Global Positioning Systems
for
Personal Travel Surveys

Lexington Area Travel Data Collection Test

FINAL REPORT

A report to

Office of Highway Information Management (HPM-40)
Office of Technology Application (HTA-1)

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by

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Executive Summary

Personal travel and how it changes is of continuing concern to transportation planners and policy makers. Transportation professionals and other users of the collected data surmise that people likely omit very short trips, like stopping at the post office or video store, using self-reported methods. Also, some data of interest such as route choice and travel by highway functional class are not accessible using traditional travel survey methods.

This research idea originated within the Office of Highway Information Management and the field test was further supported by the Office of Technology Application, both offices of the Federal Highway Administration. The plan focused on an automated data collection device that incorporated self-reported information and Global Positioning System (GPS) information for the collection of personal travel data. This device offers a more robust data source for defining personal travel than current methods, which rely on telephone interviews and daily travel diaries.

The Lexington Area Metropolitan Planning Organization, the principal planning agency for a two-county area in central Kentucky, volunteered to participate by hosting the field test. Fayette and Jessamine counties encompass an area of approximately 461 square miles with a total population of approximately 350,000. A presolicitation letter from the Lexington MPO, with an enclosed copy of an article from the local newspaper describing the study, was sent to approximately 1,300 households with listed telephone numbers. Once the telephone interviewers determined that there was an eligible driver in the household, 67% of those eligible consented to participate in the field test.

The sample comprised 100 households. The average household size was 2.94 persons, with an average of 2.17 vehicles. There were 216 licensed drivers (100 male, 116 female) in the households with ages ranging from 16 to 77 years. The average estimate of annual miles driven was 13,118 per respondent. This average is believed to be higher than a typical average for the area because the sample selection process excluded individuals that drove less than 3 days per week.

This research project configured the automatic data collection device and deployed the devices in the Lexington MPO planning area to record information about the personal travel behavior of the 100 respondents. In addition, these respondents participated in a post-usage interview that mimicked the recall interview of the National Personal Transportation Survey (NPTS) and explored their attitudes about learning and using the automatic data collection device.

The field test equipment successfully captured both the GPS data and self-reported information from approximately 85% of the respondents. The respondents were eager to use the new technology, found it easy to install in their vehicle and use, and expressed a preference for the automatic data collection device over more traditional methods. Respondents had only a few concerns over the using the device, mostly related to the security of the vehicle while the device was installed, and expressed a willingness to use the device again for similar purposes.

The recall survey in Lexington captured mostly private vehicle driver trips (91.5%), and some walk, bike, and trips by other modes. The preponderance of driver trips compared to passenger trips is largely due to the sample selection process and the recall interview procedure. Only drivers who drove at least three days a week were eligible to participate in the survey. Also, in order to compare the recall day with machine-recorded data, the recall day was limited to those days where the selected driver drove the vehicle which had the equipment installed.

The results indicate that the Lexington respondents take more trips of shorter distances than past national estimates would suggest. The GPS data reveal complex route choice decisions and, when combined with Geographic Information System (GIS) street maps, permit summaries of usage by highway functional class. As a measure of respondent burden, approximately 74% of the respondents reported that entering trip information took 1.0 minute or less per trip, and over 95% reported 2 minutes or less.

The data retrieved from the devices provide several insights on personal travel data. Trip start times, in minutes past the hour, and trip distances both show radically different distributions when measured by the data collection device versus recall interviews. These results provide insight to the real distributions of personal travel start times and trip distances, which vary substantially from the distributions based on recall interviews.

Matching recall trips to machine-recorded trips for trip-to-trip comparison is a difficult task due to a number of factors. Variations in travel start times, durations, distances, and destination addresses between machine-recorded data and recall data all serve to confound the process. The methodology employed here matched approximately 61% of the recall trips with machine-recorded trips. Overall, the data suggest that the number of machine-recorded trips exceeds the number of recall trips; that is, the recall data likely underestimate the total number of trips. Trip-to-trip comparison of recall and machine-recorded data shows that the recall estimates generally overstate both travel time and travel distance as compared to the travel measurements recorded by the data collection device.

This was a successful “proof of concept” project. Already, other projects in the field, and in the planning stages, have built on this project’s experience. In particular, use of GPS with hand-held computers is gaining much wider acceptance in the field.

Using GPS technology with small hand-held computers to collect personal travel data is a functional reality and has significant potential for future application in travel surveys. Advances in both the hardware and software are expected to improve these capabilities and make them available to more users as implementation costs decline. Smaller and even more lightweight units with extended battery operating capabilities would also make it possible to use this technology to capture non-vehicle trips.

Acknowledgments

The successful conclusion of this project is a direct result of the active and enthusiastic support of the field test by Mr. Robert Kennedy, Manager of the Lexington Area MPO, Mr. Marc Guindon, who managed the field operations for the MPO, the entire MPO staff, and of course, the cooperation and active participation of the citizens of Fayette and Jessamine counties, Kentucky.

User interface software development was performed by FASTLINE, Inc. Key elements of GPS and GIS post-processing and data analysis performed by TransCore (formerly JHK & Associates). Cambridge Systematics, Inc. and Etak, Inc. participated in research planning and the early phases of this research program.

Battelle Memorial Institute was the prime contractor for the program and managed the hardware and software development and executed the field test and subsequent analyses. This program involved Battelle staff in Columbus, Ohio and Baltimore, Maryland.

This research program was sponsored by the Office of Highway Information Management and the Office of Technology Application, Federal Highway Administration, U.S. Department of Transportation.

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Acronyms

ASCII	A standardized code for character representation in computer storage and transmission.
ATM	Automatic Teller Machine
CASI	Computer Aided Self Interview
DGPS	Differential Global Positioning System
FHWA	Federal Highway Administration
GIS	Geographic Information System
GPS	Global Positioning System
MPH	Miles Per Hour
MPO	Metropolitan Planning Organization
NMEA	National Marine Electronics Association
NPTS	Nationwide Personal Travel Survey
OEM	Original Equipment Manufacturer
PC	Personal Computer
PCMCIA	Personal Computer Memory Card International Association
PDA	Personal Digital Assistant
PMT	Person Miles of Travel
PTS	Personal Travel Survey
RTCM	Radio Technical Commission for Maritime Services
SA	Selective Availability
SRAM	Static Random Access Memory
TIGER	Topologically Integrated Geographic Encoding and Referencing data base
UTC	Coordinated Universal Time
VMT	Vehicle Miles of Travel

Global Positioning Systems for Personal Travel Surveys
Lexington Area Travel Data Collection Test

1. Introduction

This report describes the development and field test of an automated data collection device that includes Global Positioning System (GPS) technology for the collection of personal travel data. The development and field test are the result of the efforts of two Federal Highway Administration offices. The idea originated within the Office of Highway Information Management and the field test was further supported by the Office of Technology Application. The resulting travel survey methodology offers a more robust data source for defining personal travel than current methods, which rely on telephone interviews and daily travel diaries. While this technology is not expected to supplant current data collection methods, this proof-of-concept development, field test, and subsequent analysis of collected data demonstrate that this approach has merit with respect to more clearly defining personal travel behavior.

1.1 Background

Personal travel and how it changes is of continuing concern to transportation planners and policy makers. Information about daily travel patterns and trip purposes, time of day decisions, mode choice decisions, and trip chaining decisions are generally captured using self-reported information using a telephone recall method, or some kind of diary.

Transportation professionals and other users of the collected data surmise that people likely omit very short trips using self-reported methods. The current trend in collecting this type of data is to use an activity, rather than a travel diary, to attempt to both capture these short trips as well as to identify at-home activities that are substituting for traditional at-work activities. Nonetheless, self-reporting is used for this as well. Other problems with self-reporting include the tendency to round travel times to 10, 15 and 30 minute intervals. Similar tendencies to round may be occurring in reporting trip distances as well. It may be that overall, VMT reporting is fairly complete using self-reporting methods, but that people neglect to report the short stops made during a journey, like stopping at the post office, ATM, or video store.

This project configured an automatic data collection device that collected self-reported information along with automatically recording GPS position information. These devices were deployed for a field test in Lexington, Kentucky, to record information about the personal travel behavior of a group of 100 volunteer respondents . In addition, the respondents participated in a post-usage interview that mimicked the recall interview of the National Personal Transportation Survey (NPTS) and explored their attitudes about learning and using the automatic data collection device. This report describes the equipment and activities associated with the Lexington Area Travel Data Collection Test and the data that were retrieved during the field test.

1.2 Objectives

The objectives of the research program were stated as follows.

1. Develop a method and hardware to integrate GPS technology with self-reported travel behavior to improve travel behavior data.

2. Document the differences between self-reported travel and GPS recorded travel and document the pros and cons of each method.

3. Determine the potential for using GPS technology with regional and national travel behavior surveys, with particular regard to subjective responses to privacy.

1.3 Project Organization

The research project was conducted in three phases.

- **Phase One** investigated available, "off-the-shelf" GPS hardware and technology, Personal Digital Assistants (PDAs) or other "palm top" computers, and other equipment that could be used for personal travel behavior surveys.

- **Phase Two** tested and evaluated several GPS units' ability to capture travel information in rural, suburban, and urban settings, as well as ease-of-use, battery life, satellite collection characteristics and other features of the devices.

- **Phase Three** acquired several "hand-held" units and configured them into self-contained data collection devices for recording personal travel information. A field test including 100 households was conducted in Lexington, Kentucky, with the cooperation of the Lexington Area Metropolitan Planning Organization.

1.4 Organization of this Report

Section 2 provides an overview description of the field test data collection device configured for the Lexington Area Travel Data Collection Test. This discussion includes both the hardware specifics and the software interface.

Section 3 describes the activities associated with the field test, including preparations, recruiting household respondents, interactions with the households, data collection device placement and retrieval, data retrieval, post-usage surveys, and database compilation. The characteristics and demographics of the 100 households that volunteered to participate in the field test are also included.

Section 4 recounts statistics on equipment performance and hardware and/or software problems experienced during the field test.

Section 5 presents the personal travel data that were collected during the field test. The presentation includes daily household travel statistics, overall travel time and distance information, and general comparisons of the recall interview data with NPTS results. Specific trip-to-trip comparisons between the Lexington recall and the machine-recorded data are discussed.

Section 6 focuses on the GPS data that were collected during the field test, the base map files that were used in the analyses, and the map-matching process that integrates the GPS data with the GIS environment.

Section 7 summarizes the respondent attitude data that were collected at the end of each household's participation in the field test. These data address the installation of the data collection equipment, use of the data collection equipment, and general concerns and issues about the data collection process.

Section 8 provides a brief summary of the findings of the field test and overall conclusions from this research project.

Appendix A recounts the activities in Phase One and Phase Two of the research project by presenting a technical paper that was prepared for the National Traffic Data Acquisition Conference held May 5 - 9, 1996.

Appendix B contains copies of the questionnaires that were used during the general recruitment of households and interviews of respondent households after completion of their participation.

Appendix C is a copy of the installation/operating instructions that were prepared for the data collection device and provided to each respondent household in addition to an instructional video tape.

Appendix D contains several items from the correspondence with the respondents, including the presolicitation letter, newspaper article, informed consent papers, and thank you letters for the respondents.

2. Field Test Data Collection Equipment

This section provides an overview description of the field test data collection device configured for the Lexington Area Travel Data Collection Test.

2.1 General Description

Figure 2.1 is an illustration of the configured field test data collection device. The data collection device was envisioned and configured as a "plug-and-play" concept that required minimal effort to install in the household vehicle. The completed unit consisted of the following individual items.

Figure 2.1. Lexington Field Test Equipment

- Hand-held computer - The hand-held computer is a Sony® MagicLink PIC-2000 personal digital assistant, with a backlit touch screen user interface.

- GPS receiver - The GPS receiver is a Garmin® TracPak-30 that is equipped with a magnetic roof mount or a suction cup device for mounting inside the windshield.

- PTS software - User interface software that identifies household drivers, passengers, and trip purposes for each household, and controls the recording of GPS data. (not visible in Figure 2.1)

- SRAM PCMCIA card - A memory card containing the PTS application software and up to 2 megabytes of memory for data collection. (not visible in Figure 2.1)

- Connecting cable - Power cable that plugs into the vehicle's accessory port (cigarette lighter) to provide power for the GPS receiver and hand-held computer, and fuse protection for these components, and serial cable that enabled communications between the GPS receiver and PTS software via the hand-held computer.

These assembled components were contained in individual canvas carrying bags during their use in the field test. Table 2.1 provides a complete equipment list for the data collection devices in the field test.

2.2 PTS Hardware Description

Tables 2.2 and 2.3 provide more detailed specifications for the Sony® hand-held device and the Garmin® GPS receiver.

2.3 PTS Software Description

The Personal Travel Survey (PTS) software developed for this field test has two principal functions: (1) allow the respondents to easily enter information about vehicle occupancy and trip purpose, and (2) capture positional data from the GPS receiver associated with each respondent-initiated trip. Since the respondents would receive little training in how to use the device, the operating approach to the software interface was intended to mimic Automatic Teller Machine (ATM) operation. That is, once started, the software would lead the respondent to the next logical section in the questionnaire. All the respondent had to do was touch a “Continue” command and the subsequent questionnaire screen would appear. When all questions were answered, the software signaled the respondent that the trip was being recorded and the data input was complete.

