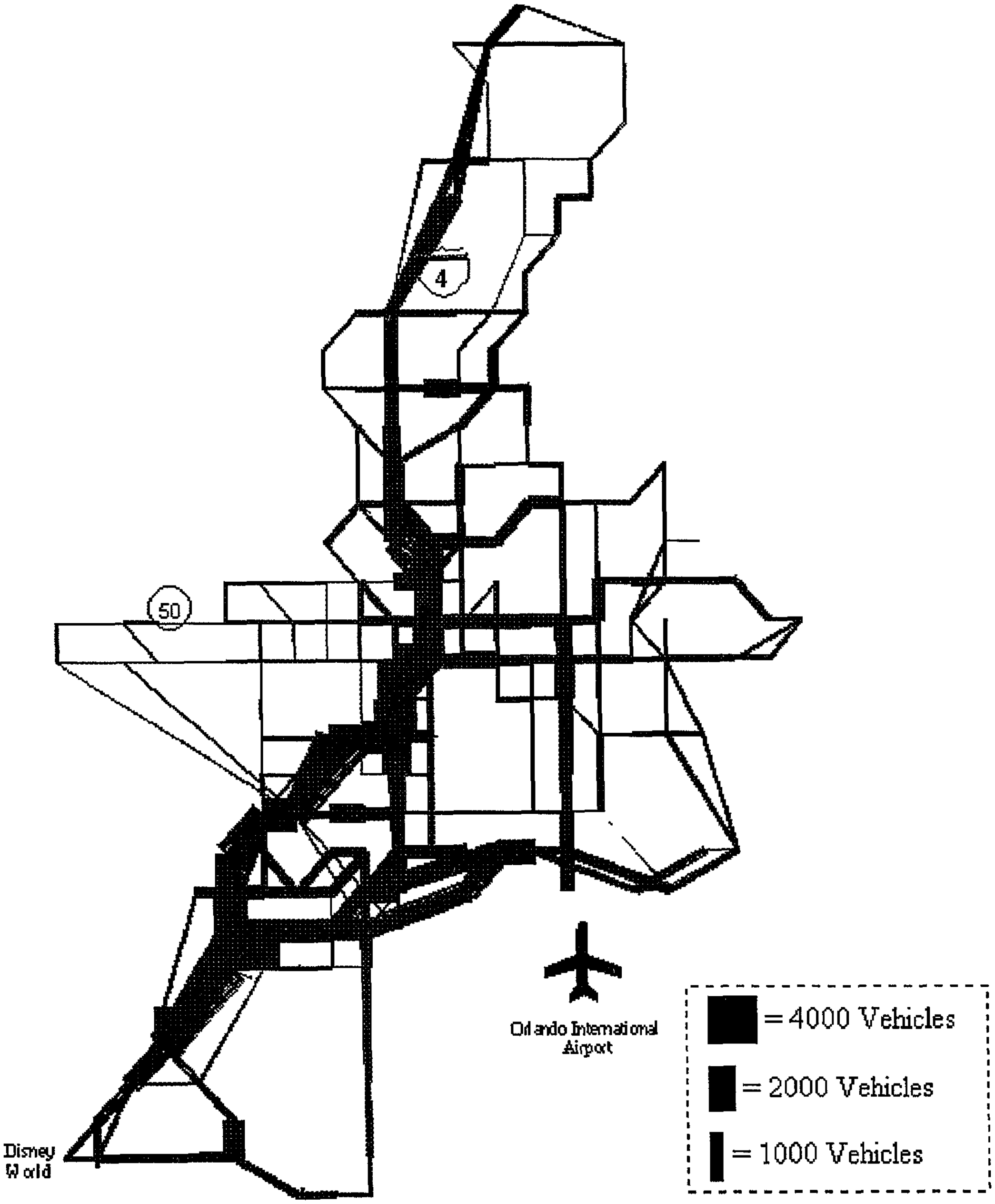

Figure 16. Probe vehicle volumes band map for operational test period.

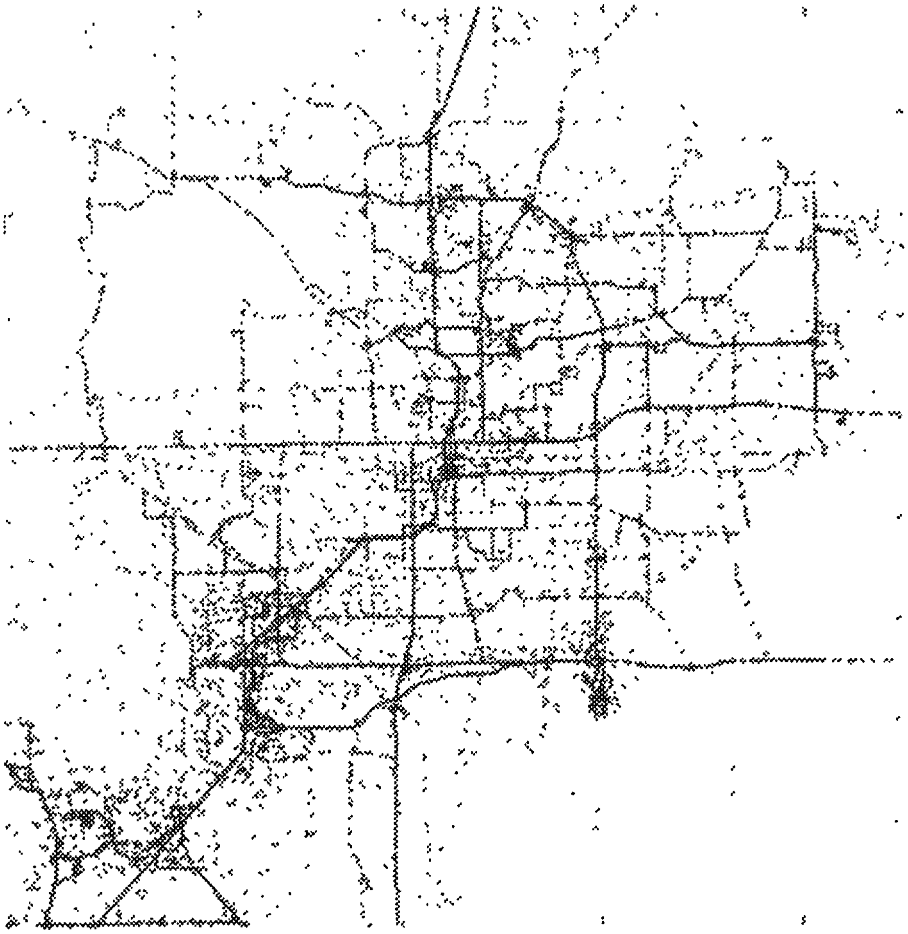

Figure 17. Plot of coordinates reported by probe vehicles during a 10-day period in September 1992.

The distributed architecture performed well. A distributed architecture was a logical choice for the implementation. It did not show any weaknesses that ultimately limited its performance. It promoted a parallel effort during development, as GM, AAA, and FHWA each were in charge of developing separate parts of the system that would later be integrated by communications. If TravTek had been implemented with a central-based architecture, much more computing power would have been required at the TMC, and much less in the vehicles. This would have simplified data base maintenance, but would have increased the communication requirements and imposed an imbalance among the system processing elements. The problems experienced by the TravTek system were largely implementation related, as opposed to architecture related. Therefore, communication system alternatives are required to permit a much larger vehicle fleet to be deployed while retaining a distributed system architecture.

Data base accuracy was good. The historical travel time data base improved over time with updates from probe vehicles. The map data bases provided a good representation of the network, as evidenced by the in-vehicle display The map data base development required a substantial effort, and maintenance was very important since the network continued to change throughout the test. There were four route map versions used during the operational test. The local information data base accuracy was good and improved with each new version, of which there were five.

The TMC data fusion algorithm worked well. The data fusion process for estimating link travel times was the core of the TMC software. This process assimilated inputs from all relevant sources and chose a winner based on a fuzzy logic algorithm. The duration of influence of probe vehicles may have been too long, but the algorithm worked well otherwise.

The TMC operator interface was functional. Although TMC operation was largely successful, there were some areas that needed improvement. Long periods of light workload were punctuated by periods of moderate workload. Workload variation, combined with relatively high levels of background noise may have lulled operators into missing incoming data. Reduced noise levels would have made operator aural alert signals more effective. Also, better training was needed to ensure that operators performed necessary data entry tasks.

A high level of automation was achieved. The TravTek system achieved a high state of automation. Link travel time data were received automatically from the probe vehicles, freeway management system, and arterial control management system. In turn these data were processed and distributed to the vehicles, all without operator intervention. However, an operator presence was required in the TMC and the gathering and processing of incident information remained an interactive process.

Better incident reporting was needed. Incident information available to TravTek was sparse and usually not timely. While incidents were the exception in traffic operations, they were nonetheless highly visible and well noted by drivers. Drivers had the expectation that the TravTek system would "know" about incidents, but this was too often not the case. In addition, posting of incident information was frequently tardy. Two factors that may have been key to the low quantity and quality of incident information were the failure to provide real-time links to police agencies, and low input data rates from Orlando's largest commercial traffic information provider. Police agencies reported incidents to the TMC by dial-up telephone (voice). Metro Traffic, Orlando's largest private traffic information provider, was supposed to have a graphics terminal on which they could both enter incidents and observe incident reports graphically in real-time. Their graphics terminal, provided by the TravTek partners, did not become available until late in the operational test.

Did End Users Perceive the System to Work?

Ratings of the TravTek system by users who had the Navigation Plus and Navigation configurations were almost universally favorable. Users reported the system to be easy to learn, easy to use, and useful.

Whereas the local information, navigation, and route guidance functions were viewed as functioning properly, the traffic information provided by TravTek was not viewed favorably. Users did not perceive TravTek as helping them to avoid congestion. Overall, users were neutral or mildly positive with respect to the utility or accuracy of other aspects of the traffic information.

DID DRIVERS SAVE TIME AND AVOID CONGESTION?

The TravTek system had several capabilities that were expected to aid motorists in saving time:

- It planned routes to selected destinations.
- It provided turn-by-turn route guidance to assist users in following the planned routes.
- It could use real-time traffic information to choose the fastest route.

The success of each of these capabilities in saving travel time are examined in turn.

Did the TravTek Trip Planning Feature Save Time?

The three TravTek field experiments each examined whether the TravTek system saved time in planning trips. In each of the experiments, drivers were asked to plan trips from an unfamiliar origin in a residential neighborhood to an unfamiliar destination in a cross-town residential neighborhood. In two of the three experiments, the drivers were visitors to the Orlando area. However, in the Camera Car Study, 12 of the users were long time residents of the Orlando area who were chosen in part because they drove extensively in the TravTek network area. In the Orlando Test Network Study, trips were planned both in the daylight and at night. In the Yoked Driver Study, the trips were planned for the peak evening travel period.

In all three experiments the results were uniformly positive: for trips to unfamiliar destinations both visitors and local users saved considerable time in planning trips when they used the TravTek system. The savings with TravTek were measured against two alternative trip planning methods: (1) phone calls to request directions, and (2) consulting an AAA paper map. During the day, the majority of drivers not using TravTek chose to use the map, whereas at night the majority chose to call the TravTek help desk for instructions. In all cases, TravTek saved considerable planning time. Figure 18 shows representative trip planning time results from the field experiments. The travel distance for these trips averaged 16 km. The three planning time bars on the left. are from the Yoked Driver Study in which all the participants were visitors. Planning times for Navigation Plus and Navigation configurations did not differ significantly, whereas both the comparison (control) planning times were significantly longer. The bar on the right shows planning time for local users who participated in the Camera Car Study and used a paper map to plan their route. Although local drivers' planning time in the control condition was significantly less than that of visitors, presumably because of local driver familiarity with the area, the local drivers nonetheless showed a significant savings when using TravTek.

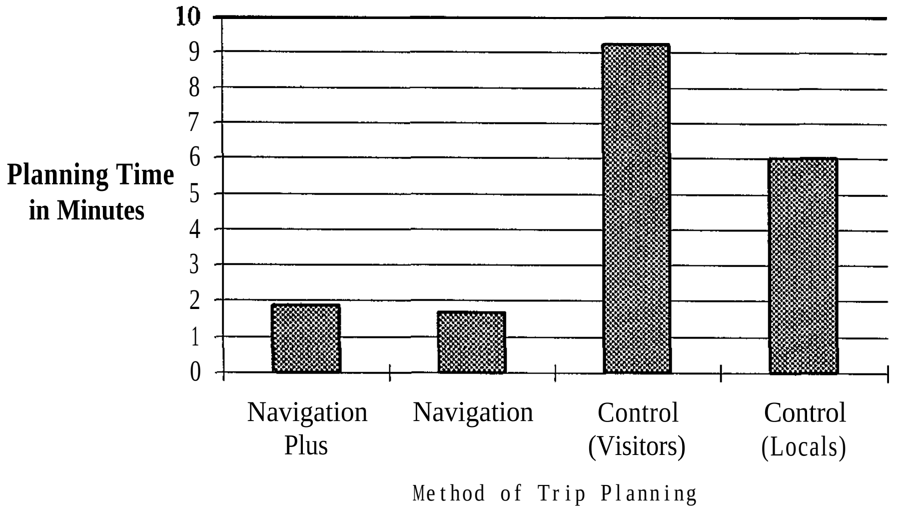

Figure 18. Trip planning times from TravTek field experiments (trips averaged 16 km).