The three operating portions of the software were (1) the administrative interface, (2) the GPS interface, and (3) the respondent interface.

2.3.1 The Administrative Interface

The administrative interface consists of two screens that allow the field test administrator to set the operational parameters of the data collection device and personalize the respondent interface for each respondent. This interface is not accessible by the household users. The administrative interface contains two screens, the password screen and the operational parameters screen, shown in Figures 2.2 and 2.3.

The password screen (Figure 2.2) simply provides protected access to the operational parameters screen. The password is input through the numeric keypad on the right-hand side of the screen. (Note:

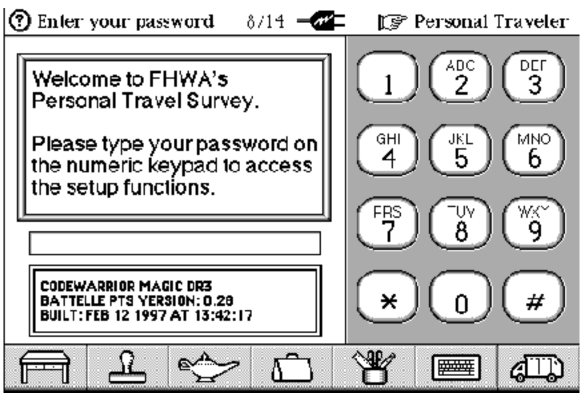


Figure 2.2 The Password Screen.

Table 2.1 GPS Personal Travel Survey Equipment List

<u>Travel Data Collection Equipment</u>

- Garmin GPS 30 TracPak PC GPS Receiver
  - Magnetic Mount

- Sony MagicLink PIC-2000 PDA
  - General Magic MagicCap version 1.5 operating system
  - Stylus
  - Lithium ion rechargeable main battery
  - Lithium backup battery
  - Protective Case
- 2.0MB PCMCIA Type II SRAM memory card
- Battelle PTS version 0.25 software
- Wrapped Connecting Cable
  - Power Cable - services PDA and GPS receiver via vehicle cigarette lighter/accessory port
  - Serial Communications Cable - enables PDA and GPS to communicate
- GPS/PTS burlap field pouch

<u>Operating Instructions</u>

- Lexington Area Travel Data Collection Test 12 minute video
- Installation and Operating Instructions

<u>Shipping Goods</u>

- Cardboard shipping box fitted with styrofoam padding
- Envelope marked with Return Date
- Return Instructions
- Return Shipping Label
- Explanatory cover letter

<u>PTS Software Developer</u>

FASTLINE, Inc.

Table 2.2 Sony MagicLink PIC-2000 Specifications

Features
- Relatively low-cost ($699)
- Off-the-shelf
- Touch (pressure-sensitive) screen interface
- Backlighting on interface
- Employs sophisticated power-management scheme
- Supports serial communications
- Based on an intuitive operating system

Performance
Processor - MC68349, 16 MHZ clock (3.3V operation)
ROM Memory - 4MB (runs system and application software)
RAM Memory - 2MB, battery backed-up
Operating System - MagicCap v1.5 (General Magic)

Physical Features
Weight - 1.3 lbs.
Size - 1.0”h x 5.2”l x 7.5”w
Op. Temp. - 0 to +50 deg C

LCD and Touch Screen
Screen Size - 3.2”h x 4.7”w
Resolution - 480 x 320
Dot Pitch - 100 dpi
Backlighting - ON/OFF switch
Contrast - manual

Power Requirements
Power Consumption - 4.8 Watts DC (max)
Power Requirement - 7.2 Vdc via lithium ion rechargeable main battery (or accessory port)
Rechargeable Main Battery Life - 6 hrs with back-lighting on and in normal operations
(1350mAh capacity) - 10 hrs with back-lighting off and in normal operations
- 15 hrs when idle
Backup Battery - On-board 3 volt lithium battery -- 7 months without main battery

Interfaces
Communications - 14-pin slide-type Magic Port multi-purpose serial bus connector
Baud Rate - 14,400 baud
Memory Card Slot - 2 PCMCIA Type II slots

Table 2.3 Garmin GPS30 TracPak PC Specifications

Features

- Relatively low-cost (<$250), high-output
- Plug ‘n play
- Tracks and uses up to 8 satellites for accurate, reliable GPS data collection
- Relatively low power requirement
- Combines a GPS engine and antenna in an all-weather, low profile housing that can be mounted in a variety of ways for in-vehicle applications
- Terminated for in-vehicle field use
- Does not require input to initialize or navigate
- Differentially correctable

Performance

Satellite Tracking - 8 channel (MultiTrac 8 engine)
Horizontal Position Accuracy - 15m (49ft) no SA, <10m (33ft) dgps, 100m (328ft) SA
Time-to-First-Fix -

<2 sec reacquisition
20 sec warm
2 min cold
7 min automated locating
15 min sky search

Physical Features

Type - Integrated Engine/Antenna
Description - Waterproof Enclosure
Weight - 7.2 oz. (TracPak), 1.1 oz. (OEM)
Size - 1.04”h x 3.80”l x 2.23”w (TracPak), .45”h x 2.75”l x 1.83”w (OEM)
Op. Temp. - -30 to +85 deg C

Power Requirements

Power - 10-30 Vdc via terminated cigarette lighter/accessory port adapter (1.2 Watts OEM)
Backup - On-board 3 volt lithium battery -- 10 year life

Interfaces

Communications - 9-pin Serial Port (part of terminated cable)
Baud Rate - 1200 to 9600 baud, user-adjustable
Update Rate - 1 PPS (Hz) +/- 1 microsecond continuous
Output - NMEA 0183 v2.0, ASCII
Input - Not required, but accepts position, date, time, and datum
Memory - Non-volatile
DGPS - RTCM SC-104

the icons across the bottom of the screen are components of the MagicLink operating system and are not relevant to the PTS software.) The operational parameters screen (Figure 2.3) allows the following activities, each with its own icon area on the screen.

Set Device Owner - The “Set Device Owner” icon allows the user to record ownership information on an internal, electronic “note card”.

Set Date & Time - The “Set Date & Time” icon allows the user to set the proper date and time in the device memory. An option is also available to automatically adjust the time for the change from standard time to daylight savings time.

seconds/sample - The “seconds/sample” icon allows the user to set the rate that GPS data points are recorded to memory. This setting is displayed in the window above the label “seconds/sample”, and the value is changed by touching the plus (+) or minus (-) indicators on each side of the window, and the value can be set between one and ten seconds per sample. This setting does not influence the operation of the GPS receiver, which generates a position record once per second. This setting only controls the frequency that these position records are written to the device memory.

max stopped time - The “max stopped time” icon allows the user to set the time duration before the device automatically shuts off, should the respondent forget to record the end of a trip. This feature is intended to conserve the device’s internal batteries when no change in velocity is observed over the max stopped time interval, as measured by the GPS receiver output. This setting is displayed in the window above the label “max stopped time”, and the value is changed by touching the plus (+) or minus (-) indicators on each side of the window, and the value can be set between one and 30 minutes.

Drivers - The “Drivers” window allows the user to specifically identify the respondents so that the “Choose the Driver” screen (described later) will be personalized for each use. Touching within the window activates a keyboard on the screen, allowing the respondent names to be entered directly. The names will be provided to the respondent interface in the same order as they are entered here. The “Drivers” window is intended to list all licensed drivers within the test household. Only one driver may be selected for a trip.

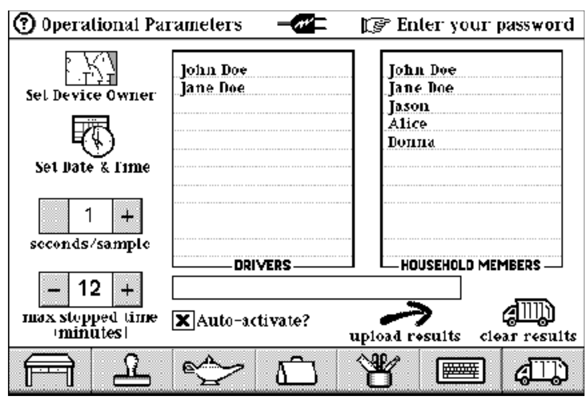


Figure 2.3 The Operational Parameters Screen.

Household Members - The “Household Members” window allows the user to specifically identify the respondents so that the “Choose a Passenger” screen (described later) will be personalized for each use. Its operation is the same as the “Drivers” window above, with the exception that several passengers may be selected for a trip. The “Household Members” window is intended to list all household members that might be passengers in the vehicle, including the potential drivers, regular car pool members, or other who regularly ride in the vehicle.

Auto-activate? - The "Auto-activate?" option allows the user to control when the PTS software is activated. If the option is "on", as indicated by the "X" in the box, the PTS software will load and run automatically anytime the MagicLink is turned on. If the option is "off", the user must activate the PTS software using the MagicLink's normal operating system.

upload results - The "upload results" icon allows the user to transfer recorded data to another device, normally a personal computer. When the proper cabling connections are made and the personal computer is prepared to receive the data stream, a touch on the icon initiates a complete transfer of the stored data. This function does not erase the data from memory.

clear results - The "clear results" icon allows the user to erase, or clear, the data memory in the device before field use. This feature does not erase the software from the memory card.

The elements of this screen constitute the complete control functions of the device allowable through the PTS software.

2.3.2 The GPS Interface

The GPS receiver output data stream in the PTS software is invisible to the respondent, and almost invisible to the test administrator. The long rectangular window located immediately below the "Drivers" window in the Operational Parameters screen (Figure 2.3) is the only visible evidence of GPS receiver operation. During data collection, this window displays raw GPS output as it is being written to memory. Following data collection, this window displays the last output record received from the GPS receiver. This window does not allow any additional user control or interface with the GPS receiver, but simply displays the last record.

2.3.3 The Respondent Interface

This interface was used by the recruited household drivers. The respondent interface consists of five separate screens designed to allow easy input of personal travel information for each trip. The five screens are (1) Start Trip, (2) Choose the Driver, (3) Choose a Passenger, (4) Add Passenger, and (5) End Trip and their functions are described below.

Start Trip - The "Start Trip" screen (Figure 2.4) is the first screen seen by the respondent when the device is turned on or at the beginning of each trip.

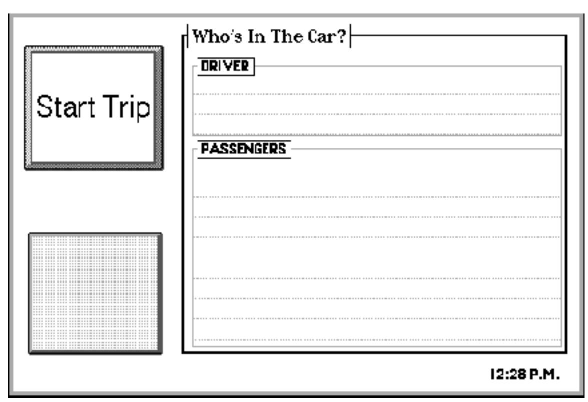


Figure 2.4 The Start Trip Screen.

The only active feature of the screen is the large "start trip" button in the upper left-hand side of the screen. When the respondent is ready to begin a trip, they touch the start trip button to initiate the data entry sequence.

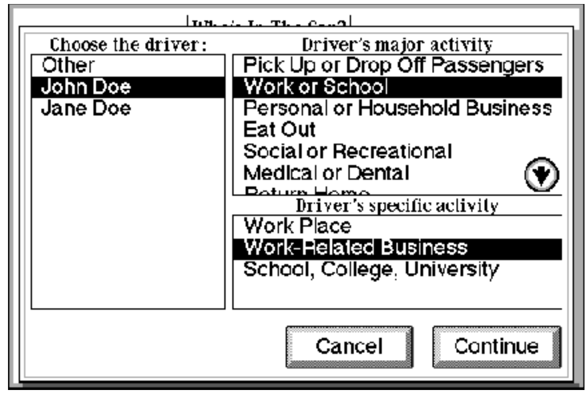


Figure 2.5 The Choose the Driver Screen.

Choose the Driver - The "Choose the Driver" screen (Figure 2.5) is the first data entry screen. On the left-hand side, the candidate drivers names appear as they had been entered in the operational parameters screen. On the right-hand side, the preprogrammed driver trip purposes appear. In some cases, the driver's trip purpose may offer a secondary choice in the bottom right-hand side of the screen, as shown in the figure. Each selection is made by touching the correct entry which will then be highlighted to verify its selection. Once the selections are made, the respondent can record the selections and continue to the next data entry screen by touching the "Continue" button, or cancel the selections and return to the "Start Trip" screen by touching the "Cancel" button.

Choose a Passenger - The "Choose a Passenger" screen (Figure 2.6) is the second data entry screen. On the left-hand side, the candidate passengers names appear as they had been entered in the operational parameters screen, with the exception of the driver selected in the previous screen. On the right-hand side, the preprogrammed passenger trip purposes appear. In some cases, the passenger's trip purpose may offer a secondary choice in the bottom right-hand side of the screen. Only one passenger can be selected at a time on this screen. If there is more than one passenger, the respondent will return to this screen to select the additional passengers. Each selection is made by touching the correct entry which will then be highlighted to verify its selection.