Did TravTek Route Guidance Save Time?

Having saved time planning their trips, did TravTek users save additional time using the system to guide them to their destination? Again, the three field experiments examined this question. The Yoked Driver Study examined travel times for visitors using the TravTek Guidance Display, versus navigating "as they normally would." The "normal" method was either to consult a paper map or a transcribed list of instructions. All trips were taken during peak evening traffic. The Orlando Test Network Study examined travel times for the same normal (control) condition versus five TravTek display alternatives: Guidance Display with Voice Guide supplement; Guidance Display without Voice Guide; Route Map with Voice Guide supplement; Route Map without Voice Guide; and, Voice Guide alone. The Camera Car Study employed comparisons similar to those of the Orlando Test Network Study, but did not examine Voice Guide alone, and used two control conditions: one with typed turn-by-turn instructions, and one with turn-by-turn instructions transcribed by the driver.

The TravTek route guidance system was found to reduce travel time in all three studies. Figure 19 shows representative travel time findings from the Orlando Test Network Study. The Camera Car Study results were similar in that travel times were longest in the control condition. However, in the Camera Car study, travel times with the Guidance Display supplemented by the Voice Guide were somewhat shorter than those shown in figure 19, and were somewhat longer for the Route Map without Voice Guide.

Did Real-Time Traffic Information Result in a Time Savings Benefit?

The Yoked Driver Study was the only field experiment that attempted to measure a travel time savings due to real-time traffic information. In that study, three TravTek vehicles left the same origin for the same destination at 2-minute intervals. All trips were during the evening peak travel period, and all crossed the usually congested downtown area. Only one of the vehicles, the Navigation Plus configured vehicle, used real-time information in planning its route. One vehicle used

TravTek without real-time information (Navigation configuration), and one vehicle was a control in that the drivers planned and navigated as they "normally would."

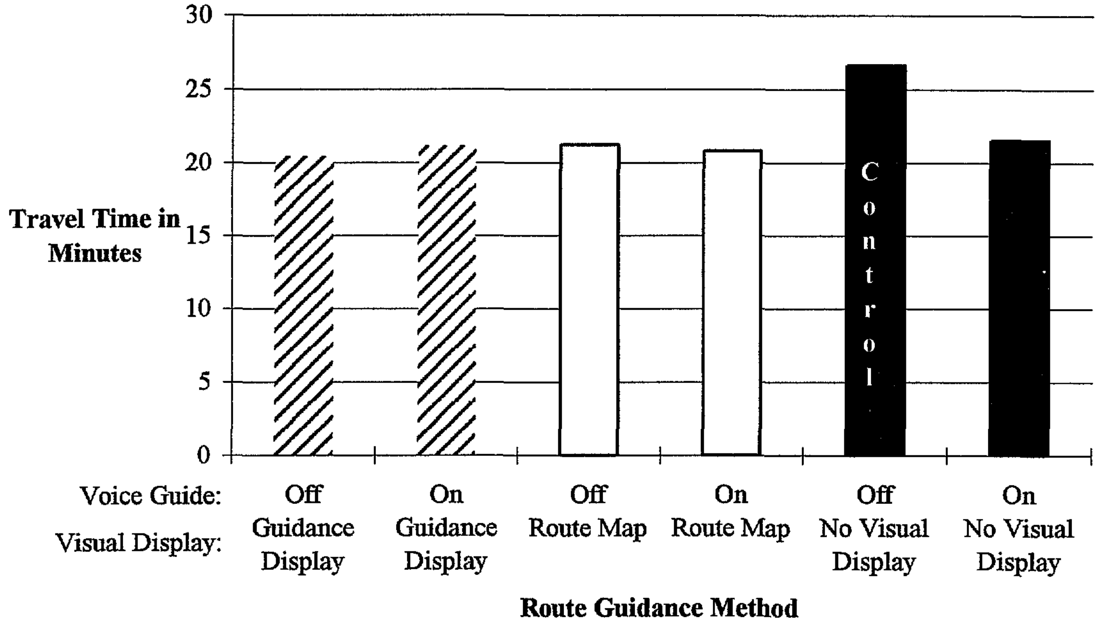

Figure 19. Representative travel time findings from the Orlando Test Network Study.

No travel time savings to users of real-time information was measured, but these users did avoid congestion. Comparisons of travel times for 67 yoked dyads of Navigation and Navigation Plus configured vehicles yielded no significant difference in travel time. However, further analyses revealed that the Navigation Plus configured vehicles did respond to real-time information, as 50 of the 67 Navigation Plus members of the yoked dyads planned routes different from those planned by the Navigation configured vehicles. In the absence of real-time information, both configurations would plan identical routes. Furthermore, despite the fact that the Navigation Plus travel times were not longer than the Navigation travel times, the Navigation Plus vehicles traveled significantly farther. When the Navigation Plus vehicles took routes different than the Navigation vehicles, the Navigation Plus vehicles tended to travel farther and on lower class roadways. To travel farther on lower class roadways without experiencing increased travel times, the Navigation Plus vehicles must have selected routes that had less congestion. This finding has two implications: (1) as implemented, TravTek successfully used real-time information to avoid congestion, and (2) avoiding congestion should result in benefits to other users of the network. The latter implication is discussed further under the section on benefits to non-TravTek users.

Although the available evidence suggests that the Navigation Plus drivers avoided congestion, questionnaire responses from those drivers indicates that they did not perceive the system to aid in avoiding congestion. Factors that may have led to the failure to perceive a benefit are: (1) the benefit was small and did not result in travel time savings, (2) the known inadequacies in incident detection may have been more salient than the measured benefit, and (3) having diverted, users would not see the congestion they avoided and thus would have little way to know that the route they were on was relatively less congested.

WILL DRIVERS USE THE SYSTEM?

The five TravTek field studies provide converging evidence that if a TravTek system is installed, it will be used. There are two types of evidence leading to this conclusion: (1) what users did, and (2) what users said.

What Users Did

Both rental and local users made extensive use of the system. In the Rental User Study and the Local User Study, participants were provided with TravTek vehicles with no constraints on how the cars would be used other than those imposed by the rental agency. Thus, participants were free to use, or not use, the TravTek system. Figure 20 shows that Rental User Study participants used TravTek on most of their trips. Renters with the least capable configuration used the local data base features on 37 percent of their trips. Renters with the Navigation and Navigation Plus configurations used TravTek on approximately 80 percent of their trips. For this analysis, a trip consisted of powering up the vehicle, and did not require that the vehicle be moved. TravTek was considered to have been used if any TravTek feature was used at least once.

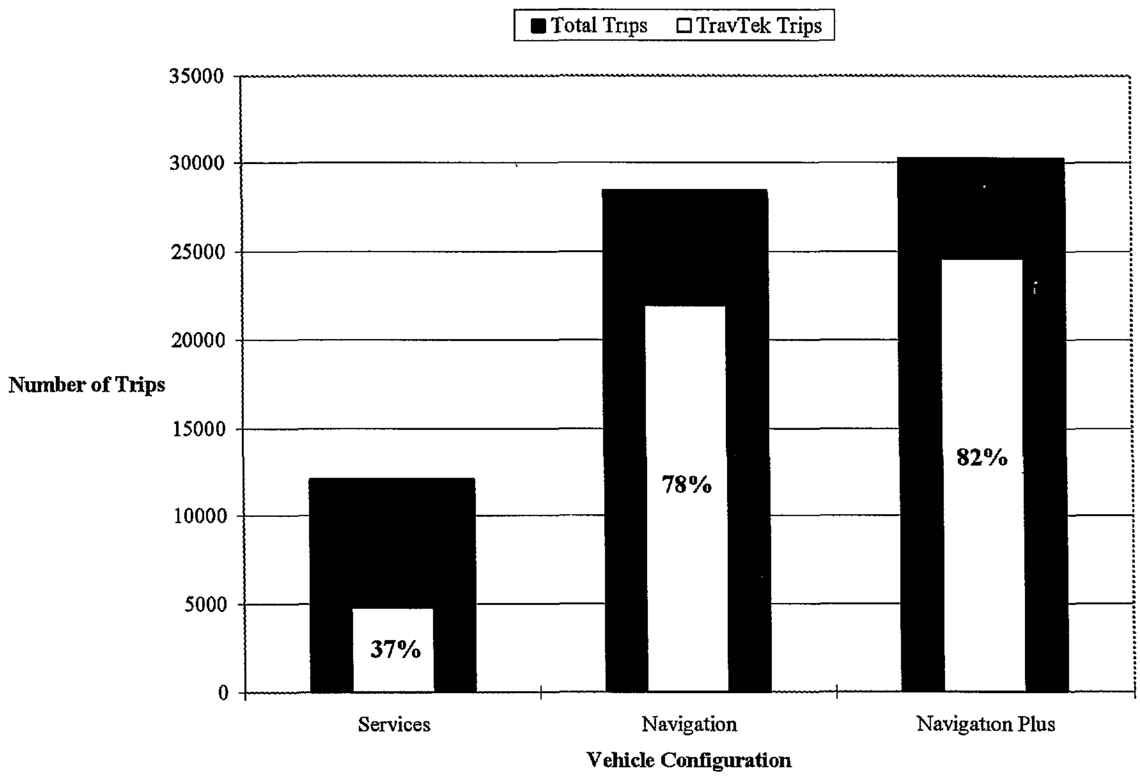

Figure 20. The percentage of trips that TravTek renters with each configuration used TravTek features.

Participants of both the Rental and Local User Studies used TravTek to plan routes for more than half their trips. Figure 21 shows the percentage of trips for which users both planned a route and then followed that route to their planned destination. For this analysis, unlike the previous analysis, the vehicle had to move. The frequency of use of the route planning and guidance feature declined slightly over time: rental drivers who took more than 40 trips installed and followed TravTek routes 42 percent of the time, and local users used the route planning function about 15 percent more during their first month, 62 percent of trips, than their second month, 47 percent of trips. Nonetheless, even after extended use, participants installed and followed routes on more than 40 percent of trips.

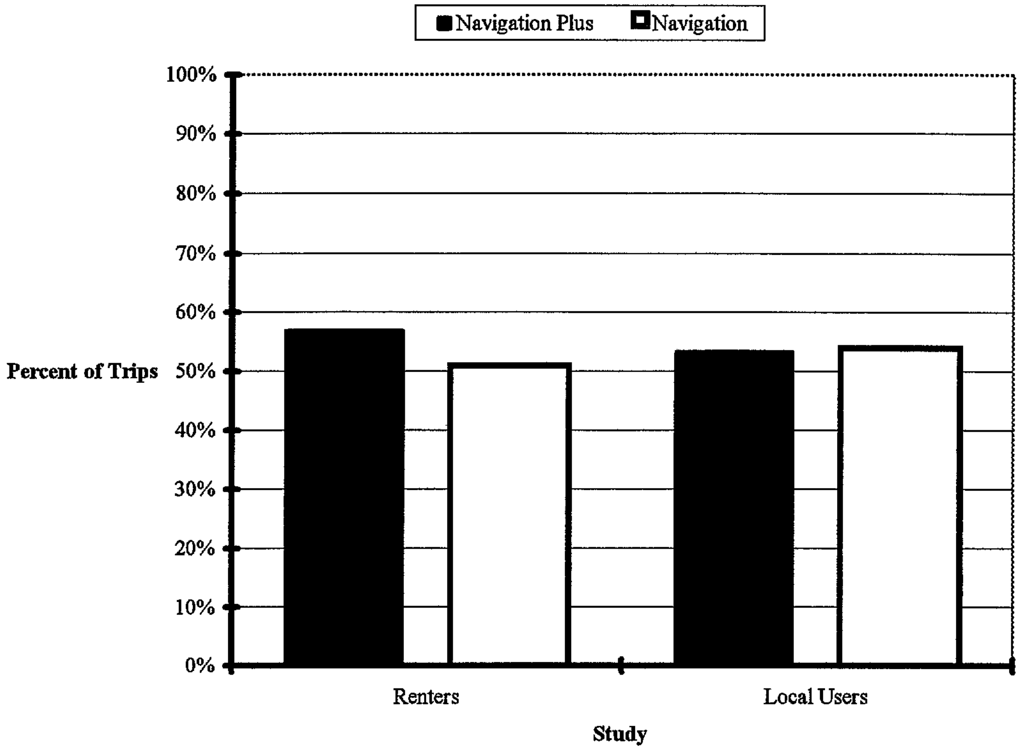

Figure 21. Percentage of trips that TravTek users installed and followed a route planned by the system.

What drivers said about using TravTek

Renters were asked, "Did having the TravTek System in your car have any effect on the length or number of trips you took?" Only Navigation Plus and Navigation configuration drivers were asked this question. Among renters, 537, or 34 percent, answered "yes," indicating that the number or length of their trips was influenced by TravTek. There was no tendency for Navigation Plus and Navigation configuration renters to differ in answering this question. To indicate the nature of the change, respondents who said that trip frequency or length had changed were asked to indicate on a scale from one to six, where one represented "never" and six represented "frequently," the frequency of having taken more, fewer, shorter, and longer trips. Forty-five percent of the respondents indicated that at least occasionally (response greater than one), TravTek caused them to take fewer trips, whereas more than 98 percent indicated that TravTek, at least occasionally, led them to take more trips.