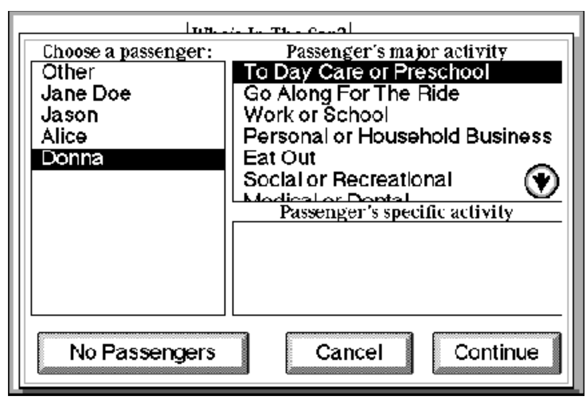


Figure 2.6 The Choose a Passenger Screen.

Once the selections are made, the respondent can record these selections and continue to the next data entry screen by touching the "Continue" button, or cancel the selections and return to the "Start Trip" screen by touching the "Cancel" button. The "No Passengers" button on the lower left-hand side of the screen provides a more direct option when the respondent is driving alone. Touching the "No Passengers" button bypasses the remaining "Add Passenger" screen and goes directly to the "End Trip" screen where data recording takes place.

Add Passenger - The "Add Passenger" screen (Figure 2.7) allows the respondent to confirm the passenger information already provided and to include additional passengers. If more passengers are in the vehicle than are shown in the window, the respondent touches the "Add Passenger" button and is returned to the "Choose a Passenger" screen to provide additional information. If there are no more passengers to be entered, the respondent can continue to the "End Trip" screen by touching the "Continue" button, or cancel the selections and return to the "Start Trip" screen by touching the "Cancel" button.

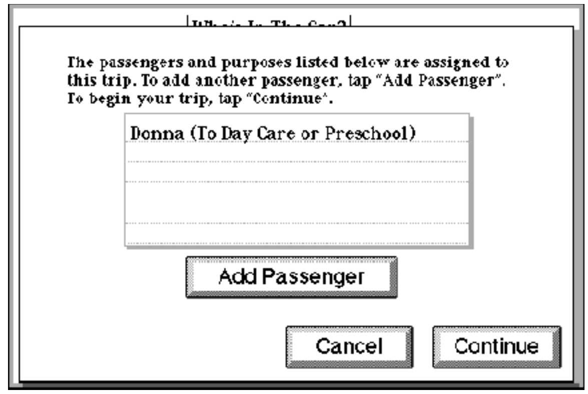


Figure 2.7 The Add Passenger Screen.

End Trip - The "End Trip" screen (Figure 2.8) confirms the information that has been entered by the respondent by displaying the driver and passenger information on the screen. This screen is displayed throughout the data recording phase of the trip. No additional input is needed unless there is an error or a change of plans that cause the information to be incorrect. In those cases, the respondent can touch the "Change" button in the lower right-hand corner of the screen and re-input driver and passenger information without canceling or erasing the basic trip information. At the end of the trip, the respondent touches the large "End Trip" button. This action closes the data file associated with the trip and returns the respondent to the "Start Trip" screen in preparation for a subsequent trip.

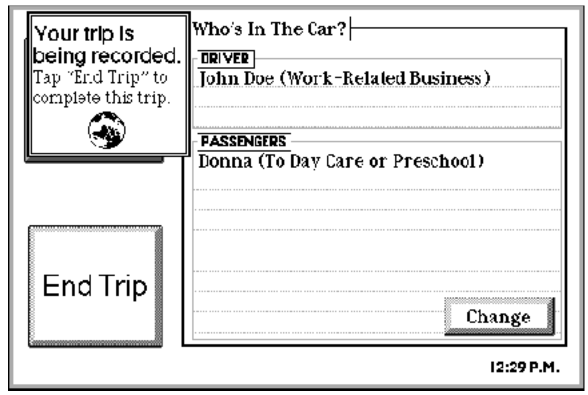


Figure 2.8 The End Trip Screen.

These five interface screens constitute the complete respondent interface in the PTS software.

2.4 Data Collected by the Field Test Equipment

Table 2.4 shows a partial data file from the field test equipment. The data are downloaded from the field equipment in an ASCII text file as shown in the table.

The data download begins with an indication of the beginning of the trip record and then lists the trip start and end times as input by the respondent. These times are recorded from the internal clock of the PDA and the date is automatically appended from the PDA internal calendar. Next, the driver and driver's trip purpose are listed, then the passengers and their trip purposes. If no passengers are on the trip, the field after the "passengers:" designator is blank.

Before listing the position samples, the download includes a statement of the number of samples collected for the trip, and then lists the position sample file. Each sample contains the following information.

Time	Date	Latitude	Longitude	Speed
18:05:38	09/23/1996	3802.2889	8433.1846	4.8 Knots

The time and date recorded in the position sample are obtained from the satellite clock and are given in UTC time. UTC time is four hours ahead of Eastern Daylight Time. The satellite clock and the PDA clock were not synchronized, however the PDA clock was set prior to being sent to each respondent to minimize possible differences. The latitude and longitude in the position sample are interpreted as follows. The first two digits are degrees, the second two digits are minutes, and the information after the decimal point is decimal minutes. The last entry in the position sample is the vehicle speed in knots[1]. Speed for this GPS receiver is calculated as the change in the vehicle position over time as measured by the receiver.

The sample data shown in Table 2.4 illustrate some of the characteristics of the data obtained during the field test. The position sample file begins with a series of "zero"records accompanied by a date of 1904. This record indicates that the GPS receiver is receiving power and is functioning normally but has not yet achieved a valid position fix. Once the position fix is achieved, the position samples contain the expected information. This initial "searching for position" by the receiver is a common occurrence throughout the data.

Another characteristic relates to the time associated with the position samples. An objective was to achieve a one-second sample rate, however the sample recording proceeds with an irregular time interval. This was the result of a communications error in the PTS software and not a function of the GPS receiver. The GPS receiver produced a position fix every second and the recording occurred at irregular intervals. This irregularity caused some complications in the subsequent analysis of the GPS data that is described in later sections of this report. The software communications feature has been repaired in subsequent versions of the software.

[1] 1 knot = 1.15 miles per hour (MPH)

Table 2.4 Sample of the Data Collected by the Field Data Collection Device

--Battelle PTS Trip Database data uploaded: 10-01-96
----begin trip record
start: 14:03:53 09/23/1996
end: 14:16:33 09/23/1996
driver: John Doe (Other Errands)
passenger(s): Donna (Go Along For The Ride), Jason (Go Along For The Ride), Alice (Go Along For The Ride)
Collected 222 samples
------begin position samples

00:00:00 01/01/1904	0000.0000	0000.0000	0.0 Knots
00:00:00 01/01/1904	0000.0000	0000.0000	0.0 Knots
00:00:00 01/01/1904	0000.0000	0000.0000	0.0 Knots
18:05:33 09/23/1996	3802.2951	8433.1813	2.3 Knots
18:05:38 09/23/1996	3802.2889	8433.1846	4.8 Knots
18:05:40 09/23/1996	3802.2906	8433.1841	1.0 Knots
18:05:43 09/23/1996	3802.3029	8433.1810	0.0 Knots
18:05:45 09/23/1996	3802.3012	8433.1804	0.0 Knots
18:05:51 09/23/1996	3802.2995	8433.1807	0.0 Knots

	---- position samples deleted ----		

18:16:29 09/23/1996	3800.9852	8433.0222	0.0 Knots
18:16:35 09/23/1996	3800.9841	8433.0256	10.0 Knots
18:16:36 09/23/1996	3800.9816	8433.0297	14.2 Knots
18:16:45 09/23/1996	3800.9308	8433.1041	27.1 Knots
18:16:52 09/23/1996	3800.9168	8433.1311	13.5 Knots
18:16:57 09/23/1996	3800.9095	8433.1504	21.3 Knots
18:16:58 09/23/1996	3800.9060	8433.1567	22.7 Knots
18:17:02 09/23/1996	3800.8884	8433.1905	30.6 Knots
18:17:03 09/23/1996	3800.8839	8433.1997	30.6 Knots
18:17:04 09/23/1996	3800.8792	8433.2094	31.3 Knots
18:17:09 09/23/1996	3800.8522	8433.2571	31.5 Knots
18:17:13 09/23/1996	3800.8386	8433.2885	27.0 Knots
18:17:14 09/23/1996	3800.8340	8433.2960	27.0 Knots
18:17:16 09/23/1996	3800.8258	8433.3053	14.6 Knots
18:17:20 09/23/1996	3800.8402	8433.3148	10.5 Knots
18:17:24 09/23/1996	3800.8553	8433.3191	10.9 Knots
18:17:25 09/23/1996	3800.8594	8433.3158	10.7 Knots
18:17:31 09/23/1996	3800.8633	8433.3126	2.5 Knots
18:17:39 09/23/1996	3800.8691	8433.3193	4.4 Knots
18:17:40 09/23/1996	3800.8702	8433.3203	3.9 Knots
18:17:42 09/23/1996	3800.8717	8433.3119	1.6 Knots
18:17:43 09/23/1996	3800.8715	8433.3154	2.2 Knots
18:17:44 09/23/1996	3800.8765	8433.3151	0.9 Knots

------end position samples
----end trip record

3. Recruiting and Field Test Operations

The field test was the focus of the proof-of-concept effort and involved the following tasks.

- Selecting a host MPO for the field test
- Recruiting participant households
- Executing field operations

3.1 Selecting a Host MPO for the Field Test

The research plan required the participation of a Metropolitan Planning Organization (MPO) as the focal point of the field operations. The basic requirements for the MPO participation included:

- Availability of an up-to-date, positionally accurate digital map file for the test area, with minimum map accuracy satisfying Federal National Map Accuracy Standards. Additional desirable map features included travel restrictions (such as one way streets), address matching capability, and the ability to distinguish overpasses from street intersections.

- Staff support for the field operations. This staff requirement was estimated at approximately 2.5 to 3 hours per household during the field test. With 100 households, the total expected commitment was approximately 250 to 300 hours.

Candidate MPOs for the field test were identified from two sources. First, in the early phases of this research, several MPOs had expressed interest in the ongoing program and possible participation in the field test. Second, a general solicitation for potential MPO participants was made through FHWA Regional Offices once participation requirements were known. After receiving approximately a dozen expressions of interest, the Lexington Area Metropolitan Planning Organization was selected as the host MPO for the field test.

The Lexington Area Metropolitan Planning Organization is the principal planning agency for a two-county area in central Kentucky. Fayette and Jessamine counties encompass an area of approximately 461 square miles with a total population of approximately 350,000. Figure 3.1 shows the Lexington Area MPO planning area.

The Lexington Area MPO demonstrated great interest and enthusiasm for the field test. At the time of the kick off visit by Battelle staff, the MPO arranged for a newspaper article in the local newspaper to describe the research project and what was expected of Lexington residents as a part of the field test. This newspaper article was later enclosed in the pre-solicitation letter that was sent to potential respondents in the Lexington area, adding local authenticity to the pre-solicitation letter (Appendix D). At the time of the training for MPO staff just prior to

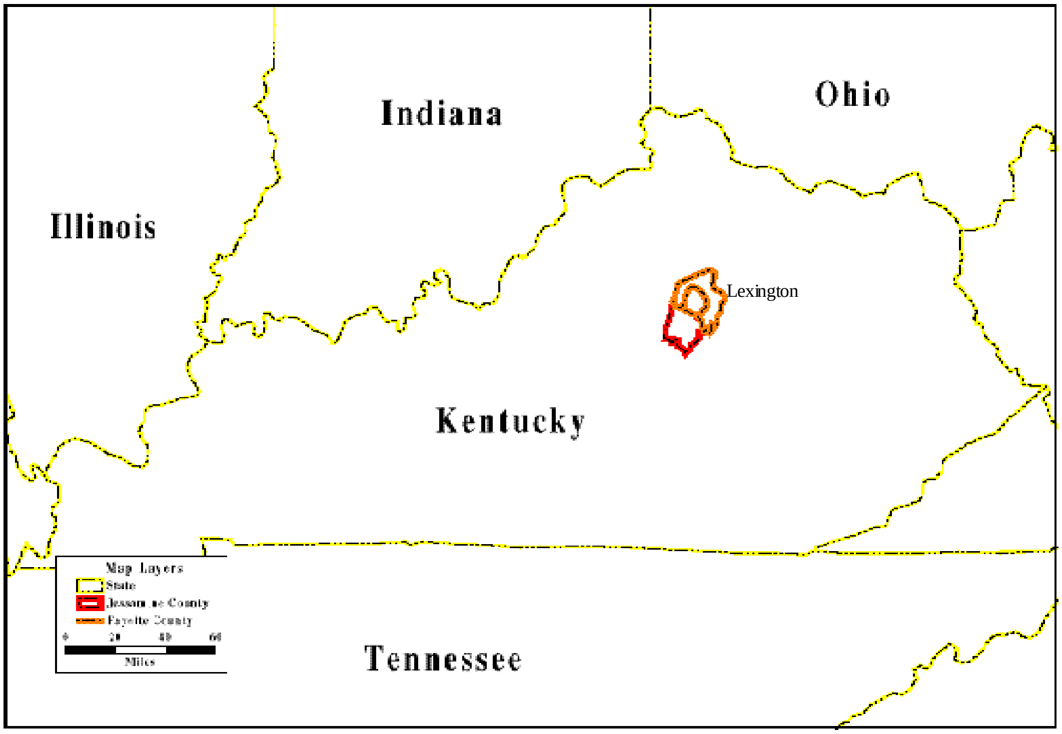


Figure 3.1 The Lexington Area MPO Planning Area in Central Kentucky.

deployment of the data collection device, the MPO arranged for coverage by a local television station. The television piece, which featured an on-screen demonstration of the device, aired in the same week that recruiting calls to potential participants began. In response, the recruiters found the Lexington area residents were very responsive in volunteering to participate in the program.

3.2 Recruiting Participant Households

This task included all activities necessary to recruit individual households to participate in the field data collection. A sample of approximately 2,000 listed telephone numbers from households in Fayette and Jessamine counties (weighted by population) was purchased from a commercial source. Participating households were recruited using a sample plan based on demographic factors. In addition to gender, the sample objectives were stratified by the following categories.

- Age 18 - 24 with no children
- Age 18 - 24 with children
- Age 25 - 49 with no children
- Age 25 - 49 with children
- Age 50 - 64 with or without children

- Age 65+ with or without children

In addition to these stratifiers, there were several other factors that affected the recruiting process and the resulting sample of volunteer participants.

- Licensed drivers under the age of 18 were not permitted to participate as the principal eligible driver within a household, and were not specifically recruited. This decision was based strictly on liability issues. A minor cannot sign the informed consent necessary for the household to participate. While this requirement eliminated these drivers as a principal eligible driver, the 16 and/or 17 year old drivers could still participate as secondary eligible drivers when there was a principal eligible driver in their household.

- Principal eligible drivers recruited into the field test were required to drive at least three days a week. The motivation for this requirement was the limited availability of equipment and the relatively short duration of the field test. An objective of the field test was to collect as much data as possible from each participant, and requiring the participant to drive at least three of the six-to-seven day data collection period was a measure adopted to support that objective.

- Individuals, who were otherwise eligible drivers, that drove company-owned or company-leased vehicles were not recruited into the field test. This condition was put in place due to perceived liability issues, but was a negligible factor in the recruiting process.

Also, once recruiting started and some degree of success was achieved, efforts were made to assure some degree of geographic distribution among the participants within the Fayette and Jessamine County planning area. This adjustment was achieved by altering the recruiting telephone calling patterns based on the postal zip code of the households.

3.2.1 Recruiting Process

Figure 3.2 illustrates the general process used to recruit the participant households. A presolicitation letter was mailed to the address prior to any contact with the household. Once the letters had been mailed, the recruiters began telephoning the households to begin the recruitment process. If the household was responsive to the initial call, they were asked to participate in a brief screening interview to determine eligibility for the field test. Telephone numbers that turned out to be businesses rather than households, disconnected, or resulted in hang ups or no answer after six attempts were discarded.

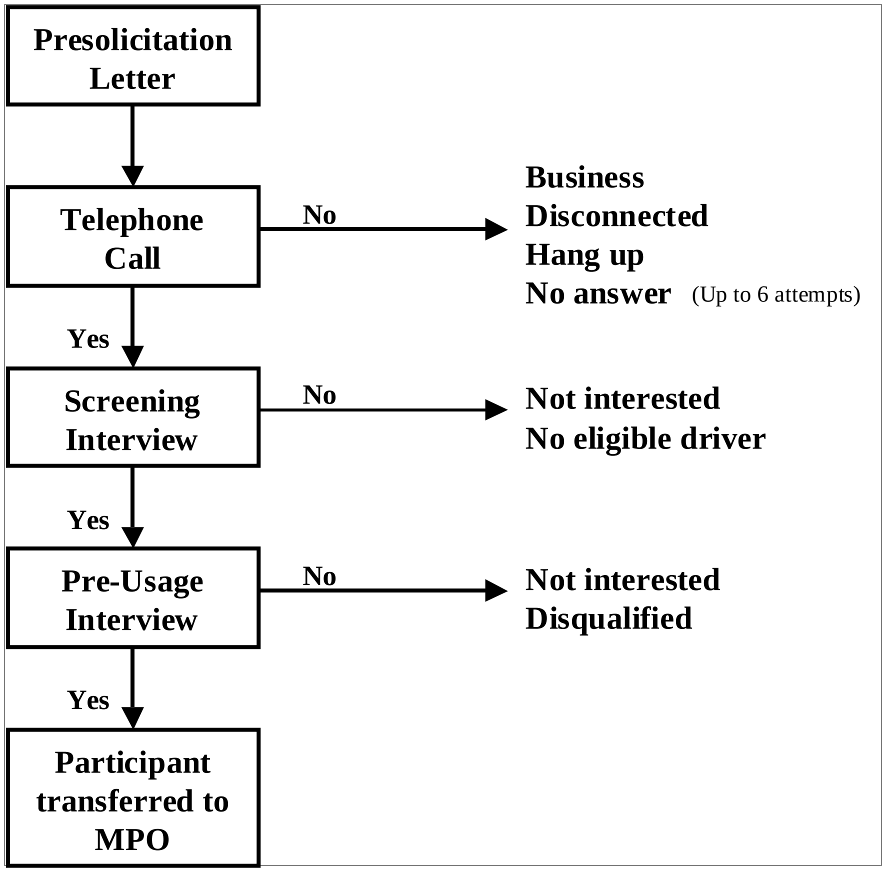


Figure 3.2 Flowchart Illustrating the Household Recruiting Process.

The screening interview was the principal tool to determine the eligibility of the household. The recruiter had up-to-date knowledge of the progress toward sample objectives and thus the screening process considered up-to-date sample needs in addition to the standard interview script. If the household was determined to contain an eligible driver, the recruiter requested that the eligible driver participate in the pre-usage interview to determine participation. Households that had no eligible drivers or were not interested in participation after the screening interview were thanked for their time and removed from the recruitment process.

The pre-usage interview with the eligible drivers determined final participation in the field test. This interview still offered an opportunity for disqualification. For example, if the eligible driver's primary transportation was a motorcycle instead of an automobile, they would be disqualified because the study plan required the use of an automobile by the principal driver. If the eligible driver met all the qualifications at the end of the pre-usage interview, the relevant information about the household was transferred to the MPO as a successful recruit.

One hundred households were successfully recruited for participation in the field test. The above requirements were used to identify and recruit individuals that were designated the principal driver within the household. The data collection device was installed in the vehicle that the principal driver used most of the time. Any licensed driver in the household was permitted and encouraged to use the device when they drove that vehicle.

3.2.2 Recruiting Success Rate

Recruitment of eligible drivers was more successful than anticipated. Media coverage likely contributed to the successful recruitment rate. The Lexington MPO had arranged for both newspaper and television coverage of the field test shortly before recruiting began. A presolicitation letter was sent to approximately 1,300 households with listed telephone numbers. Once the telephone interviewers determined that there was an eligible driver in the household, 67% of those eligible consented to participate in the field test. Their agreement to participate was followed by a mailing including the informed consent papers for them to read, sign, and return before the equipment would be released for their use. Only two of the households declined to participate after reviewing the informed consent papers.

3.2.3 Description of the Sample

The total sample for the field test was targeted at 100 households, which allows some inferences about the automatic data collection equipment versus telephone interview techniques for personal travel data collection. Time and cost constraints also dictated a relatively small sample. Although the total sample was small, the sample was stratified by three characteristics: age, gender and presence/absence of children.

In general, different age groups were expected to respond differently to a “high technology” project requiring the use of a computer. Also, young adult males tend to have low response rates to traditionally conducted surveys. Similarly, women were expected to have more concerns about installing equipment on their car and more concerns about their privacy. Finally, people with children were expected to be more easily distracted, or in a hurry, and thus more likely to forget to use the equipment when they got into the car. The sampling strategy is shown in Table 3.1, showing both the targeted values and the actual sample that was achieved for the field test.

For the 100 households, the average household size was 2.94 persons, with an average of 2.17 vehicles. There were 216 licensed drivers (100 male, 116 female) in the households with ages ranging from 16 to 77 years.

The sample of drivers was quite highly educated, with 20 percent completing college, and 20 percent with post-graduate education. The Fayette and Jessamine County area is the home of the University of Kentucky, Asbury College, Transylvania University, and other nearby higher education institutions.

The average estimate of annual miles driven was 13,118. This average is believed to be higher than a typical average for the area because the sample selection process excluded individuals that drove less than 3 days per week.

Table 3.1 Sampling Strategy for the Lexington Field Test

Bin	Age	Gender	Children	Target[1]	Actual[2]
1	18-24	M	Yes	8	4
2	18-24	F	Yes	8	7
3	18-24	M	No	8	8
4	18-24	F	No	8	8
5	25-29	M	Yes	9	9
6	25-29	F	Yes	9	10
7	25-49	M	No	9	10
8	25-49	F	No	9	9
9	50-64	M	Y or N	8	9
10	50-64	F	Y or N	8	9
11	65+	M	Y or N	8	8
12	65+	F	Y or N	8	9

3.3 Executing Field Operations

The field operations involved coordinating the activities of five entities to successfully identify participants, prepare and place the data collection devices, retrieve the devices and the collected data, respond to inquires and problems, and conduct post-usage interviews. Figure 3.3 is a flowchart describing the general activities throughout the field operations.

The general roles and responsibilities for each of these entities are described below.

FHWA/Office of Highway Information Management - Formulating general research strategy, sampling plans, and technical requirements.

[1]Number of households desired with the stated characteristics.

[2]Number of households achieved with the stated characteristics.

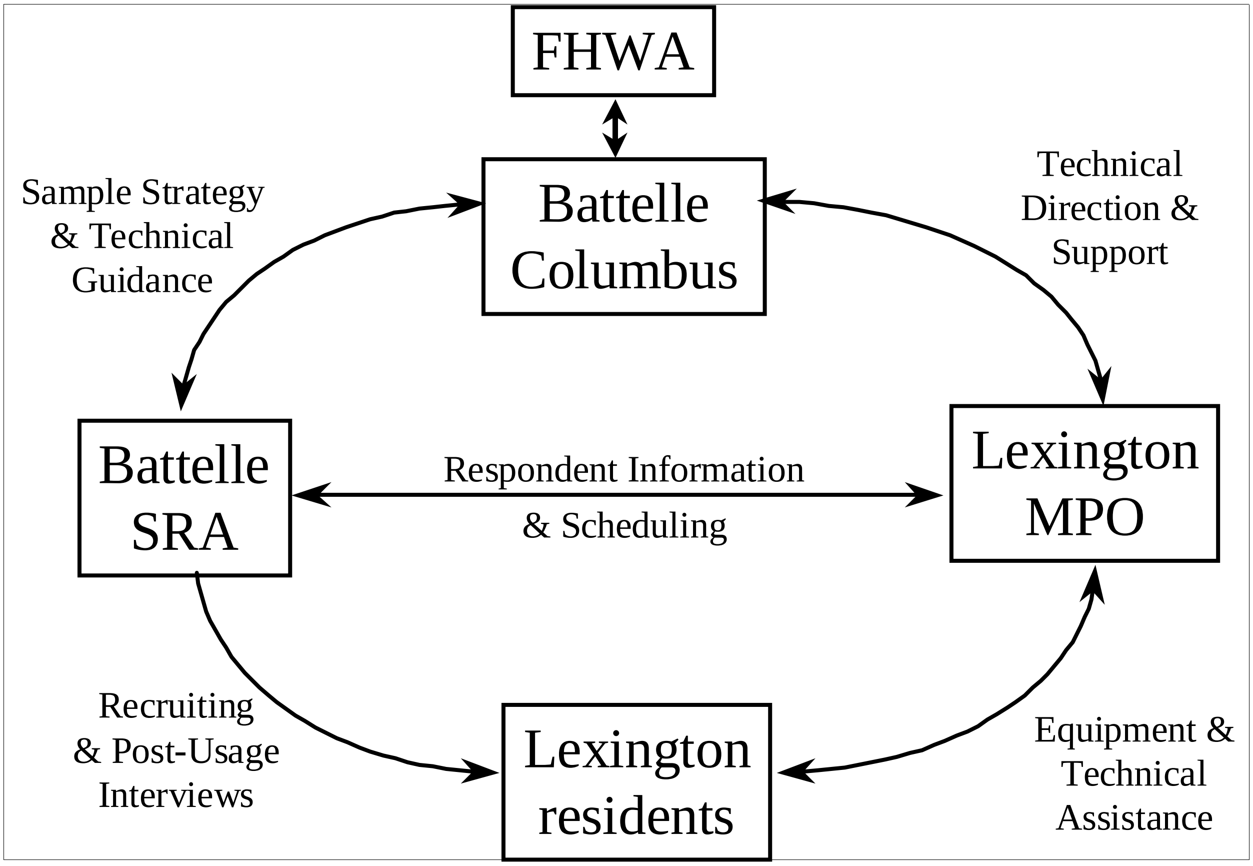


Figure 3.3 Flowchart Depicting General Field Operations.