Renters were also asked, "Did you ever change your plans to visit a destination based on the information you received from TravTek?" There were 62 Navigation Plus drivers and 56 Navigation drivers who answered "yes" to this question. Of Navigation Plus and Navigation configuration renters who said they altered plans to visit a destination because of TravTek, those with Navigation Plus were more likely than those with Navigation to say that they changed destinations, X^2 (3) = 22.4, $p < 0.0001$. Although respondents were not asked why they changed destinations, this finding is consistent with the use of real-time information to avoid trips into heavy congestion or to facilities with closed parking lots.

In summary, questionnaire responses suggest that TravTek rental users, most of whom were visitors to the Orlando area, took more and longer trips as a result of having in-vehicle route planning and route guidance. The questionnaire data also suggest that renters used real-time traffic information to help in choosing destinations.

Use of the TravTek system by drivers unconstrained by research requirements is fully described in the *TravTek Evaluation Rental and Local User Studies Final Report*.(4)

HOW EFFECTIVE WERE THE TURN-BY-TURN, MOVING MAP, AND VOICE GUIDANCE DISPLAYS?

Measures for evaluating the effectiveness of the TravTek in-vehicle display options included:

- Driving performance.
- Navigation performance.
- Driving safety.
- Ease of learning.
- Ease of use.
- User preference.

Driving Performance

The three field experiments provided the best driving performance data. All of the field studies and experiments provided data regarding driver perceptions of effects on performance. Effects on travel time and the perception of effects on travel time were discussed in the preceding section.

Other measures of driving performance that were assessed were:

- Eye glance patterns.
- Abrupt maneuvers.
- Subjective workload.

There were remarkably few differences in driving performance among the alternative display configurations. The subjective workload ratings seemed to be the most revealing measures. Overall, these indicated that any TravTek configuration was preferable to the control conditions. Among TravTek configurations, the Route Map without supplemental Voice Guide instructions yielded slightly higher workload and marginally lower performance compared to: the Guidance Display (with or without Voice Guide); the Route Map with Voice Guide; or the Voice Guide alone.

The eye glance data come from the Camera Car Study. It was found that regardless of which TravTek display configuration was used, or which navigation control configuration was used, drivers looked most often, and for the longest duration, at the forward roadway. Overall, the eye glance data indicated that any TravTek configuration was preferable to the control conditions, and that among TravTek configurations, the Route Map without supplemental Voice Guide instructions yielded slightly higher workload and marginally lower performance compared to: the Guidance Display (with or without Voice Guide); the Route Map with Voice Guide; or the Voice Guide alone. It is interesting to note that while driving under the paper map and paper list control conditions, drivers made fewer glances away from the road while driving than they did while using TravTek. In the map control condition, drivers made more stops, often abrupt stops, to look at the map. Also interesting was the finding that drivers in the control conditions made many more glances to the left and right of the roadway than drivers using TravTek. In the Camera Car Study report, these glances to the left and right were interpreted as attending to traffic. However, an alternative interpretation (that was not tested) is that these glances were searches for road signs. Because TravTek continually displayed the vehicle's proximity to intersections where turns were required, drivers had little uncertainty as to where to turn. When using a paper map, driver acquisition of road signs is generally necessary in order to determine proximity to intersections where turns are required. The latter interpretation is consistent with the finding in both the Orlando Test Network Study and Camera Car Study that visual workload was higher in the control conditions.

Drivers generally reported that TravTek improved their ability to attend to their driving. In questionnaires, users were asked to rate the assertion that various TravTek control and display options "interfered with my driving." The ratings were on a scale from one to six, where one was labeled "strongly disagree" and six was labeled "strongly agree." Drivers in all studies disagreed with the assertion, regardless of the control or display in question. Similarly, users were asked to rate the assertion that various control and display options "helped me pay more attention to my driving." Users from all studies agreed with these statements. Typical results for the "interfered with my driving" assertions are shown in table 4.

Navigation Performance

In general, navigation performance with the TravTek displays was good. The Orlando Test Network Study found that drivers navigating without a visual display, either with a paper map or with only the TravTek Voice Guide, spent more time off of the planned route than drivers that had a TravTek visual display — either the Route Map or the Guidance Display. It should be noted that the Voice Guide was designed as a supplement to the TravTek visual displays, not as a stand-alone navigation aid.[14]

Table 4. Rental users' assessment of whether TravTek interfered with their driving.

Question	***Mean[1]***	***N***	***No Response***	***Did Not Use***
Overall, the TravTek system (interfered with my driving)	2.1	1524	53	na[2]
The TravTek system's Guidance Display (interfered with my driving)	2.4	1378	165	34
The TravTek system's Route Map (interfered with my driving)	2.3	1440	98	39
The TravTek system's technique of displaying a local map for driving without a destination (interfered with my driving)	2.1	1157	81	339
The TravTek system's Voice Guide feature (interfered with my driving)	1.8	1365	83	129
Overall, the steering wheel buttons (interfered with my driving)	2.0	1497	80	na[2]
The TravTek system's SWAP MAP feature (interfered with my driving)	2.2	1036	85	456
The TravTek system's OK New Route feature (interfered with my driving)	2.3	1285	101	191
The TravTeksystem' sWHERE AM I feature (interfered with mydriving)	1.8	1227	81	269
The TravTek systems REPEAT VOICE feature (interfered with my driving)	1.8	1090	85	402
The TravTek system's Hop Right/Hop Left feature (interfered with my driving)	2 5 .	802	117	658
The TravTek system's Zoom In/Zoom Out feature (interfered with my driving)	2.3	1349	76	152

1 1 = "strongly disagree," 6 = "strongly agree."
2 "Did not use" was not an available option.

Drivers reported that TravTek helped them find their way. In response to questionnaires, users from all TravTek field studies agreed with the assertion that various TravTek displays and controls "helped me find my way." The ratings were on a scale from one to six, where one was labeled "strongly disagree" and six was labeled "strongly agree." Table 5 provides results from the Local User Study that reflect overall questionnaire findings for responses to the "helped me find my way' assertions.

Table 5. Local user's perceptions of TravTek's ability to help them find their way.

Question	***Mean[1]***	***N***	***No Response***	***Did Not Use***
Overall, the TravTek system (helped me find my way)	5.4	51	0	na[2]
The TravTek system's Guidance Display (helped me find my way)	5.5	51	0	0
The TravTek system's Route Map (helped me find my way)	5.3	51	0	0
The TravTek system's Voice Guide feature (helped me find my way)	5.1	50	1	0
Overall, the steering wheel buttons (helped me find my way)	4.9	51	0	na[2]
The TravTek system's OK New Route feature (helped me find my way)	5 1	50	1	0
The TravTek system's WHERE AM I feature (helped me find my way)	4.7	51	0	0
The TravTek system's REPEAT VOICE feature (helped me find my way)	4.4	47	0	4
The TravTek system's Hop Right/Hop Left feature (helped me find my way)	4.0	34	17	0
The TravTek system's Zoom In/Zoom Out feature (helped me find my way)	5.0	33	14	4

1 1 = "strongly disagree," 6 = "strongly agree."
2 "Did not use" was not an available option.

Driving safety

The issue of whether TravTek was safe, or would be safe in a fully deployed system, is reviewed in the next major section of this report. Here we briefly describe differences between the TravTek display alternatives that were evaluated in the field studies. For a thorough but concise summary of the safety-related comparisons of the TravTek display configurations, refer to the *TravTek Evaluation Safety Study*.[9]

In the two field experiments that provided the data for comparisons of performance across the TravTek display alternatives, the Camera Car Study and, to a lesser degree the Orlando Test Network Study (OTNS), drivers were asked to complete trips exclusively using one display alternative. The display alternatives were:

- Guidance Display with Voice Guide (Camera Car and OTNS).
- Guidance Display without Voice Guide (Camera Car and OTNS).
- Route Map with Voice Guide (Camera Car and OTNS).
- Route Map without Voice Guide (Camera Car and OTNS).
- Voice Guide alone (OTNS).
- "Paper Map" control (Camera Car).
- Printed list control (Camera Car).
- "As you normally would without TravTek" control (OTNS).

An important qualification on the safety-related findings of both studies was that drivers were required to use only one display configuration for an entire trip. The TravTek driver interface was designed such that the user could easily switch between display alternatives to obtain the most appropriate information as it was needed. Therefore, it can be argued that in the field experiments, users were not permitted to use the system in the manner for which it was designed. This restriction provided good experimental control, and allowed the evaluators to quantify performance with each display, but may have appeared to make certain displays less safe, or more difficult to use, than they would have been in practice. Users in the field experiments were limited to the use of displays in situations for which they might have otherwise chosen not to use them.

As will be shown shortly, renters and local users, when free to choose display options, most frequently chose to use the Guidance Display with the Voice Guide. The available evidence suggests that this was also the safest display combination, safer in many respects than the control conditions. The Route Map without Voice Guide was the least frequently used display combination, and this display combination had the most indications of safety risk factors. The high mileage local users were the most likely drivers to turn the Voice Guide off, or to drive with the Route Map. The Camera Car Study found that after 6 weeks experience, local users' driving performance with the Route Map without Voice Guide was not markedly different from performance in the control conditions. Thus any increased risk that may be associated with the Route Map without Voice Guide may have been of short duration.

The field experiments showed the Guidance Display with Voice Guide yielded the best safety-related driving performance from among the TravTek display combinations. The

Route Map with Voice Guide scored almost as favorably, followed by the Guidance Display without Voice Guide. Thus, the recommendation for ATIS displays is to provide an auditory supplement to visual displays, and that well implemented turn-by-turn visual displays, such as the Guidance Display used in TravTek, may be preferable to moving map displays. These recommendations must be kept in perspective: a well implemented moving map display may well yield better performance than a poorly implemented turn-by-turn display. TravTek provided for only single implementations of voice supplement, turn-by-turn, and moving map displays, and a great deal of human factors research went into the implementation.[13,14,15] Therefore, whereas the TravTek findings are instructive with respect to the safety of design alternatives, they should not be interpreted as applicable to all other implementations: the application of sound human factors practices to the design and evaluation of any implementation is strongly advised.

Ease of learning

All indications are that TravTek users found the system easy to learn. Table 6 shows Rental User Study respondents' agreement with the assertion that various TravTek features were "easy to learn," The ratings were on a scale from one to six, where one was labeled "strongly disagree" and six was labeled "strongly agree." User ratings from the field experiments and the Local User Study were similarly positive.

Table 6. Representative ease of learning ratings for TravTek in-vehicle system components.

Question	*Mean**	*N*
Overall, the TravTek system (was easy to learn)	5.2	1680
The TravTek system's Guidance Display (was easy to learn)	5.4	1504
The TravTek system's Route Map (was easy to learn)	5.4	1323
The TravTek system's VOICE GUIDE feature (was easy to learn)	5.5	1401
The TravTek system's technique of displaying a local map for driving without a pre-selected destination (was easy to learn)	5.4	1316
The TravTek system's steering wheel buttons (were easy to learn)	5.4	1513
The TravTek system's OK New Route feature (was easy to learn)	5.5	1495
The TravTek system's "Hop Right/Hop Left" feature (was easy to learn)	5.0	836
The TravTek system's technique of displaying updated traffic conditions on the Route Map (was easy to learn)	5.0	1096
The TravTek system's WHERE AM I feature (was easy to learn)	5.6	1261
The TravTek system's TRAFFIC REPORT feature (was easy to learn)	5.6	565
The TravTek system's Repeat Voice feature (was easy to learn)	5.7	1118
The TravTek system's technique of displaying updated traffic conditions on the Guidance Display (was easy to learn)	5.3	610

* 1 = "strongly disagree," 6 = "strongly agree."

Observations of drivers using the system for the first time in the field experiments confirm that users found the system easy to learn. Observers in the Orlando Test Network and Yoked Driver studies recorded user performance on eight steps necessary to enter an intersection as a destination. Table 7 shows the average number of trials before drivers in the respective groups performed all eight steps without error or hesitation. It can be seen that most drivers were proficient in entering destinations by their second trial. Older adults were proficient by their third trial and at night users took slightly longer to master the system.

Table 7. Mean number of trials and sample size (in parentheses) 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)

Ease of Use

The TravTek system proved to be very easy to use. Drivers in the Orlando Test Network and Yoked Driver studies were given a brief (approximately 10 minutes) briefing on the entire TravTek system prior to hands-on experience which began about 30 minutes later. During the hands-on training, observers quizzed the drivers on system concepts that had been covered during the briefing. The system was intuitive enough that 75 to 90 percent of the drivers answered each of the questions correctly the first time they were asked. Virtually all drivers answered correctly the second time they were asked.

Questionnaire responses also confirm that the system was easy to use. Table 8 provides Rental User Study respondents' ratings of the degree to which TravTek system features were "easy to use" or (as noted) "easy to understand." The ratings were on a scale from one to six, where one was labeled "strongly disagree" and six was labeled "strongly agree." Ratings from other user groups were similar.

Table 8. Rental user ratings of TravTek's usability and understandability.