Battelle, Columbus, OH - Assembling and testing of data collection devices, training of MPO staff on device usage, consulting with Lexington MPO and Battelle SRA on problems and in-field difficulties, downloading and collating the collected field data into the project database.

Battelle Survey Research Associates (SRA) - Recruiting household respondents including screening and pre-usage questionnaires, identifying respondent information to the MPO, coordinating scheduling of devices between recruiting efforts and the MPO, post-usage interviews, and other direct contacts with the respondents.

Lexington MPO - Preparing devices for use by each household, obtaining informed consent from each household, coordinating delivery and pick up of the device for each household, responding to in-field trouble calls and questions, communicating data on device usage and availability to other team members, and transmitting the collected data to Battelle.

Lexington residents - Install and use the data collection device in their personal vehicles, return the devices in a timely manner, participate in post-usage interview and usage attitude survey.

Field operations began in early September 1996 and continued until the end of December 1996. The field test used a total of twenty survey devices[3] and included 100 households in the Lexington MPO planning area.

The Lexington MPO recognized early in the field test that organization would be the key to the success of effort. An Administrative Coordinator was assigned to the project and the tasks were divided into two categories: Clerical and Technical. The clerical work included such things as keeping participant and shipping records, programming the machines with participant names, and assuring the return of the forms and machines. The technical side dealt with trouble shooting, installation, field assistance and equipment checking. These efforts were conducted concurrently, rather than sequentially, in order to minimize the turn-around time and keep as many machines in the field as possible. The greatest number of machines turned around in one day was seven.

The first notifications of eligible participants were received by the MPO staff on September 10, 1996. The participants were required to complete and sign an Informed Consent form, which discussed responsibility and liabilities, before they could receive a device. Return of the Informed Consent form by the participants averaged 8.6 days. The minimum turnover time was two days, while the maximum was over three weeks.

Within the first week of the field operations, all fifteen available machines were shipped to participants (throughout the first two and a half months of the study, only fifteen devices were available). Delivery of the survey devices averaged twelve days after receipt of the Informed Consent form. The objective was to ship the survey instruments on the day the Informed Consent form was received, however, after the second or third week a month's backlog of participants were waiting for survey instruments.

When a survey device was returned, the PCMCIA card with the data was retrieved and sent to Battelle for incorporation into the project database. Battelle SRA was notified that the participant had completed the field data collection and was scheduled for the post-usage interview. The physical condition of the machine, its component parts and connecting wires were checked. Each piece was examined for damage to assure that it would operate in the field again. Some of the software settings were also checked to ensure that they had not changed during field use.

After checking the physical condition of the equipment, a new PCMCIA card was inserted and programmed for the next participant. Each participant received a survey instrument that was programmed specifically for their household. The settings of the software were checked and the device was packaged for shipment. Included in the package was an incentive money order, return shipping instructions (including how and when to return the machine), instructions in both

[3]Only 15 devices were available for the first two and one-half months of the field test.

video and written formats and the address of the MPO. A local courier service was contracted to deliver and pick up the devices.

While the survey devices were in the field, the MPO staff had several responsibilities. If requested, the staff would install a machine in the participant's car. This happened in only three percent of the cases. The MPO staff also maintained a "hot line" to answer any question or respond to any difficulties that the participants experienced, and would also travel to the participants' homes if they had problems.

4. Equipment Performance

Equipment performance and durability were a point of interest in the field test. The individual units consisted of approximately $1,400 of equipment, most which was designed for personal use by a single user. The equipment was not “ruggedized” for the field test but placed in the field in essentially “off-the-shelf” condition. The following sections describe the field performance of the hardware and software.

4.1 Hardware Performance

The hardware performed much better in the field than had been anticipated. Each of the 15 initial units completed from 5 to 7 cycles of shipping, field use, and return shipping.

Only one equipment failure was experienced that required returning the unit to the manufacturer for repair. Repairs took the unit out of service for about a week, then it was returned to the field test and experienced no further problems. Several malfunctions resulted from apparent problems with the internal battery of the devices, that apparently resulted from two sources. The expected problem, loss of charge, occurred on several occasions. Two instances were likely due to defective power adaptor plugs, which were replaced. Other instances were more likely related to the individual vehicle characteristics or use cycle. In fact, one respondent discovered that the accessory port (cigarette lighter) in his vehicle was not functioning after the data collection device failed to maintain a battery charge.

The battery compartment cover in the Magic Link® was found unlatched more than once, which interrupts power to the device and gives the appearance that the device is totally non-functional. The device functions normally after the battery compartment is properly latched and the battery has sufficient charge. While not a serious problem with the device, these occurrences interrupted the field data collection for the individual respondent.

One serial extension cable was pulled apart and had to be replaced and one GPS receiver cable showed minor wear and was repaired with tape. Otherwise, the equipment survived the field test with normal wear and tear.

4.2 Software Performance

The software user interface and respondent data collection generally worked well. However one-second GPS data capture was not achieved as planned. GPS data points were recorded at irregular intervals, averaging between 20 and 30 records per minute. This irregular recording was a software communication problem that has since been corrected in later versions of the software.

Other software anomalies appeared infrequently. These anomalies generally centered on the intermittent appearance or total disappearance of the respondents’ names in the user interface menus. These problems apparently resulted from an unexpected conflict between the PTS software and the Magic Link operating system and each has been investigated for correction.

Data collection performance was generally good. The equipment was returned with absolutely no data records on the memory card in only two instances. The cause of these failures was undetermined. The battery power supply in the PDA was sufficient to capture the respondent-input portions of the data without an external power source, however no such data were recorded. Both of these collection failures were replaced by other field samples.

There were 14 instances were there were no GPS data recorded for the individual respondent, however the data records for the user-input trip information were intact. In these cases, a faulty external power supply is the most likely cause since the GPS receiver requires an active power source to produce position data. The fault in the power supply could have been a poor connection with the vehicle's accessory port (cigarette lighter) or non-functioning accessory port. None of the GPS receivers were found to be failed.

Another issue with the GPS data collection is the validity of the collected GPS data. Three types of errors were observed in the collected GPS data.

- First, in some cases, the GPS receiver did not achieve a positional fix during the trip. The collected data clearly indicate that the GPS receiver was functioning, however the data records are unusable for establishing any information about the trip.

- The second error is that in other instances, the GPS receiver experienced a loss of fix during the trip, thus there is a time period where the data are unusable and must be discarded from the trip record. This was most often observed at the beginning of trips, prior to the GPS receiver achieving its initial positional fix. However, other instances were observed were the loss of fix occurs in the middle of a trip and the data record clearly shows valid data points both before and after the loss of fix.

- The third error observed in the GPS data were occasional, large shifts in positional data. These shifts in position were generally several hundred miles from the Lexington area, and in some cases, appear in the middle of a data record with valid GPS data at both the beginning and end of the trip.

Overall, the 100 respondents returned data identifying 3,254 individual trips during the field test. Tables 4.1 and 4.2 provide some summary statistics on the results of the data collection process. Table 4.1 provides summary statistics for the complete data set, and Table 4.2 contains statistics on the data collected for each individual respondent. The terms used to describe these data summaries are explained below.

- PDA data - Trip data input into the PDA by the respondent.
  - Total PDA trips - The total number of trips recorded by an individual respondent.
  - "Bad" PDA trips - The number of PDA trips with a total duration of less than one minute. These records generally indicate a "practice" session or that a mistake was made and the respondent restarted the trip record. These records are not considered valid trips and are not included in the subsequent data analyses.
  - "Good" PDA trips - The total number of valid trip records. These good PDA trips are also shown as the percentage of the total PDA trips.

- GPS data - The GPS positional data collected for the "Good" PDA trips.
  - "Zero" valid GPS points (pts.) - The number of trips where no valid GPS positional points were collected.
  - "Bad" GPS points (pts.) - The number of trips where fewer than 15 valid GPS positional points were collected. Records with fewer than 15 GPS positional points were judged inadequate for the required map-matching analysis. These records are not considered valid trips and are not included in the subsequent data analyses.
  - "Good GPS points (pts.) - The number of trips that collected more than 15 valid GPS positional points. "Good" GPS points are shown as a percentage of the total number of good PDA trips.

The summary for the complete data set (Table 4.1) is presented for all samples taken and also without the 14 samples where no GPS data were recorded. This subset of the data set represents a set of samples where all the equipment was known to be in good working order and had an adequate power supply for some portion of the sample time period. The biggest difference in these data sets is illustrated in the fraction of PDA trips that have valid GPS data.

When the 14 no-GPS samples are removed, just over 70% of the valid PDA trips have valid GPS positional data. Another result is that approximately 23% of the good PDA trips have no valid GPS positional points. This loss rate is higher than expected since, in these samples, the data collection equipment is known to be working for at least a portion of the sample period. A review of the individual sample summary (Table 4.2) shows that all 86 of these samples have valid GPS trips. Most also have some trips with no GPS data or "bad" GPS data (fewer than 15 valid GPS points). These losses are likely attributable to shorter trips or conditions where achieving a GPS position fix was difficult. There is no obvious trend to these losses, and a more detailed, trip-by-trip analysis would be required to determine if there are similarities in these losses across the samples.

Table 4.1 Summary Data Collection Statistics for the Field Test.

No. of Obs.	PDA Data				GPS Data			
	Total PDA Trips Recorded	< 1 min. PDA Trips	> 1 min. PDA Trips	% Good PDA of Total PDA Trips	Trips w/ Zero Valid GPS pts.	Trips w/ <15 Valid GPS pts.	Trips w/ >15 Valid GPS pts.	% Good GPS of Good PDA Trips
		"Bad"	"Good"		"Zero"	"Bad"	"Good"	
Summary statistics for all samples taken during the field test.								
100	3254	508	2746	84.4%	861	156	1729	63.0%
Summary statistics after removal of the 14 samples that recorded no GPS positional data.								
86	2919	456	2463	84.4%	578	156	1729	70.2%

Table 4.2 Data Collection Statistics for Each Observation in the Field Test (continued)

Table 4.2 Data Collection Statistics for Each Observation in the Field Test

Obs	PDA Data				GPS Data			
	Total PDA Trips Recorded	< 1 min. PDA Trips "Bad"	> 1 min. PDA Trips "Good"	% Good PDA of Total PDA Trips	Trips w/ Zero Valid GPS pts. "Zero"	Trips w/ <15 Valid GPS pts. "Bad"	Trips w/ >15 Valid GPS pts. "Good"	% Good GPS of Good PDA Trips
1	14		14	100.0%			14	100.0%
2	26		26	100.0%			26	100.0%
3	13		13	100.0%	2		11	84.6%
4	10		10	100.0%	1	1	8	80.0%
5	10		10	100.0%	1	1	8	80.0%
6	21		21	100.0%	2	3	16	76.2%
7	37		37	100.0%	2	8	27	73.0%
8	24		24	100.0%	12	1	11	45.8%
9	15		15	100.0%	15			0.0%
10	37	1	36	97.3%	1	3	32	88.9%
11	34	1	33	97.1%	2	3	28	84.8%
12	65	2	63	96.9%	2	1	60	95.2%
13	31	1	30	96.8%	3	5	22	73.3%
14	27	1	26	96.3%	6	1	19	73.1%
15	22	1	21	95.5%	2		19	90.5%
16	21	1	20	95.2%		3	17	85.0%
17	19	1	18	94.7%	4	1	13	72.2%
18	18	1	17	94.4%	1	3	13	76.5%
19	30	2	28	93.3%	11		17	60.7%
20	15	1	14	93.3%	7	1	6	42.9%
21	29	2	27	93.1%	27			0.0%
22	28	2	26	92.9%		2	24	92.3%
23	54	4	50	92.6%	1	1	48	96.0%
24	27	2	25	92.6%	14	1	10	40.0%
25	26	2	24	92.3%		3	21	87.5%
26	38	3	35	92.1%	10	1	24	68.6%
27	12	1	11	91.7%	1		10	90.9%
28	60	5	55	91.7%	19	4	32	58.2%
29	24	2	22	91.7%	12	3	7	31.8%
30	24	2	22	91.7%	22			0.0%
31	22	2	20	90.9%	1	2	17	85.0%
32	43	4	39	90.7%		2	37	94.9%
33	21	2	19	90.5%	3		16	84.2%
34	31	3	28	90.3%		3	25	89.3%
35	31	3	28	90.3%	23	1	4	14.3%

Table 4.2 Data Collection Statistics for Each Observation in the Field Test (continued)