Question	*Mean**	*N*
The TravTek system's Guidance Display (was easy to use)	5.4	1498
The TravTek system's Route Map (was easy to use)	5.3	1495
The TravTek system's Voice Guide feature (was easy to use)	5.6	1355
The TravTek system's technique of displaying a local map for driving without a pre-selected destination (was easy to use)	5 5	1188
The TravTek system's steering wheel buttons (were easy to use)	5.4	1515
The TravTek system's Swap Map feature (was easy to use)	5.5	1064
The TravTek system's OK New Route feature (was easy to use)	5.4	1322
The TravTek system's WHERE AM I feature (was easy to use)	5.6	1259
The TravTek system's REPEAT VOICE feature (was easy to use)	5.7	1119
The TravTek system's TRAFFIC REPORT feature (was easy to use)	5.6	564
The TravTek system's technique of displaying updated traffic conditions on the Guidance Display (was easy to use)	5 3	607
The TravTek system's technique of displaying updated traffic conditions on the Route Map (was easy to use)	4 8	633
The TravTek system's Hop Right/Hop Left feature (was easy to understand)	4.9	836
The TravTek system's TRAFFIC REPORT feature (was easy to understand)	5.2	561
Overall, the TravTek system was understandable (was easy to understand)	5.2	1539

* 1 = "strongly disagree," 6 = "strongly agree."

User Preference

In earlier sections (see figure 21), it was shown that renters and local users installed planned routes on more than half of the trips they took. Once a user was on the planned route, the TravTek system defaulted to the Turn-by-Turn Guidance Display with the Voice Guide on. Separate switches on the steering wheel hub could be used to swap between the Route Map and Guidance Display and to turn the Voice Guide off or on. Renters in the Navigation Plus configuration pressed the SWAP MAP button an average of 3.1 times per trip whereas those with Navigation pressed the button 2.3 times per trip on average. Figure 22 shows the average number of seconds per trip that each display combination was selected. Because traffic information could be viewed on the Route Map but not on the Guidance Display, the difference in display usage between Navigation Plus and Navigation users is probably the result of Navigation Plus users seeking to view traffic information — traffic information was not available in the Navigation configuration.[4]

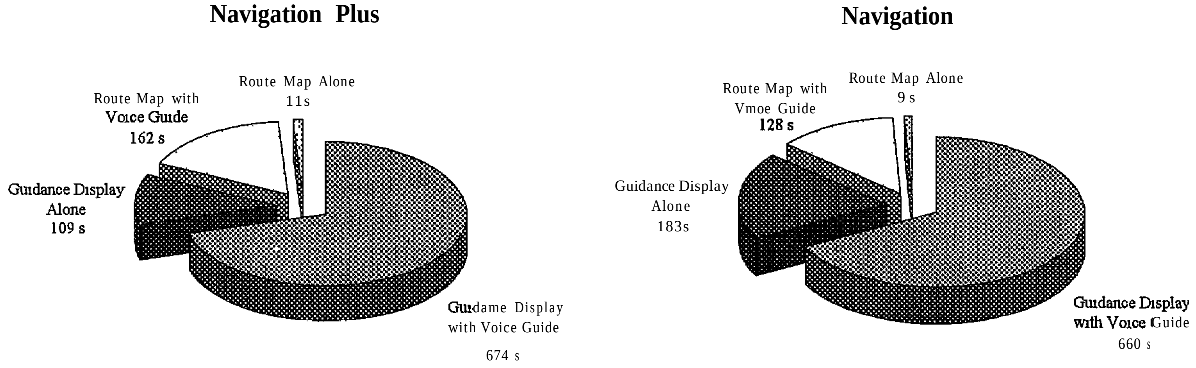

Figure 22. Average seconds per trip that each TravTek display option was selected by rental users.

Figure 23 shows display usage of local users. Although local users also drove most often with the Voice Guide on and with the Guidance Display, they used the Route Map more often than renters, and were more likely than renters to turn the Voice Guide off. Local users, but not renters, occasionally complained that the Voice Guide interrupted radio programs, and this may explain their greater tendency to turn the Voice Guide off. The reason for the greater tendency of locals to use the Route Map may be due to a greater desire to obtain traffic information or to assess alternative routes.

In questionnaires, users were asked to rate how well they liked the two route guidance visual displays, with and without Voice Guide. All ratings were on a scale from one to six, where one was labeled “disliked” and six was labeled “liked.” Ratings for the visual displays with and without supplemental voice guidance are shown in table 9. It can be seen that the renters strongly pre-

4 When there was traffic information available on the Route Map, a large yellow dot and the words “caution ahead” were presented in the lower right corner of the Guidance Display. The Guidance Display gave no indication of the location or nature of traffic incidents or congestions.

ferred the visual displays supplemented by voice guidance and were nearly neutral with respect to the visual displays without voice supplement. Ratings of renters who had traffic information (Navigation Plus) did not differ from those who did not (Navigation). Local users, on average, liked all the display combinations but most preferred the Route Map without voice supplement.

Local Users

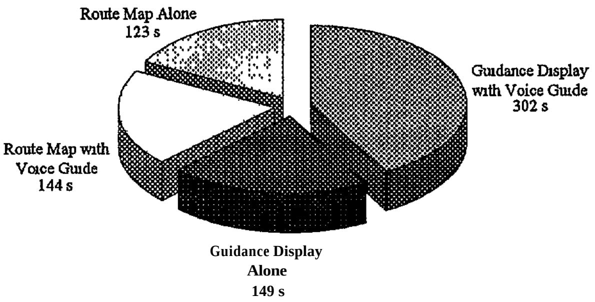

Figure 23. Average seconds per trip that each TravTek display option was selected by local users.

Table 9. Rental user ratings of liking for the visual route guidance displays with and without supplemental voice guidance.

Study	***Visual Display***	***Voice Guide***	
		On	***Off***
Renters	Guidance Display	5.3 *	**3.6**
	Route Map	**5.2**	**3.7**
Local Users	Guidance Display	4.6	**4.6**
	Route Map	**4.5**	**5.0**

*** 1 = "disliked," 6 = "liked."**

In summary, both renters and local users, when free to choose which displays they could use, most often chose the default display combination: Guidance Display with Voice Guide. Local users chose the Route Map about a third of the time and also drove with the Voice Guide off about 30 percent of the time. Renters expressed a strong preference for the Guidance Display and Voice Guide; whereas, locals were nearly equally positive towards all displays.

WAS TRAVTEK SAFE?

The TravTek field studies and safety evaluation showed that an ATIS can be employed under normal operational conditions without degrading safety. Development of the TravTek driver interface included human factors research and analysis. [13,14,15] This work paid off in the field testing of a system that was easy to use, required minimal training, and was safe. Human factors principles with respect to the reduction of driver attentional demand were applied in the design of the TravTek driver interface, and were verified in the Camera Car Study.

The Modeling Study results predicted that a TravTek-like system would present an increase in risk to users under conditions of high traffic demand and low levels of ATIS market penetration. The Modeling Study evaluated TravTek only as implemented in the Navigation Plus configuration: the configuration that used real-time information in route planning. The INTEGRATION computer model was calibrated to approximate the TravTek network. Therefore modeling study projections are based on the assumptions that all TravTek equipped vehicles received real-time information and operated in a network with the characteristics of the Orlando network during the operational test. Modeling Study projections of accident experience for TravTek equipped and non-equipped (background) vehicles are illustrated in figure 24 as a function of market penetration and traffic demand. Traffic demand is relative to the levels of demand observed in Orlando during the afternoon travel peak. That is, at the 40 percent level of traffic demand, the number of vehicles starting trips was modeled to be 40 percent of that observed during the afternoon peak. At the 110 percent level, the demand was modeled to be 10 percent more than that calibrated to represent a weekday afternoon peak. Traffic demand differs from traffic volume in that volume is limited by roadway capacity, whereas demand is the number of vehicles that attempt to use a roadway: when demand exceeds capacity, queues develop.

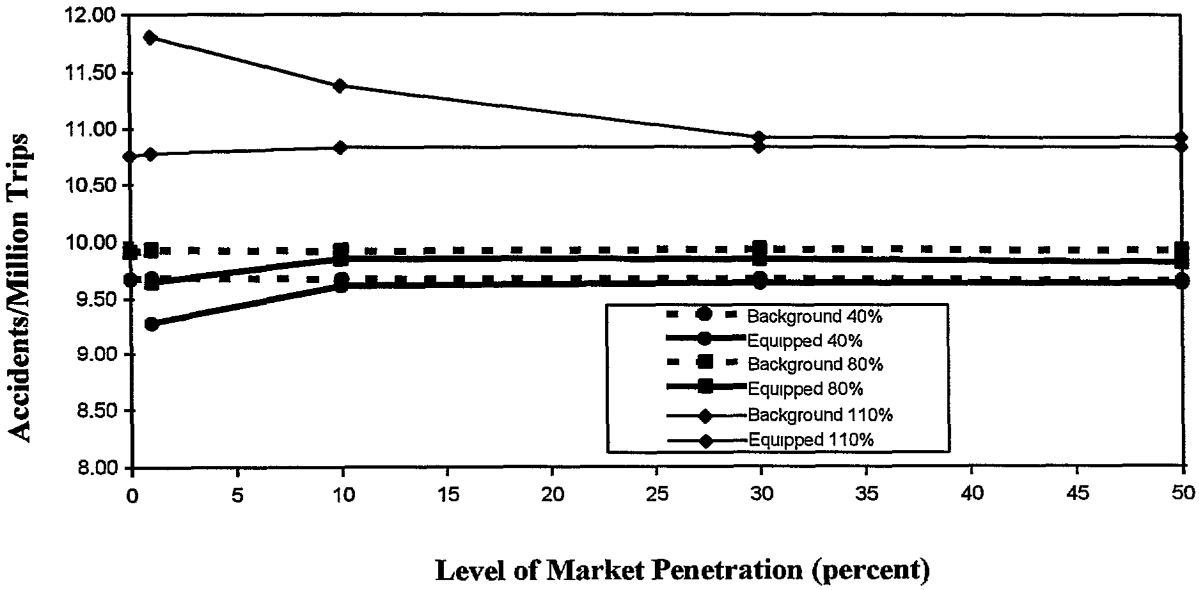

Figure 24. Orlando network effects of level of market penetration and traffic demand on accident risk.[5]

[5] The percentages in the figure legend refer to levels of traffic demand represented in the model relative to demand calibrated to approximate those in Orlando during the weekday afternoon peak. Thus, "Background 40%" refers to non-equipped vehicles operating in an environment with traffic demand that is 40 percent of afternoon weekday peak demand in Orlando during the operational test. "Equipped 110%" refers to TravTek equipped vehicles in a traffic demand environment that is 110 percent of weekday peak demand.

The predicted safety penalty to equipped vehicles at market penetration levels below 30 percent with high levels of traffic demand results because TravTek equipped vehicles divert from the congested freeway to arterials; whereas, non-equipped vehicles have a greater tendency to stay on the freeway. As arterials experience accident rates approximately 2.5 times those of freeways, equipped vehicles that divert do so from the safer freeway to the less safe arterials. At market penetration levels above 30 percent, the projected penalty becomes negligible because as some equipped vehicles divert, congestion on the freeway is alleviated, and subsequent equipped vehicles are less likely to leave the freeway. That is, as equipped vehicles leave the freeway, equipped and non-equipped vehicles that remain on the freeway benefit.

The safety penalty might well not be found if TravTek-like systems are deployed in networks that are different from Orlando's. Orlando has only one north-south freeway, so diversions from the freeway are necessarily to arterials. In other cities, diversions from arterial to freeway or freeway to freeway could result in markedly different results.

Modeling was necessary to evaluate safety effects of the TravTek system, because, even with 100 vehicles driven for an entire year, there was not a sufficient number of kilometers driven to allow for appropriate statistical evaluation of accident rates. It was estimated that there are 1.75 police reported crashes annually in the United States (involving 1.6 vehicles per crash) for every million kilometers driven. In the TravTek operational test, less than 2.4 million vehicle kilometers were driven. Besides lacking enough exposure to support robust statistical analysis, other problems arise in attempting to analyze accident experience in any operational test. These problems include: lack of baseline statistics for the appropriate control population and failures to report accidents, particularly among control populations. A number of the problems confronting those attempting to perform analysis of accident experience in operational tests is detailed in the TravTek Safety Study final report.[9]

The TravTek evaluators applied the modeling approach to overcome these obstacles, However, the modeling results rely on simplifying assumptions: TravTek equipped vehicles were assumed to behave as Navigation Plus vehicles behaved in the TravTek field studies; and, non-equipped vehicles were assumed to behave as Services vehicles were observed to behave in the field studies. In the TravTek analysis, for instance, it was assumed that TravTek users would follow the routes planned by the system, and that all vehicles on the network would make wrong turns at the same rate as was observed in the TravTek field experiments. It is likely that both of these assumptions (and undoubtedly others) are inaccurate to some unknown extent. That is, although a high rate of acceptance of TravTek routes was observed in the field studies, it is likely that some drivers would decline to accept routes offered by a TravTek-like system. It is also likely that wrong turns would occur at different rates than were observed, both for equipped and non-equipped vehicles: recall that the TravTek field experiments utilized mostly Orlando visitors, and all field study participants were navigating to unfamiliar destinations,

That TravTek modeling results rest on tenuous assumptions is not offered as a reason not to do modeling, or reason not to trust the TravTek modeling results. Rather, because future operational tests will be faced with similar analytical dilemmas, it is recommended that the modeling approach be extended. Extensions to the approach could clarity the effects of necessary simplifying assumptions, and could reduce the number of untested assumptions that must be made. The number of assumptions can be reduced by collecting additional data. For instance, additional data on the probability of wrong turns could reduce the impact of one of the assumptions required in modeling the TravTek results.

COULD TRAVTEK BENE IT TRAVELERS WHO DO NOT HAVE THE TRAVTEK SYSTEM?

Modeling Study finding suggest that traffic network users, both those equipped with the systems and those not equipped, would derive numerous benefits from deployment of TravTek-like systems. TravTek was a prototype system. Were the TravTek system fully developed and deployed, improvements might be expected. Some of those improvements might result from what was learned in the operational test. However, given that a system were fully deployed such that it worked as it did during the operational test, TravTek users and other drivers not using TravTek might still expect benefits beyond those measured during the test.

As the level of market penetration (LMP of TravTek in-vehicle devices increases, it can be expected that both TravTek users and non-users will experience changing network conditions. The Modeling Study examined the effects of LMP on benefits to both TravTek users and non-users with respect to nine measures of performance:

- Trip time.
- Trip distance.
- Number of stops.
- Number of missed turns.
- Fuel consumption.
- Hydrocarbon (HC) emissions.
- Carbon monoxide (CO) emissions,
- Nitrous Oxide (NO,) emissions.
- Accident Risk.

At 50 percent market penetration, trip duration benefits are substantial for all vehicles using the traffic network. TravTek users will experience benefits that generally increase with increasing levels of market penetration. Figure 25 shows projections from the TravTek Modeling Study of the benefits in travel time for TravTek users and non-users (background). The figure shows that TravTek users can expect increasing travel time benefits as market penetration increases from 0 to 50 percent. The figure also shows that, as a function of market penetration, background vehicles (vehicles not equipped with the TravTek device) experience benefits that increase more quickly than the increase for equipped vehicles.

As discussed under the findings for safety, these results followed from the assumption that drivers of the TravTek vehicles would behave as they did in the TravTek field experiments, although some aspects of modeled system differed somewhat from the TravTek system . Some assumptions made in the modeling exercise were that the information broadcast to the TravTek vehicles was not delayed (as it was in the test), that the travel time updates were continuous (rather than discrete as in the test), and that the probability of a wrong turn, by both equipped and non-equipped vehicles, was the same as experienced in the test. For further discussion of the advantages and limitations of traffic modeling in the projection of ATIS and ATMS benefits, the reader is referred to the *TravTek Evaluation Modeling Study.*[8]

Figures 26 through 33 show projections of TravTek benefits to users (equipped) and non-users (background) for the remaining measures of performance. Largely because TravTek equipped vehicles avoided congestion, and thereby avoided increasing that congestion, for most measures of effectiveness benefits were projected to grow directly with market penetration. As market penetration increased, non-users were projected to experience substantial benefits with reductions to travel time, number of stops, fuel consumption, hydrocarbon emissions, and CO emissions. Non-users were projected to experience a small safety benefit. Non-users were projected to experience no effect on travel distance, or number of wrong turns. Non-users and users were projected to experience an increase in NO_x emissions, as these emissions increase with speed, and projected reduced congestion resulted in a projected increases in speed.

It can be seen in the figures that for all measures except accident risk, TravTek users were projected to experience some benefit. In most cases, the projected benefit increased with increasing levels of market penetration. In a few cases, the size of the benefit to equipped vehicles decreased at certain levels of market penetration, as TravTek equipped vehicles took longer routes to avoid congestion. At high levels of market penetration, fewer simulated TravTek vehicles diverted — because other TravTek vehicles had already diverted — and the TravTek fleet experienced less of a travel distance penalty, although, obviously not all members of the simulated fleet benefited equally. Because in Orlando, diversions from I-4 to avoid congestion requires travel on arterials that are less safe than the freeway, accident risk for the TravTek fleet was projected to increase until market penetration exceeded 30 percent. At levels of market penetration exceeding 30 percent, the diversion of some simulated TravTek vehicles from the freeway reduced the need for freeway diversions and the negative impact in accident exposure for the fleet as a whole became negligible.

Figures 25 through 33 are shown to summarize the benefit findings from the Modeling Study. An appreciation of the generalizability of the findings requires a greater depth of coverage than can be provided here. Readers who require more than a high level summary of results are urged to consult the final report of the Modeling Study.[8]

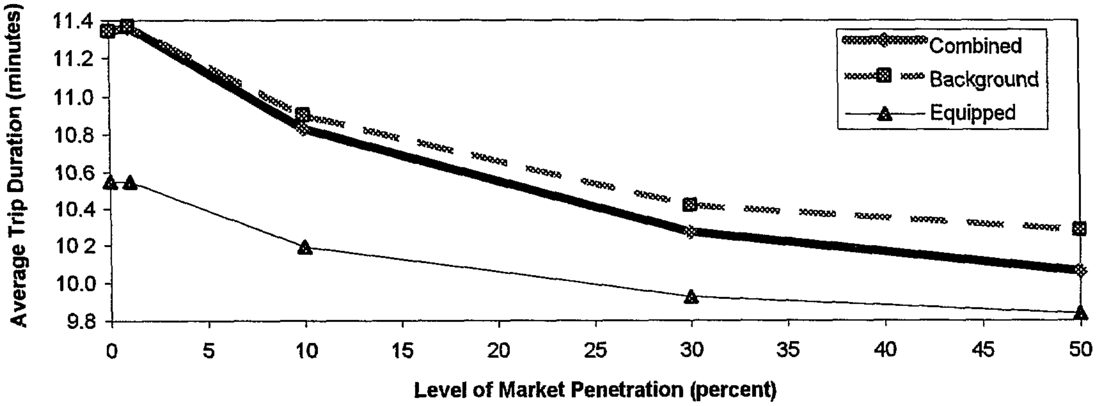

Figure 25. Impact of LMP on trip travel time.

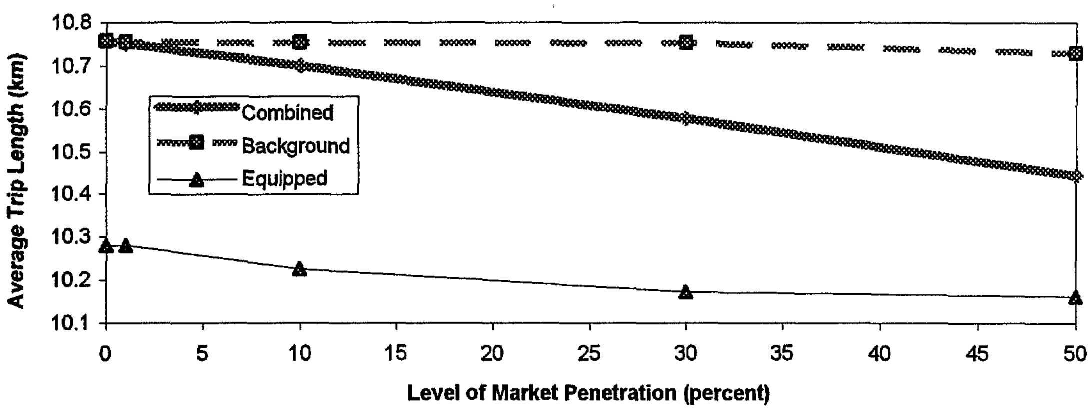

Figure 26. Impact of LMP on trip length.

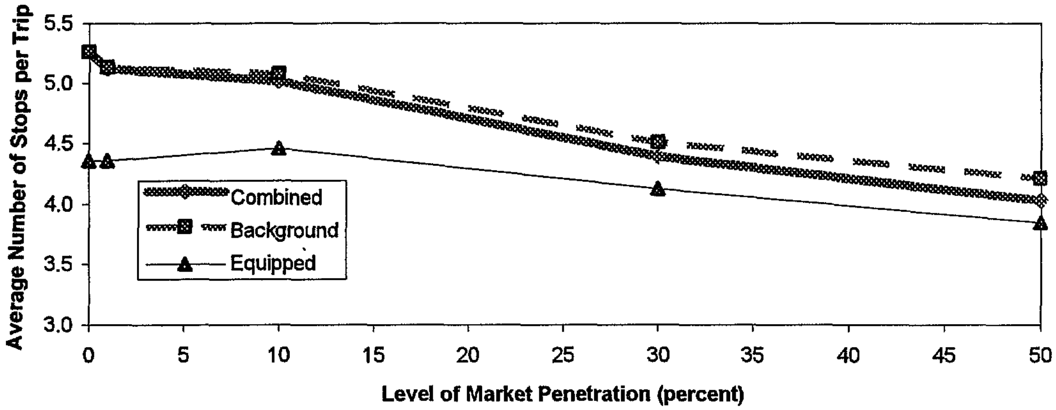

Figure 27. Impact of LMP on the average number of stops.

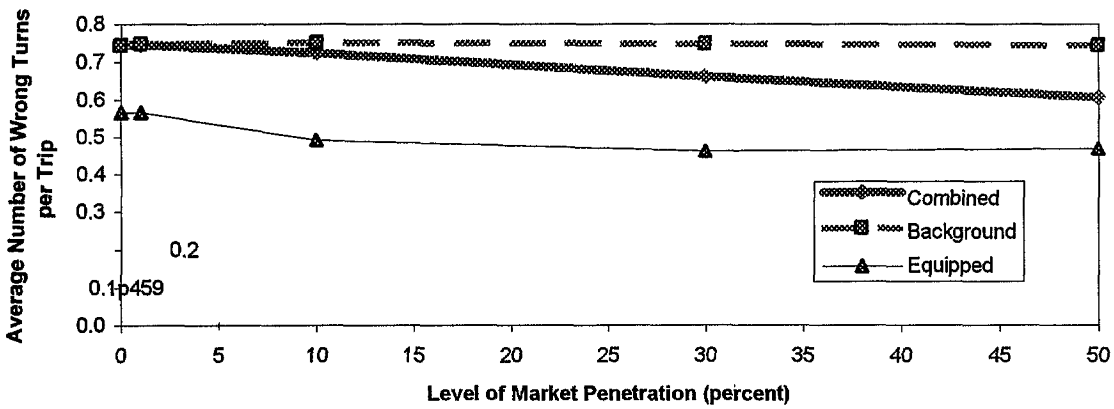

Figure 28. Impact of LMP on the average number of wrong turns.

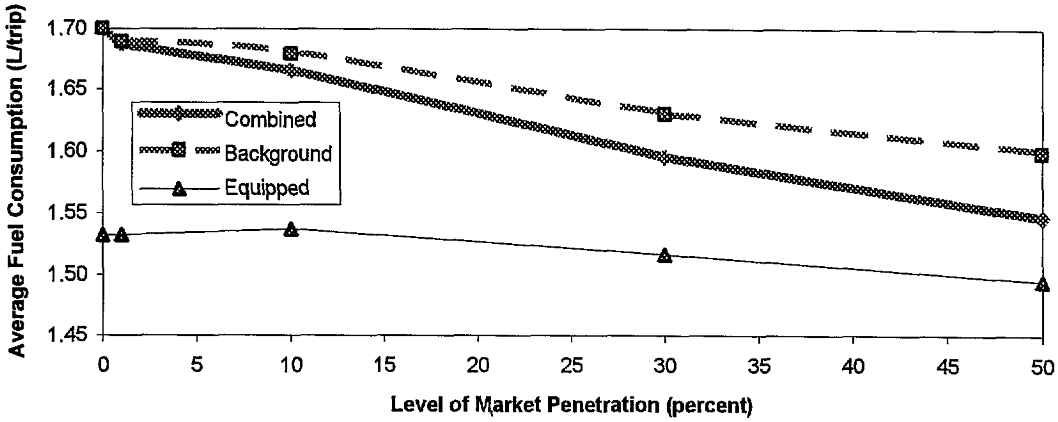

Figure 29. Impact of LMP on average fuel consumption.

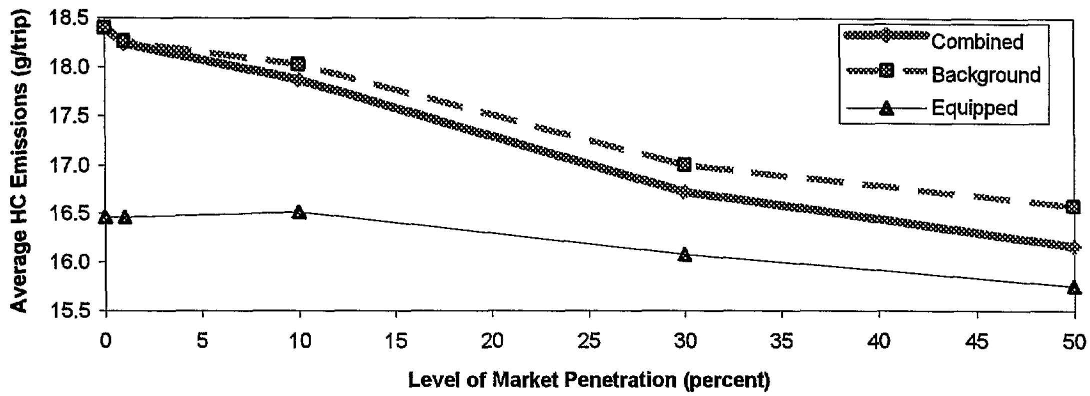

Figure 30. Impact of LMP on HC emissions.