Obs	PDA Data				GPS Data			
	Total PDA Trips Recorded	< 1 min. PDA Trips “Bad”	> 1 min. PDA Trips “Good”	% Good PDA of Total PDA Trips	Trips w/ Zero Valid GPS pts. “Zero”	Trips w/ <15 Valid GPS pts. “Bad”	Trips w/ >15 Valid GPS pts. “Good”	% Good GPS of Good PDA Trips
36	41	4	37	90.2%	20	2	15	40.5%
37	38	4	34	89.5%	34			0.0%
38	47	5	42	89.4%	28	3	11	26.2%
39	9	1	8	88.9%	8			0.0%
40	9	1	8	88.9%	8			0.0%
41	27	3	24	88.9%	24			0.0%
42	36	4	32	88.9%	32			0.0%
43	52	6	46	88.5%	5	6	35	76.1%
44	69	8	61	88.4%	20	4	37	60.7%
45	43	5	38	88.4%	3	1	34	89.5%
46	51	6	45	88.2%	7	1	37	82.2%
47	65	8	57	87.7%	9	8	40	70.2%
48	24	3	21	87.5%			21	100.0%
49	48	6	42	87.5%	16	2	24	57.1%
50	22	3	19	86.4%	6		13	68.4%
51	29	4	25	86.2%	5	2	18	72.0%
52	28	4	24	85.7%	7	1	16	66.7%
53	27	4	23	85.2%		4	19	82.6%
54	27	4	23	85.2%	23			0.0%
55	39	6	33	84.6%	4	2	27	81.8%
56	13	2	11	84.6%	1	1	9	81.8%
57	26	4	22	84.6%	7	4	11	50.0%
58	13	2	11	84.6%	6		5	45.5%
59	58	9	49	84.5%	5	1	43	87.8%
60	19	3	16	84.2%	2	1	13	81.3%
61	43	7	36	83.7%	4	3	29	80.6%
62	55	9	46	83.6%	11	4	31	67.4%
63	23	4	19	82.6%	3		16	84.2%
64	74	13	61	82.4%	3	5	53	86.9%
65	55	10	45	81.8%	13		32	71.1%
66	49	9	40	81.6%	10	4	26	65.0%
67	38	7	31	81.6%	20	1	10	32.3%
68	27	5	22	81.5%	22			0.0%
69	16	3	13	81.3%	2		11	84.6%
70	85	16	69	81.2%	32	2	35	50.7%
71	36	7	29	80.6%	6	2	21	72.4%
72	36	7	29	80.6%	4	5	20	69.0%

Table 4.2 Data Collection Statistics for Each Observation in the Field Test (continued)

Obs	PDA Data				GPS Data			
	Total PDA Trips Recorded	< 1 min. PDA Trips	> 1 min. PDA Trips	% Good PDA of Total PDA Trips	Trips w/ Zero Valid GPS pts.	Trips w/ <15 Valid GPS pts.	Trips w/ >15 Valid GPS pts.	% Good GPS of Good PDA Trips
		"Bad"	"Good"		"Zero"	"Bad"	"Good"	
73	45	9	36	80.0%	27	2	7	19.4%
74	34	7	27	79.4%	14		13	48.1%
75	29	6	23	79.3%	1	1	21	91.3%
76	67	14	53	79.1%	4	2	47	88.7%
77	28	6	22	78.6%	11	5	6	27.3%
78	55	12	43	78.2%	9	2	32	74.4%
79	39	9	30	76.9%	30			0.0%
80	43	10	33	76.7%	14		19	57.6%
81	64	15	49	76.6%	8		41	83.7%
82	16	4	12	75.0%	3		9	75.0%
83	27	7	20	74.1%	3	4	13	65.0%
84	26	7	19	73.1%	3	1	15	78.9%
85	18	5	13	72.2%	7	1	5	38.5%
86	46	13	33	71.7%	33			0.0%
87	43	13	30	69.8%		1	29	96.7%
88	36	11	25	69.4%	1	2	22	88.0%
89	13	4	9	69.2%			9	100.0%
90	51	16	35	68.6%	7	1	27	77.1%
91	82	27	55	67.1%	38		17	30.9%
92	21	7	14	66.7%	1	2	11	78.6%
93	30	10	20	66.7%	12	1	7	35.0%
94	8	3	5	62.5%	1		4	80.0%
95	24	10	14	58.3%	3	2	9	64.3%
96	7	3	4	57.1%	4			0.0%
97	26	12	14	53.8%	4	2	8	57.1%
98	8	4	4	50.0%	1		3	75.0%
99	10	5	5	50.0%	4		1	20.0%
100	2	1	1	50.0%	1			0.0%
Totals	3254	508	2746	84.4%	861	156	1729	63.0%

5. Trip Data

This section presents and compares summaries of the trip data collected during the field test. There are five data sets that are referenced in this report and discussed in the comparisons that follow. Four of the data sets are specific to the Lexington field test, the fifth is the Nationwide Personal Transportation Survey (NPTS) data set. These five data sets are briefly defined below.

- **PDA data** - information and statistics derived directly from the data recorded from the MagicLink Personal Digital Assistant (PDA). These data include trip start and end times, trip occupancy and trip purpose, and were input by the individual respondents.

- **GPS data** - information and statistics derived directly from the data recorded from the GPS receiver. These data include positional data (latitude and longitude), speed, trip start and end times, and calculated trip distances.

- **Match data** - information and statistics derived directly from post-processing the GPS data in conjunction with the GIS-based travel network. These data include trip start and end times, network link identification, highway functional class, and trip distances. (Additional information about the map-matching analysis is provided in Section 6.)

- **Recall Data** - information and statistics derived directly from the post-usage interviews of the Lexington field test respondents. These data include trip start and end times, trip distance, destination and trip purpose.

- **NPTS data** - information and statistics derived directly from national telephone interviews to collect personal travel data. These data include trip start and end times, trip distance, travel time, and trip purpose. The NPTS data represent the entire U.S., and not just the Lexington, KY region.

The following sections present the data summaries from these data sets, compared with the NPTS data summaries where appropriate.

5.1 Comparisons of Accumulated Travel

This section offers several perspectives on the accumulated travel of the Lexington population sample. For these comparisons, trips were defined as those files having a recorded time of at least one minute and 15 valid GPS positional data points. Data files that contained less than one minute of information were considered “practice” or errors that were corrected by the user[1]. Data files with less than 15 valid GPS data points were subject to large errors in the map-matching analysis due to the paucity of positional data. Wherever possible, these travel

[1] Data indicate that one to two minutes are needed to enter data for a valid trip.

measures are compared with NPTS results to add perspective to the Lexington population data set.

The recall survey in Lexington captured mostly private vehicle driver trips (Table 5.1). The preponderance of driver trips compared to passenger trips is largely due to the sample selection process and the recall interview procedure. Only drivers who drove at least three days a week were eligible to participate in the survey. Also, in order to compare the recall day with PDA/GPS data, the recall day was limited to those days where the selected driver drove the vehicle which had the equipment installed.

Table 5.1 Comparison of Person Trips by Mode

Percent of Person Trips	Lexington Recall Day (n=495 trips)	1995 NPTS Pre-test Recall (n=5647 trips)
Private Vehicle-Driver	91.5%	73%
Private Vehicle-Passenger	3.4%	18%
Walk	3.6%	5.8%
Bike	0.2%	0.3%
Other	1.2%	2.8%

5.1.1 Daily Summary Statistics

Table 5.2 provides some average statistics associated with the Lexington field test. These statistics are compared to 1995 NPTS statistics for persons 18 and over with driver's licenses, since the sample population in the Lexington field test focused on eligible drivers age 18 and over.

The measures of average trips per day and vehicle trips per day (Table 5.2) show a higher count for the Lexington test than for NPTS. The Lexington respondents were required to drive at least three days a week in order to participate in the field test. This statistic supports the belief that, as a group, the Lexington respondents drive more than the average citizen captured in this NPTS sample.

The Lexington average vehicle miles of travel per day is somewhat smaller than the NPTS value as measured by the data collection equipment, however the recall estimate is about the same as the NPTS value. The fact that Lexington is a smaller urban area may support this statistic, since drivers may not drive as far to reach employment or the services that they need. Also, travel length distributions for the Lexington data, presented later in this section, support this result. The average time the vehicle is driven per day is also less than NPTS value for all measures.

Table 5.2 Total Number of Trips and Total Number of Vehicle Trips per Day.

Item	Lexington 6 Days PDA[2]	Lexington Recall Day	1995 NPTS[3]
Average # of trips/day		5.14[4]	4.63 trips
Average # of vehicle trips/day	4.68 (PDA) 4.24 (GPS)	4.73	3.57 trips
Average vehicle miles of travel per day	27.3 (GPS) 25.0 (MAP)	33.0	32.4 miles
Average time vehicle driven per day	61.3 (GPS) 60.2 (MAP)	63.0	73.7 minutes

Figure 5.1 shows the distribution of most frequent trip purposes from the field test. This trip purpose is provided for both the driver and passenger. The most frequent trip purpose for both groups is "return home" from some activity. The second most frequent driver's trip purpose was "shopping", and the second most frequent passenger's trip purpose was "go along for the ride". The "return home" and "shopping" trip purposes account for about one-third of the driver trips, and the "return home" and "go along for the ride" trip purposes account for approximately 41% of the passenger trips.

5.1.2 Travel Time

Figures 5.2 through 5.4 show the distributions of person trips and person miles of travel as a function of trip travel time. Trip travel time was measurable in three ways for the Lexington field test data.

- PDA - The PDA time is the time interval from when the respondent first touched the "start trip" button, initiating a trip, to the touch of the "end trip" button at the terminus of the trip. The PDA time interval is expected to be slightly longer than the actual trip time because the time interval includes the time required to enter data into the PDA.

- GPS - The GPS time is the time interval from receiving the first valid GPS data record on the trip to the receipt of the last valid GPS record. The GPS time interval will always

[2]Values are on a per vehicle basis.

[3]1995 NPTS--persons 18 and over with a driver's license.

[4]Includes all trips made by a respondent, including walking, transit, and other modes. Other values in this column are on a per vehicle basis.

Figure 5.1. Distribution of Most Frequent Trip Purposes from the Field Test (includes trips with more than 15 valid GPS points).

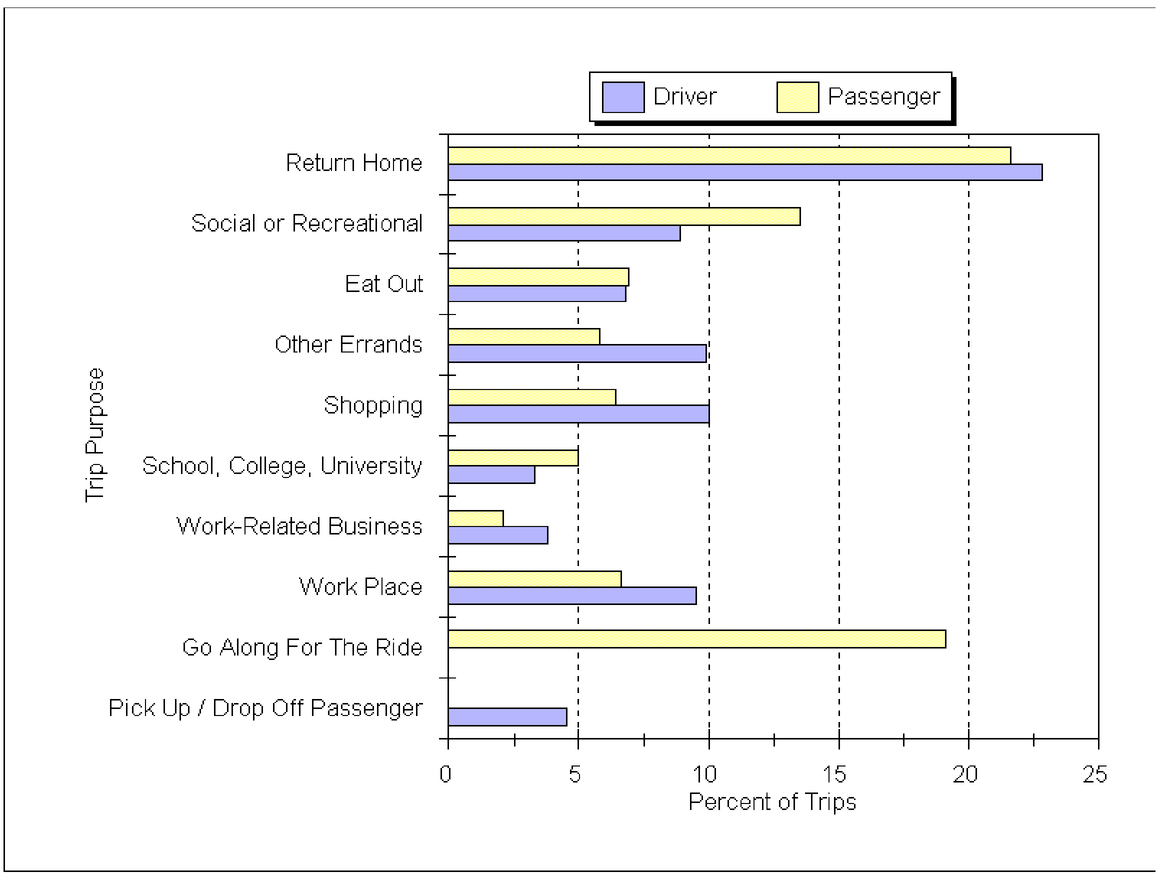


Figure 5.2. Distribution of Person Trips and Person Miles of Travel (PMT) as a Function of PDA Travel Time (PDA trips with more than one minute PDA duration). 1990 NPTS travel time distribution provided for comparison.

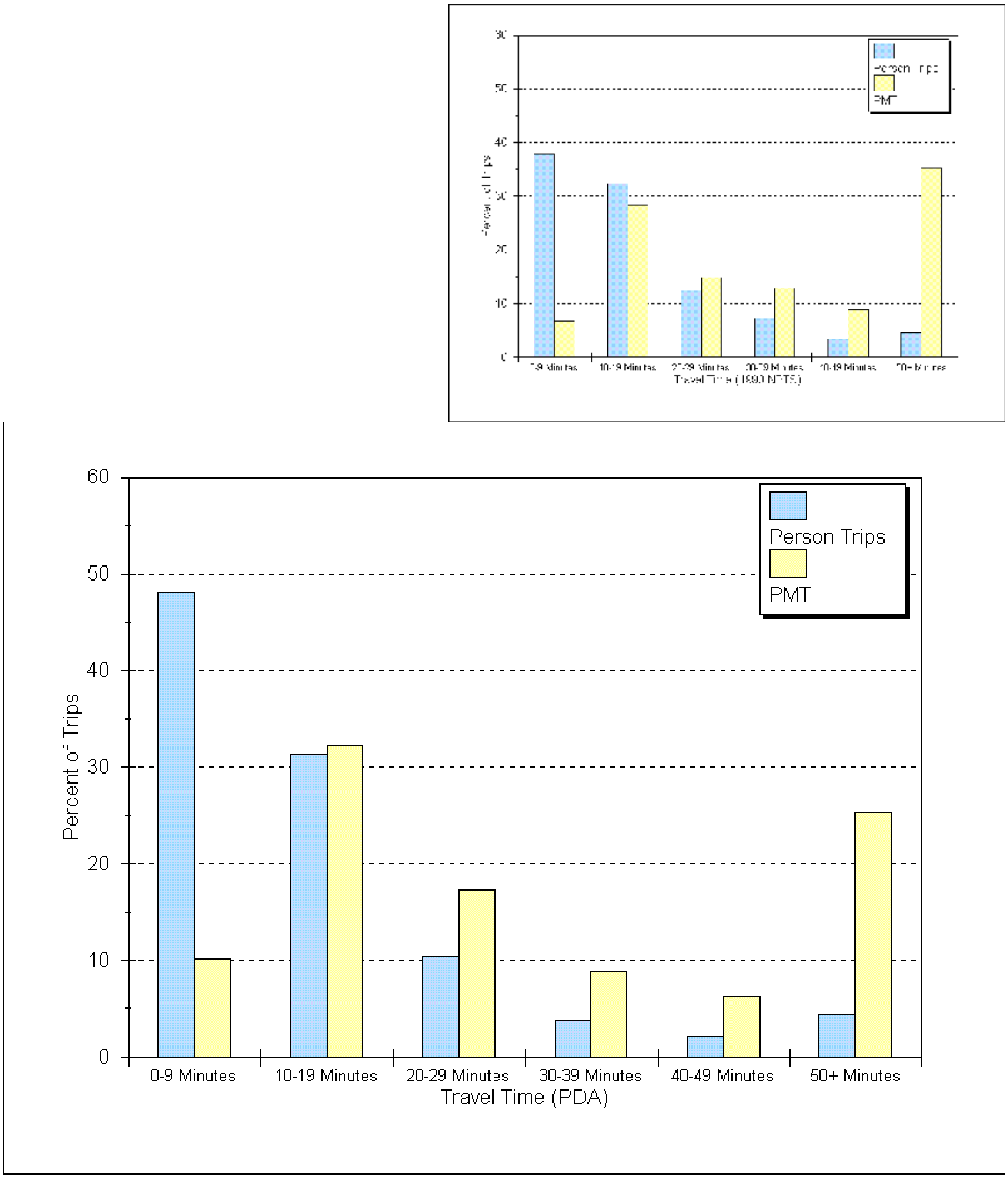
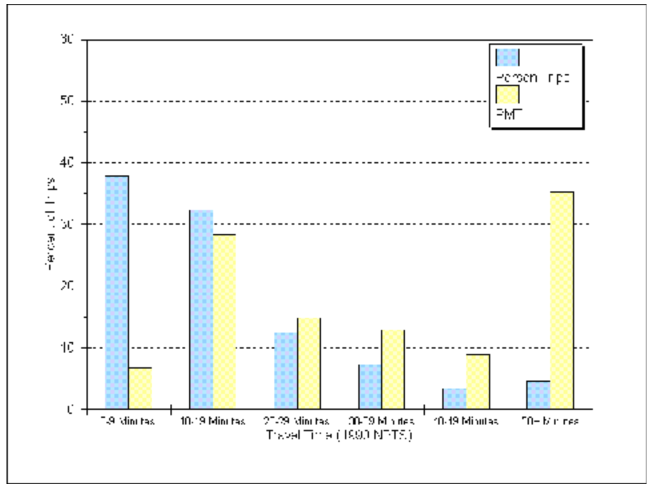


Figure 5.3. Distribution of Person Trips and Person Miles of Travel (PMT) as a Function of GPS Travel Time (GPS trips with more than 15 valid GPS points). 1990 NPTS travel time distribution provided for comparison.



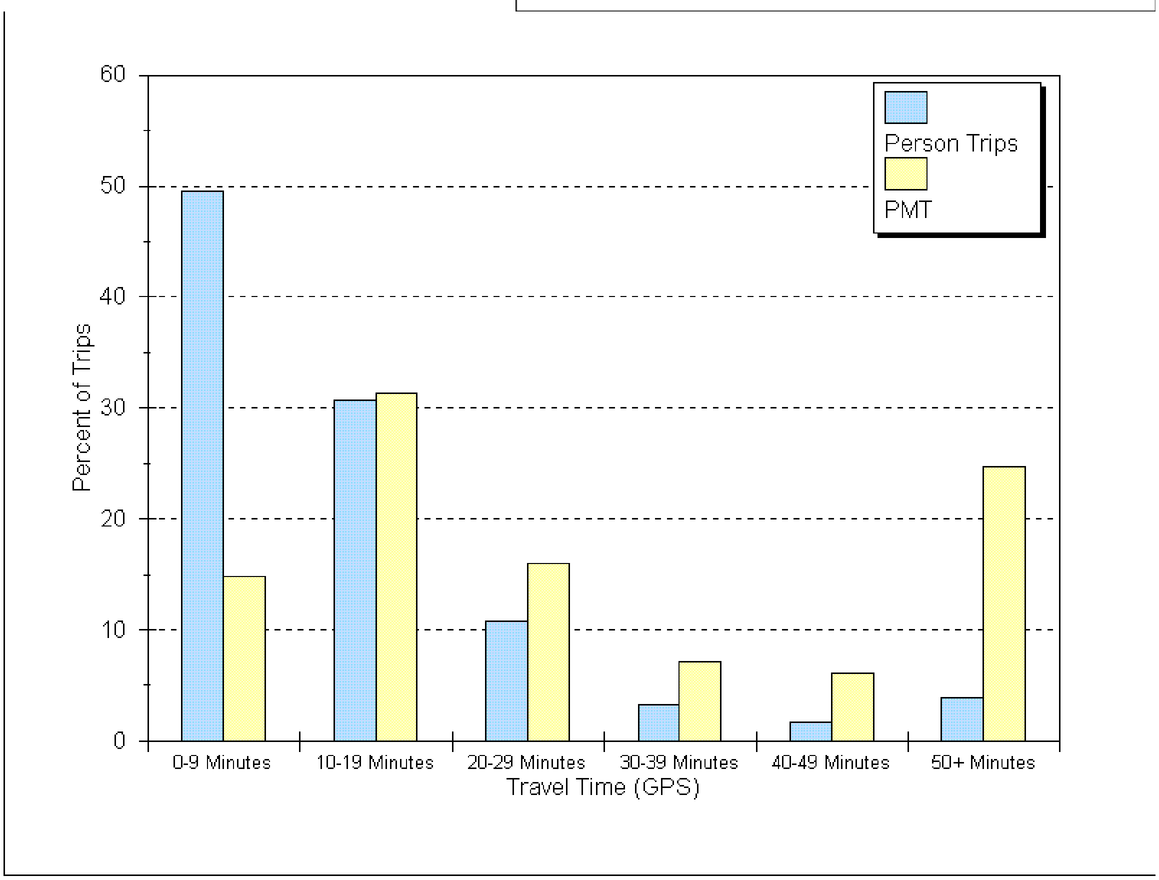
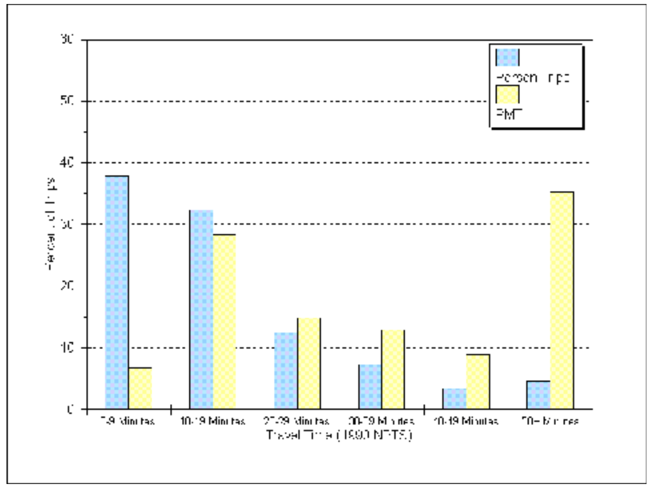
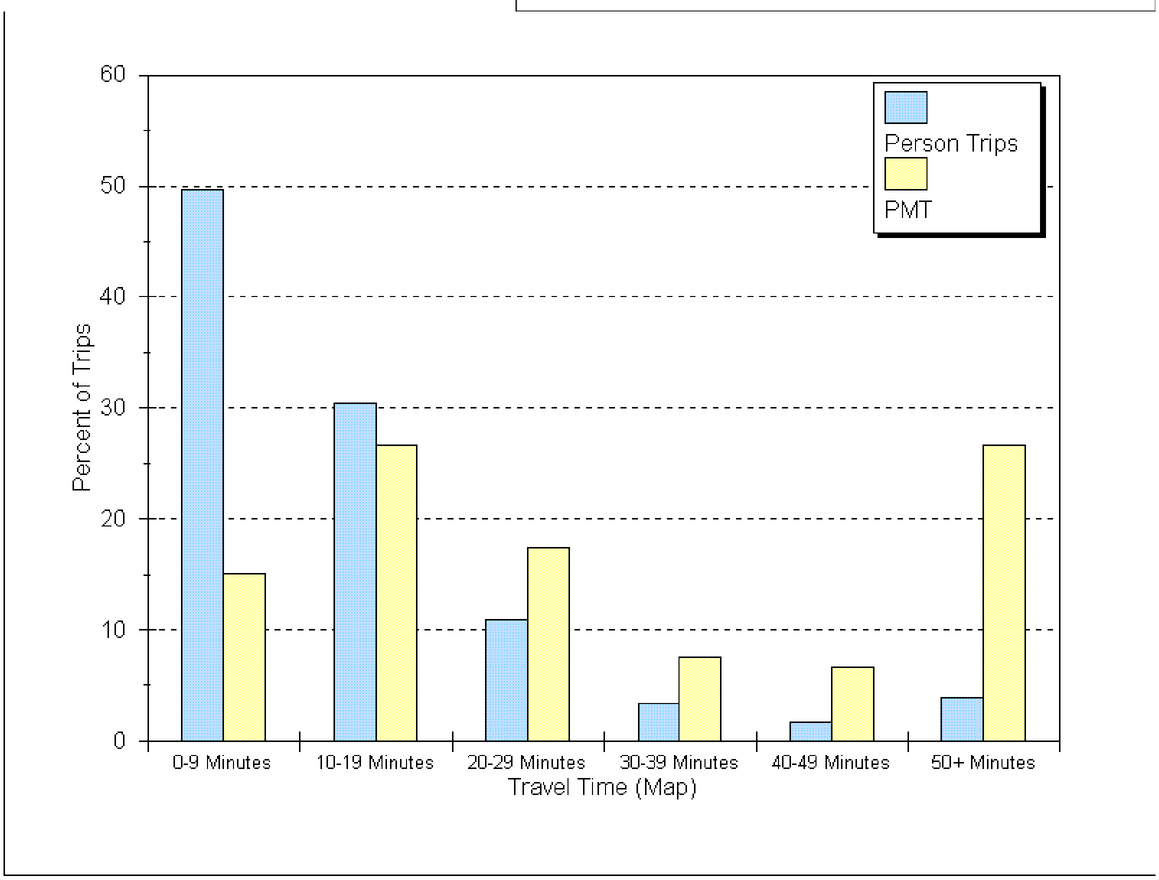


Figure 5.4. Distribution of Person Trips and Person Miles of Travel (PMT) as a Function of Map Travel Time (trips with more than 15 valid GPS points and one minute matched trip duration). 1990 NPTS travel time distribution provided for comparison.





be less than the PDA time interval, because recording of GPS data did not occur until the respondent touched the “start trip” button.