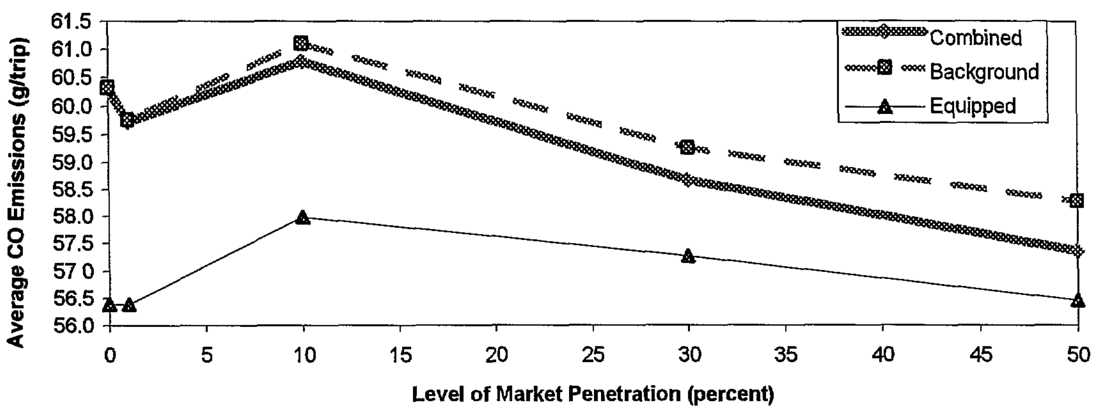

Figure 31. Impact of LMP on average CO emissions.

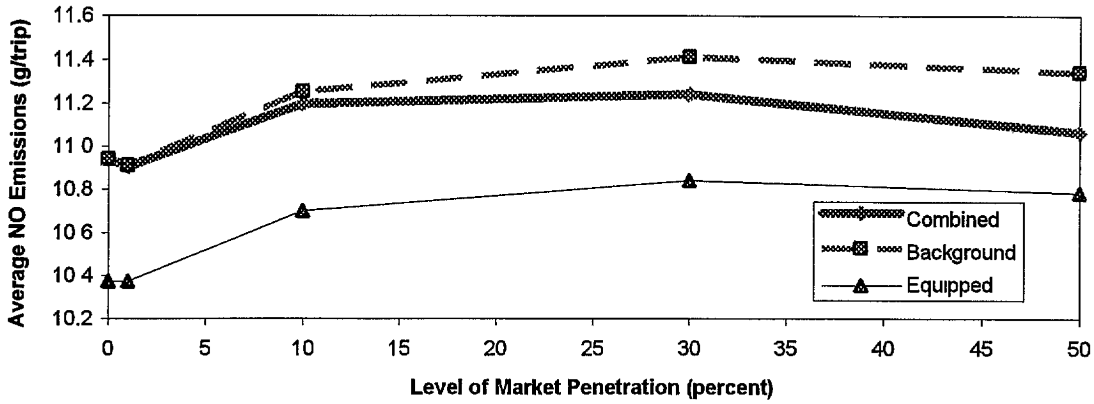

Figure 32. Impact of LMP on NO_x emissions.

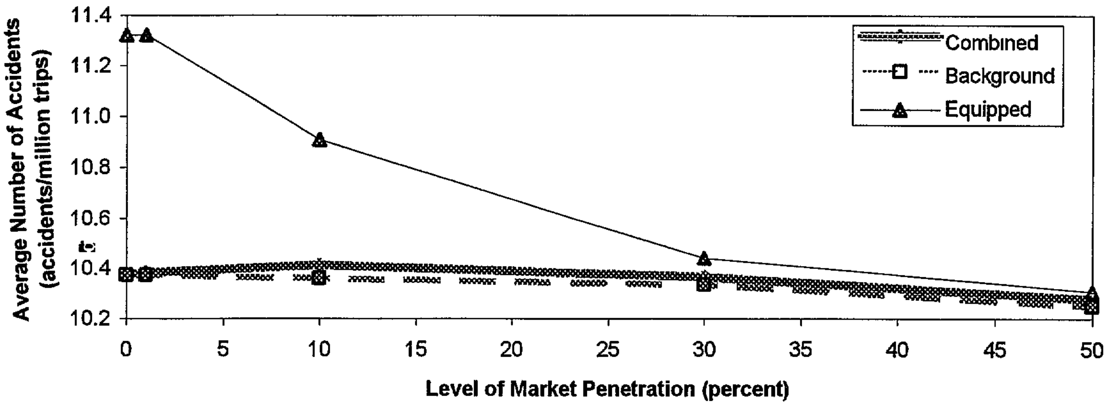

Figure 33. Impact of LMP on average accident risk.

WILL PEOPLE BE WILLING TO PAY OR TRAVTEK EATURES?

Across all field studies, users indicated that they would be willing to pay more than nine hundred dollars for a TravTek system. Figure 34 shows representative findings from the Rental User Study. Services, Navigation, and Navigation Plus users responded to the question "How much would you be willing to pay for a TravTek system such as the one you drove in Orlando?" Fifty percent of the Navigation and Navigation Plus renters indicated that they would be willing to pay $1000 or more. Fifty percent of the Services configuration users indicated that they would be willing to pay $500 or more for a system with a data base of local services and attractions such as was featured in the system they drove. The median willingness to pay estimate from local users was slightly under $1000 and the median estimate of respondents in the Yoked Study and Orlando Test Network Study provided median estimates slightly over $1000.

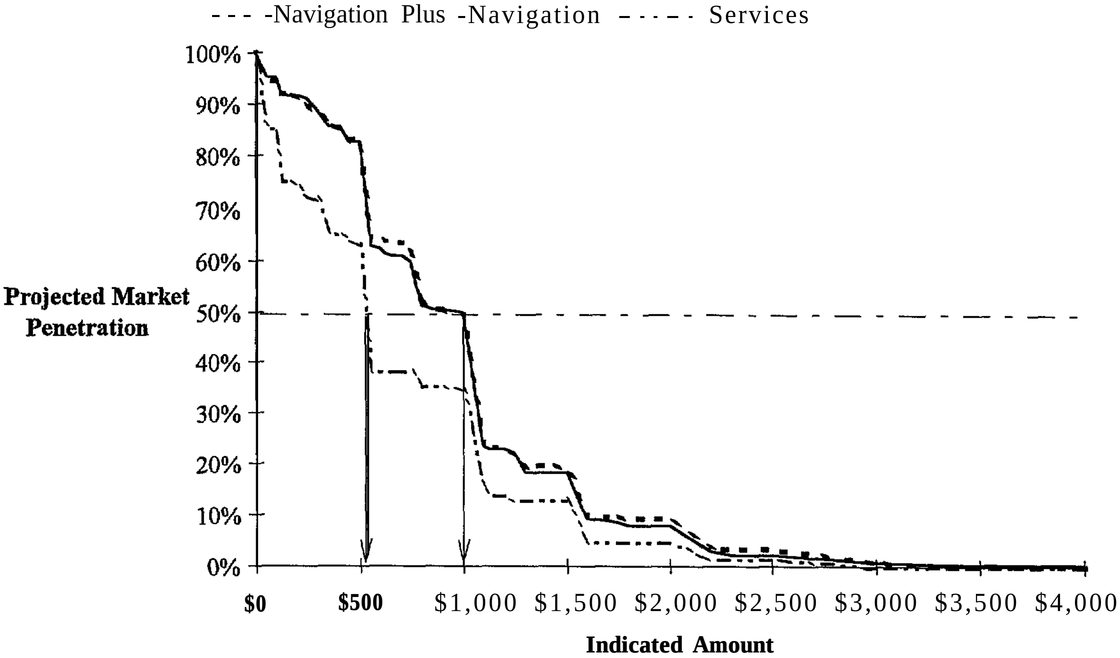

Figure 34. dumulative willingness-to-pay indicated by renters for a TravTek system such as the one they drove.

Users indicated that the route planning and route guidance features contributed most to their willingness to pay for the complete TravTek system. Services, Navigation, and Navigation Plus users all rated the value of TravTek features similarly — an indication that experience with particular features was not critical to assessment of their value.

Across the field studies, median estimates of the added value of the full TravTek system in a rental car ranged from $28 to $35. There appears to be a strong market for TravTek-like ATIS systems if they can be priced close to, or less than, $1000.

LESSONS LEARNED AND RECOMMENDATIONS FROM EVALUATING THE TRAVTEK OPERATIONAL TEST

Because TravTek was the first large operational field test of a system of its kind, many lessons were learned. The following sections present these lessons and some recommendations based on experiences from the three major TravTek project activities:

1. TravTek design.
2. TravTek operations.
3. TravTek evaluation.

Because the TravTek partners considered evaluation activities during the very first steps of system conceptualization, and carried these considerations through the system design and the remaining operational test phases, there was no evaluation phase per se — evaluation activities occurred for the entirety of the project.

TRAVTEK DESIGN

The TravTek system took about 3 years to design and build. TravTek design included technical testing activities required to ensure the system worked as planned. That testing was performed by the design team and did not include the intended TravTek system users (i.e., recruited drivers of TravTek cars, Traffic Information Network users, or operators of the Traffic Management Center). The following are some of the more important lessons learned from the design activities.

Designing for Safety of the TravTek System Paid Off

The safety of in-vehicle traveler information systems is a major concern of the highway research and development community and was of equal concern to the TravTek partners.[12] The partners were committed to using the TravTek operational field test as an opportunity to obtain greater insight into ATIS safety issues. A fundamental requirement was to ensure that the design of the TravTek system received comprehensive attention to safety concerns. Concerns included the attentional demand characteristics of the driver control and display interface, and the implications for the accuracy of route guidance information.[11]

A major benefit of using the 1992 Toronado was that GM could take advantage of preceding safety considerations made by Oldsmobile in their design of the touch screen video display. This avoided otherwise necessary safety evaluations. For instance, the builders did not have to be concerned that TravTek equipment be clear of the air bag deployment zones; become a projectile during a crash, or, an impediment to safe operations.

GM employed numerous design strategies for informing TRAVTEK drivers without overloading their attentional capacity. Strategies included:

- **Restricting the use of controls and visual displays.** The only TravTek screens available while the vehicle was in DRIVE were navigation and traffic information screens that were controlled with steering wheel buttons. All touch screen functions were disabled when the vehicle was in DRIVE except the zoom buttons that were only available when the vehicle was stopped. Use of the Services and Attractions menu, entering destinations, etc. were only available when the vehicle was in PARR.

- **Reducing the information density of drive screens.** The simplified, turn-by-turn Guidance Display was developed and made the default route guidance display. This display minimized the amount of information on the screen so that the driver could extract the salient navigational information in a brief glance. This display was developed as an alternative to the moving map (Route Map) which could display more street information than necessary to follow a planned route, and thus might distract from the information salient to following the route.
- **Supplementing visual displays with voice guidance.** The Voice Guide was developed to orient drivers and prepare them for upcoming turns, thereby reducing visual demands.[13]

Results of the TravTek evaluation show that the above strategies were worthwhile. There was no evidence from any of the TravTek evaluation studies that the TravTek system presented a safety hazard. Corroborating evidence from multiple studies highlighted the safety benefit of TravTek's supplemental Voice Guide feature. The TravTek design philosophy and observed results reinforce the fact that ITS designers can address safety issues when fielding prototype systems.

A major design challenge to the TravTek partners was to avoid the delivery of inaccurate guidance information to drivers. Such information could be distracting or send someone in the wrong direction down a one-way street. A principal strategy therefore, was to ensure that navigation and local information data bases were accurate. This leads to a discussion of the next lesson learned.

Resources Required for Data Base Development and Maintenance were Underestimated

A significant and unforeseen level of effort was required to test and improve the accuracy of the navigation data bases (e.g., street names, geographic coordinates, traffic restrictions) and local information (e.g., local attraction names, addresses, and phone numbers).[16] In order to support the route guidance function, and to achieve customer satisfaction and security, the TravTek partners invested significantly more time and effort than they had originally planned. Considerable human resources were needed to develop and test the data bases. Part of the challenge was in obtaining up-to-date map data, planned road construction data, and parking lot data, because there was no infrastructure in place to support sharing of such data across local jurisdictions. The private sector should anticipate such costs, and local jurisdictions must work together, if information infrastructures that can support cross-jurisdiction traffic management initiatives are to succeed.

Time Needed for Testing, Validation, and System Shake-Down was Underestimated

TravTek system shake-down required 3 months more than was anticipated. Although individual parts of the system had tested satisfactorily, end-to-end testing — from data acquisition, through data processing, to driver observation of information — had not been accomplished before the date the operational field test was to begin. This raised partner concerns over information accuracy and customer satisfaction and decreased the time available for evaluation. The full period of operation and evaluation was ultimately retained due to a 3-month extension of the field test. ITS developers should schedule end-to-end testing of the system before it is released to the public. Ensuing corrections to the system design should be made without compromising the integrity of the evaluation plan.

TRAVTEK OPERATIONS

The data collection phase of the TravTek operational field test took place over a 12-month period. There were 100 TravTek vehicles (not including the Camera Car). The Rental User Study employed 75 of the vehicles that were rented through Avis. Three vehicles were retained by GM, the City of Orlando, and AAA, respectively, to support operations and maintenance checks of the system. The remaining 22 cars were leased from Avis by the evaluation contractor. Those 22 vehicles were used for the Local User Study, the Yoked Driver Study and the Orlando Test Network Study. The following are some of the lessons learned during the actual field test.

Lack of a System Manager During the Implementation Phase Delayed System Maintenance and Impeded Real-Time Diagnosis of System Health

The lack of a system manager resulted in one of the biggest problems experienced during the test, and could have implications for early deployments of ITS. Once the test implementation began in Orlando, there was no partner representative with responsibility to oversee the day-to-day management of the operational test. Consequently, the system experienced problems that were not detected or dealt with in a timely fashion. Problems surfaced through complaints registered with Avis or AAA by renters, and through incidental discoveries made by TravTek team members. Attempts to solve the problems through modification of a support contract were slow, funding was insufficient, and the support contractor was not staffed to provide this management function.

An onsite operational test manager was needed. Future ITS operational tests and systems in early stages of deployment should ensure that a manager is appointed. This manager should have sufficient authority to intervene quickly to correct problems. This manager should be available on a 24-hour basis and should be provided necessary communications (e.g., pager, cellular phone) to ensure that 24-hour access is possible.

A Verification and Validation Team was Needed to Test and Evaluate Proposed Changes to the System Configuration

There were no dedicated resources or set of procedures for systematic testing of the proposed updates to software for installation in the fleet. The American Automobile Association, responsible for the accuracy of the local information and navigation data bases, employed drivers to perform verification and validation in the geographical areas where they knew applicable changes in the data base had been made. Likewise, other TravTek partners deployed their representatives to check proposed changes that might affect their subsystem's performance. However, there was no entity assigned to look at the performance of the system as a whole. There were no standards against which to test the adequacy of system configuration changes. No one systematically collected and analyzed data taken from the TravTek system to verify the accuracy and reliability of the way it functioned before new versions were fielded.

Some thought that because the independent evaluator was responsible for systematic data collection and analysis, the evaluator could perform the system validation and verification role. Others thought that because the modifications were being proposed by the partners' representatives as improvements to the system, the job of verification and validation should fall on the partner making the change. There was no clear cut solution to this problem, and, as a result there are no objective data on how each system modification affected system performance relative to baseline performance.

It is recommended that a verification and validation team be formed to test and evaluate proposed changes to the system configuration. Members of the verification and validation team can be either partner representatives, independent evaluator representatives, or some combination of the two. As with the need for a system manager, good leadership of the verification and validation team is necessary. This leader must be intimately familiar with the design of the entire system and should place emphasis on end-to-end testing as a matter of routine. Such testing will help to prevent insidious glitches that might not be readily apparent to the developer but could be obvious to the system users. An example of a change to the TravTek system that had an unanticipated effect was a software update that resulted in all updated vehicles being routed to Bumby Avenue, regardless of their intended destination.

The lack of a systematic process for end-to-end verification and validation was managed by intense catch-up when problems occurred. Exposure to faulty or non-optimal software versions was limited by removing cars from the fleet. In the case of much broader scale operational tests that involve many more ITS users, ITS partners must thoroughly consider how upgrades will be introduced, and how verification and validation will be implemented to prevent large-scale problems.

A Configuration Control Board was Essential

An ideal operational field test evaluation would have been conducted on a system that successfully completed technical testing in the design phase. Upon entering the operational phase, the system designers would not make further design changes. This did not happen with TravTek and may rarely happen with other tests.

To ensure a fair evaluation, the TravTek partners instituted a Configuration Control Board to review proposed changes to the design baseline. This board provided a forum for coordination among design engineers and evaluation representatives. In this forum, the need for changes was evaluated, and if appropriate, procedures for implementing the changes were established. Among other duties, the Board resolved issues arising from the evaluator's desire to have a stable platform and the designers' desire to improve the system. Even when issues could not be satisfactorily resolved from an evaluation perspective, the board served two useful evaluation functions: First, it kept the evaluators informed as to when system changes would be made. Second, it kept careful documentation of the changes. This proved important during the evaluation analysis, as the evaluator was able to accurately determine under which system configuration data were collected.

The Help Desk Equipped with a TravTek Simulator was Extremely Useful

A Help Desk, available 24 hours a day, was part of the Traveler Information Services Center (TISC) design concept.[16] Drivers were instructed during their training on how to use the cellular telephone to call the Help Desk. Operators at the Help Desk used the simulator to replicate the drivers' experiences and walk them through the procedures for using the system. This capability proved invaluable in tracking down a number of user and system problems. When appropriate, the use of a Help Desk with a user interface simulator is strongly recommended.

TRAVTEK EVALUATION

The TravTek evaluation consisted of a number of closely integrated studies that were formulated to address how well TravTek met its goals and objectives. The following are some of the more important lessons learned during the conduct of the TravTek evaluation.

The Organizational Design Adopted by the TravTek Partners Ensured Coordination of Design, Operation, and Evaluation Activities

From the beginning of the project, the TravTek organizational structure resulted in close, active, ‘and documented coordination between the design and evaluation teams. That organizational structure is illustrated in figure 3 5.

The TravTek Steering Committee consisted of top level executives from each of the partner organizations. This committee named a Program Manager to head the TravTek Partners' Working Group that met quarterly to review progress. The Partners' Working Group consisted of core leaders and two sub-committees, the Technical Working Group and the Evaluation Working Group. Each TravTek partner was represented on the Technical Working Group by design engineers. The Evaluation Working Group consisted of more research-oriented partner representatives.

The Partners' Working Group subcommittees met for 2 to 3 days about every 4 to 6 weeks through completion of the operational phase of the test. During the first 1 or 2 days of those meetings, the Technical and Evaluation working groups met separately, with core Partner Working Group members attending portions of each subcommittee meeting. The Evaluation Working Group reviewed evaluation approaches, system design and operations, and provided guidance to the evaluation contractor team. In some cases, the Evaluation Working Group requested that the Technical Working Group initiate changes in system operations to support the evaluation. The Technical Working Group reviewed design progress, system requirements, test schedules, and subsystem interface requirements. A plenary session of the Partner Working Group that involved all working groups was convened on the last meeting day to summarize progress and coordinate action items.

The TravTek meeting format was viewed by many participants as a particularly effective method for keeping the project on track, designing the system to meet partner objectives, and ensuring a responsive evaluation. Minutes were kept for both working groups, and the minutes and action items were shared across groups. In the weeks between meetings, the system design, operations, and evaluation activities continued with participation and communication among the committee members. Fundamental to the effectiveness of the TravTek committees was strong and persistent leadership at all levels, with resources committed to seeing that the committee structure worked.

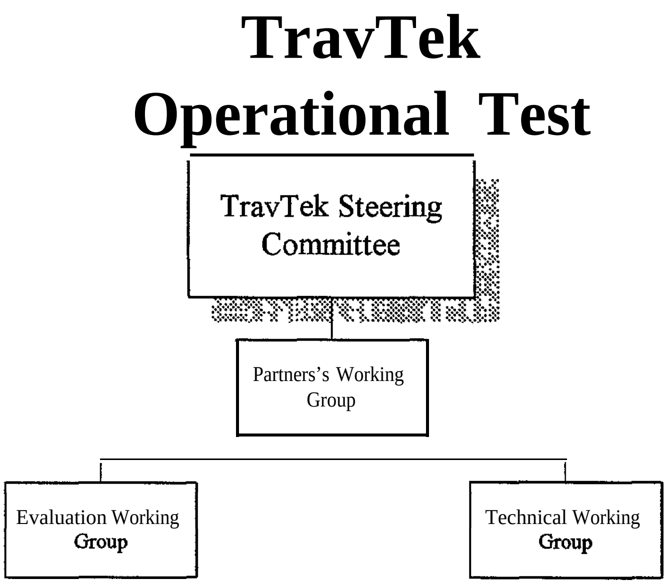

Figure 3 5. TravTek organizational structure.

Early Consideration of the Evaluation Objectives Paid Off

Much of the success of the TravTek evaluation can be attributed to the achievement of an agreed upon set of project and evaluation goals and objectives early in the project. The process of establishing these goals and objectives is described in the paper *Research and Evaluation Plans for the TravTek IVHS Operational Field Test.* [11] Early establishment of objectives facilitated the design and execution of well integrated evaluation studies. Of the objectives proposed by the individual partners, a few were derived from only one partner. However the majority of objectives were shared by more than one partner and, over a short period of time, the objectives evolved into a common set of transcendent project objectives (e.g., save time, avoid congestion, reduce navigational waste, research safety implications, etc.). Based on these project objectives, the partners formulated evaluation objectives to measure how well the project objectives were met.

The agreed-upon objectives became an integrating force for the project. The partners prioritized the TravTek project objectives in order to apportion study resources. Because the objectives were well documented, the partners could always refer back to them. After agreeing to a set of evaluation objectives, the partners developed a program of evaluation studies. These studies were included in a Request for Proposal for prospective evaluation contractors. The evaluation contractor was hired under contract to the Federal Highway Administration and was responsible for the evaluation's detailed design and implementation. The contractor was responsible for such design details as designation of sample sizes, identification of origin-destination pairs, and Local User

Study and field experiment driver recruitment. The contractor performed data analyses, and presented and published technical papers on the evaluation status and results. The partners' planning and design for evaluation ensured an evaluation that could meaningfully address all of the partners' objectives.

Building TravTek for Evaluation Paid Off

The TravTek partners were committed to empirically determining success in meeting project objectives. Their commitment was reflected by the assignment of research scientists to the Evaluation Working Group. These scientists ensured that the TravTek evaluation would pose the correct research questions, provide for responsive sampling, and participate in system design decisions.

Members of the Evaluation Working Group participated in the design of the TravTek system to ensure data collection elements would support evaluation of system performance. Each major subsystem, the Traffic Management Center, the TravTek Vehicles, and the Traveler Information Services Center, collected performance measures solely to support evaluation. The design-for-evaluation philosophy also resulted in the design of an automobile that, with a few button pushes, could be activated into one of three configurations: the Navigation Plus, Navigation, and Services configurations described in preceding sections of this document.

The three different vehicle configurations enabled a highly controlled methodology for quantitatively evaluating the merits of alternative features. Until TravTek, the measurement of the value of such alternative ITS configurations in an operational test setting had not been attempted. The implementation of alternative designs within a single test was a precedent setting accomplishment. The Services configuration provided a scientifically sound control group against which the benefits of TravTek's navigation and route guidance components could be assessed. The incremental addition of traffic information to the Navigation Plus configuration enabled the scientifically valid parsing of contributions of real-time traffic information separate from navigation and route guidance components.

TravTek generated a vast amount of data. What separates TravTek from operational tests that are not so thoroughly designed with evaluation in mind, is that the TravTek data have been successfully transformed to quantifiable benefits, and hypothesized benefits have been scientifically tested and validated.

Recruitment of Test Subjects was Resource Intensive

For all of the TravTek evaluation studies, the resources required to recruit drivers were consistently underestimated. Each study had certain sampling requirements that presented unique problems

Obtaining sufficient volunteers in targeted demographic groups, such as elderly, female, and younger drivers presented challenges. Recruitment for night tests was more difficult than for day tests, especially with regard to older and female drivers. The addition of a female recruiter was found to help in recruitment of female drivers.

Because of the difficulty in recruiting females and older drivers, it is likely that the females and older drivers that were recruited were not as representative of the larger driving population as were the middle aged males who were not as difficult to recruit. For instance, older drivers who volunteered to be tested at night might be hypothesized to be willing to do so because they experience fewer visual difficulties than peers who are only willing to drive during the day. In small studies, it may be possible to carefully screen participants to mitigate such "self selection" confounds. However it is likely that future large operational tests will face similar recruitment dilemmas.

For the Rental User Study, recruitment of equal numbers of participants into the Services, Navigation, and Navigation Plus configurations was problematic. Publicity and recruitment materials featured Navigation and Navigation Plus capabilities of the system. This resulted in drivers recruited into the Services configuration expressing disappointment and even anger. As the recruits were also AAA and Avis customers, it was necessary for good customer relations to switch these users to one of the navigation configurations. This problem was not just a matter of logistics: a necessary assumption to the treatment of Services as a control group was that drivers in the three configurations were sampled, more or less randomly, from the same population. By allowing drivers to, in effect, choose their configuration, some of the advantage of the Services configuration as a control group may have been lost, as it is possible that drivers who requested navigation capabilities were different from those who did not.

The recruitment problem might be partially ameliorated by more careful recruitment efforts to ensure participants are not biased by recruiting strategies. Rental users offset project costs by paying for the rentals. TravTek features were publicized to induce users to rent the vehicles. Had the vehicles been offered for free, or at substantially greater discounts, then TravTek features could have been introduced as incidental features, and the need to publicize TravTek reduced. Future ITS operational tests should be cognizant of the conflict between partner desires for public visibility for their contributions against the need for an objective evaluation, They should also carefully consider the impacts of recruitment publicity on the attainment of evaluation objectives.

Recruiting young people was also problematic. Because rental vehicles were used for all evaluation studies except the Camera Car Study, drivers under the age of 25 were excluded from participating in most studies. This was because of insurance-based car rental restrictions against drivers under 25. Operational tests that seek to use rental fleets will need to deal with this restriction if they are interested in including younger drivers.

Although the TravTek evaluation was largely successful, efficient and unbiased recruitment of ITS participants remains a formidable challenge.

Test Subjects Did Not Make Their Privacy an Issue

TravTek vehicles, including Services vehicles, served as traffic probes. Once each minute they reported their locations and their travel times across any TravTek traffic network links they may have traversed. In addition, the vehicles identified themselves to support the evaluation and to make it possible for the help desk to provide assistance. The help desk also maintained personal information about rental drivers. All records of users' travel were, of course, kept confidential and were not available to the public. Operational test personnel access to user data were also carefully limited and controlled. However, prior to the beginning of the test, it was uncertain how the public would react to having an instrumented vehicle that informed others of its whereabouts. The TravTek partners were committed to the practice of "informed consent" as an ethical requirement for use of humans in research. All volunteers participating in TravTek studies were required to read and sign a statement that described the TravTek system and potential risks associated with participation in the studies. The consent form clearly stated the vehicle tracking capability of the system. No recruit raised privacy as an issue or expressed concern about it. No driver withdrew from participation as a result of the informed consent procedure.

Partners in future ITS operational field tests should be aware of their responsibilities for ethical treatment of participants and provide volunteers with an informed consent form. The TravTek experience suggests that if proper safeguards on personal information are maintained, the public will regard necessary privacy risks as acceptable.

Measuring the Impact of TravTek on Safety was Challenging

Opposing hypotheses about the safety of in-vehicle routing and navigation systems are clear:

- Such systems are beneficial because they route drivers around congestion and delay-causing incidents and keep drivers from being lost and confused about their locations.
- Such systems distract drivers' attention from the road for such a long time that they lead to unsafe driving.[12]

The TravTek Safety Study made great strides in defining a foundation for exploring these hypotheses and the relationships between Intelligent Transportation Systems technologies and safety. Effectively integrating results from multiple separate studies presented a challenge. The heart of this challenge was development of a methodology for combining disparate data that were purported to reflect safety. Such data included: crashes per million vehicle kilometers; number of observed close calls; self-reported close calls; observed abrupt stops; observed safety-related errors; lane deviations; longitudinal acceleration maneuvers; eye glances to the display that were greater than 2.5 seconds; and, subjective estimates of workload.

There were several challenges to meaningful interpretation of the data. One challenge was that the expected number of accidents was small because of the relatively small number of kilometers logged. Another problem was that there were no directly comparable baseline data against which safety data obtained from TravTek could be compared. Among the challenges to accident involvement analysis:

- The Toronado was not part of the regular rental fleet.
- Rental agencies did not separate accident damage from other types of damage (e.g., hail).
- Many accidents in the general population go unreported, whereas operational test vehicle damage was nearly always detected.

Although near miss and “unsafe” driving behaviors were observed in the camera car, no definitive linkage between these measures and accidents could be made.

The Safety Study approach to meeting the challenges was to convert various measures taken from the different studies into a common metric based upon risk. The conversion, or data fusion process, provided a methodology by which to explicitly combine the multiple safety-related measures. The methodology supported the conduct of modeling studies and served to provide a framework for designing future safety evaluations of ITS. Those performing safety evaluations of other intelligent transportation systems may capitalize on the analytical and empirical work that is presented in the Safety Study report. After critically reviewing that report, they may desire to refine, expand, test, and, or validate this approach.

Resources Required for Processing, Checking, and Archiving TravTek Evaluation Data were Underestimated

TravTek data sources included the following: Traveler Information Services Center, Traffic Management Center, in-vehicle logs, Freeway Management Center, questionnaires, debriefings, specialized video, and other data sources in the camera car.

Although automated evaluation data collection was built into the TravTek system, and this was a key asset, the data collection mechanism was not perfect. Early estimates by the system designers lead to the projection that 5 gigabytes of electronically coded data would be amassed at the end of operations. This estimate was far exceeded, as more than 50 gigabytes of data were archived by the end of the study.

There were two shortcomings in the data collection effort:

- Data flows were not optimized.
- Not all data required by the evaluation team were logged.

Both short comings, though perhaps inevitable in large projects, could have been diminished by earlier and greater involvement of the evaluation team in specifying data requirements. Whereas the partners gave the utmost attention to designing the system for evaluation, the contents of the data bases were largely finalized early in the design process. One oversight in data storage resulted when the original TMC software design did not call for storage of travel time estimates that were broadcast to the vehicles. This oversight made it difficult to evaluate the data fusion algorithm used to determine link travel times. The software was eventually revised so that data from all sources were stored during the last 3 months of operations.

Although designers did not fall into the trap of collecting more data than can be used, the flow of data from system logs to the evaluator was not optimized, nor validated, before operations began. As a result, data that were scheduled to be delivered to study leaders were periodically delayed or interrupted while processing and validation methods were modified. Through data base design, the 50 gigabytes of data delivered were reduced to less than half that amount without a loss of information. Overall costs could have been reduced and data processing speeded, had more resources been devoted to data management planning during the system design and project evaluation planning phases.

Integrated Data Base Design was Valuable

The data base collection capability that was built into each TravTek system component was coordinated such that vehicles and users had the same identification number in each data base. This not only enabled analysis of users and vehicles from multiple perspectives, but also facilitated data validation and verification. Coordination of data base design among the system developers was a valuable asset to the evaluation of TravTek.

GENERAL BECOMMENDATIONS BASED ON TBAVTEK EVALUATION LESSONS LEARNED

A major reason for the success of the TravTek evaluation was the emphasis placed on planning and front-end design for evaluation. By explicitly defining the goals and objectives of the TravTek program and committing to measuring how well these goals were achieved, the partners could literally focus on success. Because TravTek was such a success, the recommendations presented in this report arise primarily from positive experiences and lead to three general recommendations regarding the management of ITS operational field tests.

Select sufficient and good leadership. Sufficient leadership includes the identification of not just a program manager, but also leaders of technical and evaluation efforts as well as an onsite system manager in charge of 24-hour operations of the operational phase. Good leaders will seriously consider the lessons learned by others and capitalize upon them. They will help the individual partners focus on group objectives and will foster a cooperative, team approach toward obtaining them.

Include evaluation considerations from the beginning of system design. Following the TravTek model, it is imperative that system designers and builders share a vision of what will make their system a success. A role of evaluation is to force the design team to think in terms of measurable success criteria. This fosters communication and frames the design vision within the context of standard measures that are understood by all involved. As the design is refined, so should be the evaluation criteria — and sometimes, as the evaluation is refined, so should be the system design. The selection of success criteria should include consideration of partner objectives, but also of the needs of the ITS community for knowledge necessary to successful deployment.

Always consider cost, schedule, and performance as the key interactive determinants of system success. Some of the recommendations identified in the preceding section were associated with underestimation of required resources. Underestimating required resources will either cause schedules to slip or failure to achieve performance objectives. Underestimating the amount of time tasks must take will require either more funds or sacrifice of system performance. By and large, the TravTek partners specified performance goals that were aligned with their resources, and they were successful because of this. If performance goals are not aligned with available resources, goals will not be met and funding will be wasted.

With complex partnership arrangements becoming common, planning and coordination of activities present many challenges. Operational field test managers and the management of sponsoring partners need to recognize from the beginning of a project that some delays are inevitable and that additional demands will be placed on project resources. Schedule and resources should therefore be planned with these contingencies in mind.

CONCLUSIONS

Overall, the TravTek operational test was a success. All of the goals and objectives that the partners identified were addressed. Furthermore, in most cases the system was found to perform at or above expectations.

The system saved users time. The system helped users avoid congestion, and modeling projected that deployment would reduce congestion for all network users, whether or not those users were equipped with a TravTek-like system.

Drivers demonstrated in words and behavior that they would use a TravTek-like system. A great deal of information was learned about the display alternatives available in the vehicle and recommendations for implementation were derived. The Voice Guide was a great success:' as a supplement to the visual displays, it was found to improve driver performance; it was used on the vast majority of trips for which route guidance was used by visitors, and for about 60 percent of route guidance trips by local residents. Users perceived that the Voice Guide helped them drive more safely. The turn-by-turn Guidance Display succeeded in reducing demands on drivers' visual attention, as compared to the moving map (Route Map) display, and the Guidance Display was the most used visual display. The Route Map also received considerable use, by local users.

The TravTek system was safe. The human factors effort that went into the design of the driver interface appears to have paid off. Design features that were of particular benefit to system safety were: the turn-by-turn Guidance Display that presented only necessary information in an easy to use format; the synthesized speech Voice Guide that minimized the need for the driver to consult the visual displays; and the restrictions on features that could be used while the vehicle was in motion.

Modeling suggested that non-users will experience substantial benefits if TravTek-like systems reach even modest, 10 to 30 percent, levels of market penetration. Projected benefits include travel time savings, fuel savings, reduced congestion, shorter travel distances, and reduced emissions.

Participants who used the system said they would pay for the TravTek system if it were available. Median estimates of willingness-to-pay for a TravTek-like system in a new car were about $1000.

The success of the TravTek Operational Test has wide implications for ATIS and ATMS. TravTek has shown that such systems can be deployed safely, that they have measurable benefits, and that there is a demand for them. TravTek has shown that drivers want in-vehicle navigation and route planning systems, and the data bases associated with these systems. It showed that with improvements to traffic information infrastructure, in-vehicle route guidance systems have the potential to measurably improve traffic network performance, in part because drivers will use such systems.

REFERENCES

1. Blumentritt, C., Balke, K., Seymour, E., and Sanchez, R. (1995). *TravTekSystem Architecture Evaluation.* FHWA-RD-94-14 1. July, 1995. Federal Highway Administration, Washington, DC.

2. Sumner, R. (199 1). Data fusion in Pathfinder and TravTek. *Vehicle Navigation & Information Systems Conference Proceedings,* Dearborn, MI, 71-75.

3. Sumner, R. (1993). The TravTek System. Unpublished FHWA report.

4. Inman, V. W., Fleischman, R. N., Sanchez, R. R., Porter, C. L., Thelen, L. A., and Golembiewski, *G.* (1996). *TravTek Evaluation Rental and Local User Study.* FHWA-RD-96-028. March, 1996. Federal Highway Administration, Washington, DC.

5. Inman, V. W., Sanchez, R. R., Porter, C. L., and Bernstein, L. *S. (1995). TravTek Evaluation Yoked Driver Study.* FHWA-RD-94- 13 9. October, 1995. Federal Highway Administration, Washington, DC.

6. Inman, V. W., Sanchez, R.R., Bernstein, L. *S.* and Porter, *C.* L. (1995). *Orlando Test Network Study.* FHWA-RD-95-162. January, 1996. Federal Highway Administration, Washington, DC.

7. Dingus, T. A., McGehee, D., Hulse, M. C., Jahns, S., Manakkal, N., Mollenhauer, M., and Fleischman, R. N. (1995). *TravTek Evaluation Task C3 Camera Car Study.* FHWA-RD-94-076. June, 1995. Federal Highway Administration, Washington, DC.

8. VanAerde, M. and Rahka, H. (1995). *TravTek Evaluation Modeling Study.* FHWA-RD-95-090. March, 1996. Federal Highway Administration, Washington, DC.

9. Perez, W.A., VanAerde, M., Rakha, H., and Robinson, M. (1995). *TravTek Evaluation Safety Study.* FHWA-RD-95-188. February, 1996. Federal Highway Administration, Washington, DC.

10. Rillings, J. H., and Lewis, J. W. (1991). TravTek. *Vehicle Navigation & Information Systems Conference Proceedings,* Dearborn, MI, 729-825.

11. Fleischman, R. N. (1991). Research and Evaluation Plans for the TravTek IVHS Operational Field Test. *Vehicle Navigation & Information Systems Conference Proceedings,* Dearborn, MI, 827-837.

12. Burgett, A. L. (199 1). Safety evaluation of TravTek. *Vehicle Navigation & Information Systems Conference Proceedings,* Dearborn, MI, 8 19-825.

13 Fleischman, R. N., Carpenter, J. T., Dingus, T. A. (1991). Human factors in the TravTek demonstration IVHS project. *Proceedings of the Human Factors Society 35th Annual Meeting. San* Francisco, CA, 1115-l 119.

14. Means, L. G , Fleischman, R. N., Carpenter, J. T., Szczublewski, F. E., Dingus, T. A., and Krage, M. K. (1993). Design of TravTek auditory interface. *Transportation Research Record,* 1403, 1-6.

15. Carpenter, J. T., Fleischman, R. N., Dingus, T. A., Szczublewski, F. E. Krage, M. K., and Means, L. G. (1991). Human factors engineering the TravTek Driver Interface. *In Conference Record of Papers at the 2nd Vehicle Navigation and Information Systems (VNlS '91) Conference,* Dearborn, Michigan, 749-75 5.

16. Taylor, K. B. (1991). TravTek — Information and Services Center. In *Conference Record of Papers at the 2nd Vehicle Navigation and Information Systems (VNIS ' 91) Conference,* Dearborn, Michigan, 763-774.

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