- Map - The Map time interval is a trip-based value that represents the time elapsed between the first and last GPS data points used in the map-matched trip. The actual time values used are those taken from the GPS receiver with the GPS data point, thus the Map time intervals should be similar to the GPS time intervals.

One travel time distribution is provided for each time interval measurement. On each page, the published 1990 NPTS travel time distribution is provided to permit comparison of the distributions. All of the travel time distributions are similar in shape and magnitude to each other as well as the 1990 NPTS travel time distribution.

Overall, the travel time distributions from the Lexington field test consistently have a larger fraction of person trips in the 0-9 minutes travel time category than the NPTS travel time distribution. The larger fraction seems to result from less person trips in the middle four categories as the longest travel time category (50+ minutes) generally remains consistent with the 1990 NPTS distribution.

The person miles of travel (PMT) also is shifted toward the shorter time intervals compared to the 1990 NPTS distribution. Also, the person miles of travel in the 50+ minutes category appears to have dropped substantially compared to the 1990 NPTS distribution.

The changes in the person trips and person miles of travel discussed above indicate that the Lexington data are comprised of shorter travel times than the 1990 NPTS distribution.

5.1.3 Trip Length

Figures 5.5 and 5.6 show the distributions of person trips and person miles of travel as a function of trip length. Trip length was measurable in two ways for the Lexington field test data.

- GPS - The GPS trip length is calculated from the individual GPS data points, using a point-to-point sum of the distance over a complete trip file.

- Map - The Map trip length is calculated from the network links that form the GIS base map. The trip length is a link-to-link sum over a complete trip file.

One trip length distribution is provided for each trip length measurement. On each page, the published 1990 NPTS trip length distribution is provided to permit comparison of the distributions. All of the trip length distributions are similar in shape and magnitude to each other as well as the 1990 NPTS trip length distribution.

Figure 5.5. Distribution of Person Trips and Person Miles of Travel (PMT) as a Function of GPS Trip Length (trips with more than 15 valid GPS points). 1990 NPTS trip length distribution provided for comparison.

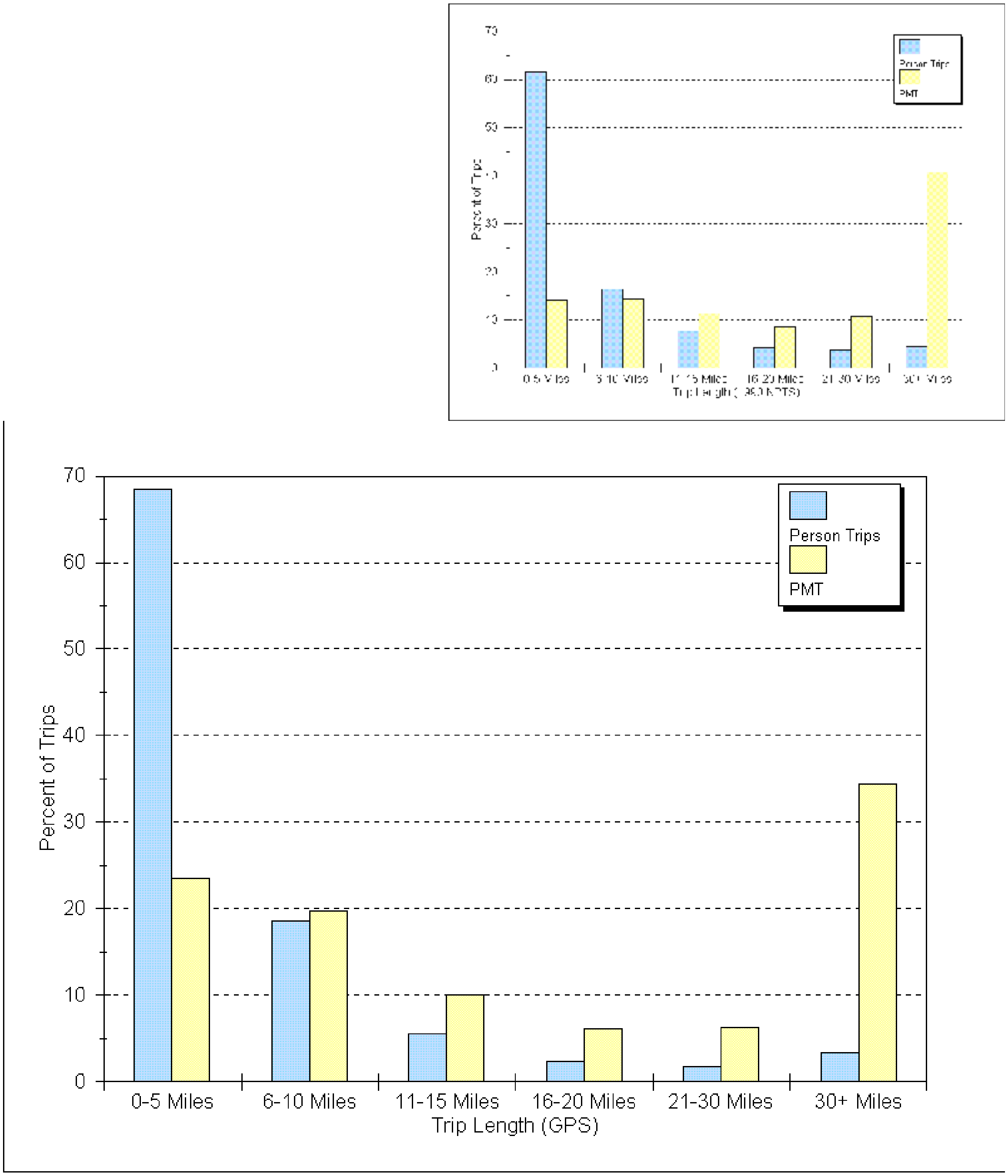
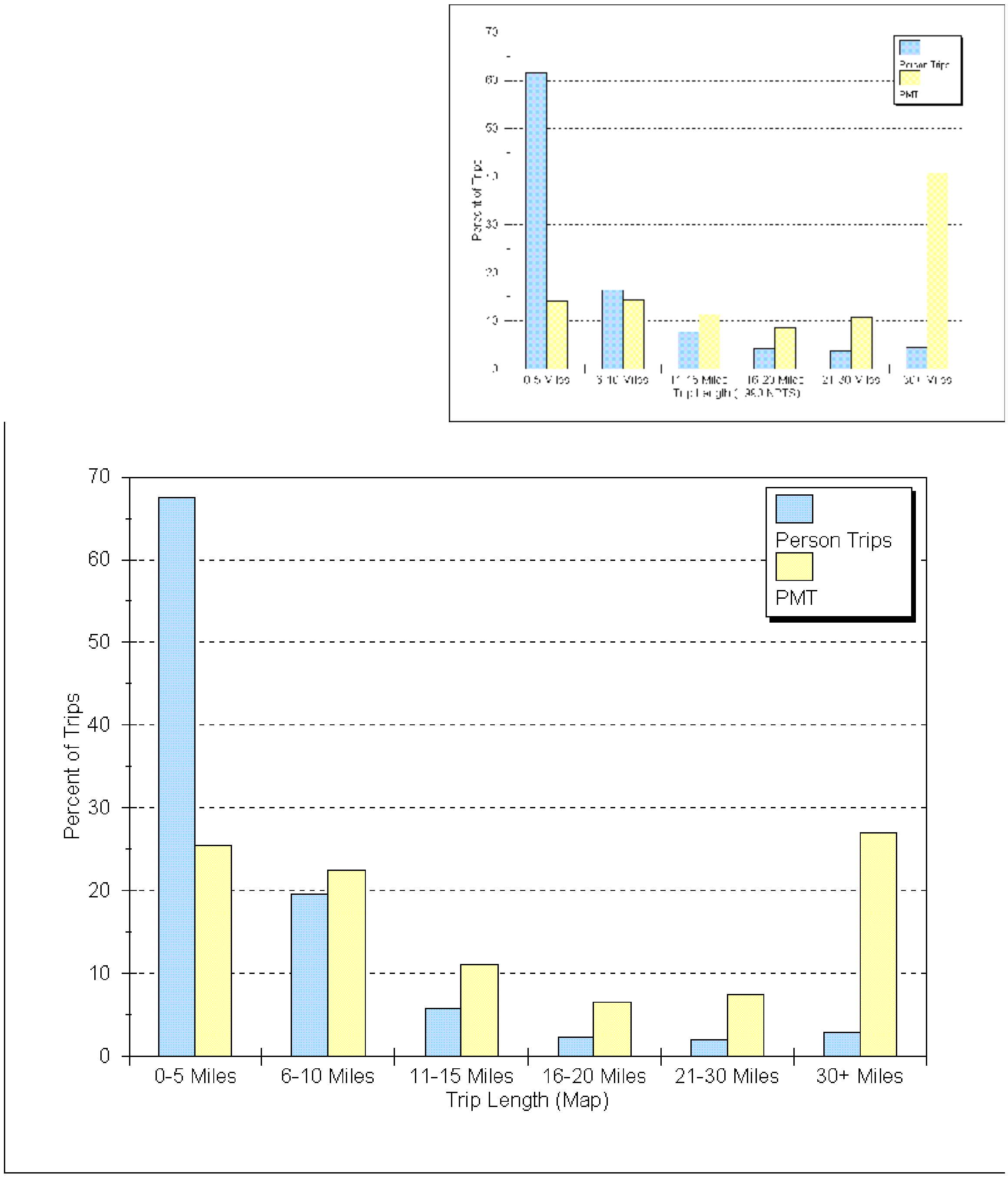


Figure 5.6. Distribution of Person Trips and Person Miles of Travel (PMT) as a Function of Map Trip Length (trips with more than 15 valid GPS points and one minute matched trip duration). 1990 NPTS trip length distribution provided for comparison.



Overall, the trip length distributions from the Lexington field test appear to have a larger fraction of person trips in the shorter trip length categories than the NPTS trip length distribution. This observation is also valid for the person miles of travel as a function of trip length.

The changes in the person trips and person miles of travel discussed above indicate that the Lexington data are comprised of shorter trips than the 1990 NPTS distribution.

5.2 Matching Recall Trips and Machine-recorded Trips

An objective of the project was to directly compare recall trips with machine-recorded data for the same travel. This comparison requires post-processing of the data in order to match the machine-recorded trips to the recall interview results. This process is not straightforward and proved to be more difficult than first anticipated for a number of reasons.

5.2.1 Recall Day

Generally the first choice for the travel recall day was the day immediately prior to the last day of device usage. Although the survey design designated Day 5 as the travel recall day, there were occasions when the respondent drove the vehicle for shorter or longer periods than six days. In cases where the driver had not driven the vehicle on the travel recall day, another day was selected for the travel recall day.   Table 5.3 identifies the frequency at which each day of usage was selected as the travel recall day.

Table 5.3 Frequency of Usage Day as Recall Day

Day of Usage as Recall Day	Frequency
1	1
2	2
3	1
4	12
5	27
6	25
7	13
8	8
>8	11

5.2.2 Issues Associated with Matching Recall Trips

Recall trip start times, travel times, and travel distances are known to be subject to rounding and therefore are not precise. Machine-recorded data, while more precise, also contains variations that can confuse the matching process.

Trip start times and travel durations will vary between the PDA and the GPS units. As designed, the PDA time markers are initiated by the respondent at the beginning and end of the trip. The GPS time markers are initiated based on when the GPS unit acquires a position fix after a trip is started and the time of the last valid position fix before the end of the trip. While the GPS time values are expected to always be less than the PDA time values, this variation can range from several seconds to several minutes.

Travel distance measurements can also vary. The GPS distance measurement is based on point-to-point calculation of distance. In addition to the losses described above (e.g., no position fix at the beginning of a trip for several minutes), loss of position fix during the trip may also influence the distance calculation if the loss of fix persists for some time. Map-matching of the GPS data to the GIS network counters some of the issues related to this mid-trip loss-of-fix, if the duration is not too long, by taking the distance measurement directly from the matched network links of the base map. However, the map-matching distance measurement is ultimately limited by the quality or shortcomings of the GPS data file which is being used to identify the matching links.

Address matching using the interview results and the matched GIS data files is another option for matching trips. Addresses derived from interviews have well-known shortcomings; the respondent may not know the exact address of their destination or the interviewer, being unfamiliar with the travel area, may misinterpret, misspell, or fail to distinguish local nuances that affect the correctness of the address. The matched GIS addresses will also have some shortcomings no matter how accurate and up-to-date the addresses contained in the base file. The matched GIS address is based on the last matched link of a trip, which depends on the GPS position fix at the end of the trip. If the GPS unit experiences a loss-of-fix at the end of a trip (e.g., lack of satellite communication, or even driving into a parking garage), the last matched link will likely not correspond to the address given in the interview. Even when the GPS unit is working perfectly and the map-matching is successful, if the respondent parks the vehicle around the corner from the ultimate address given in the interview, the matched GIS address may not resemble the interview results.

Finally, due to the design of the device, the respondent may have simply forgotten (or refused) to turn on the equipment or to enter the trip data into the PDA. Equipment malfunction is also a possible contributor to poor machine-recorded trip records. In these cases, there will simply be no machine-recorded trip data for matching or comparing with a recall trip.

5.2.3 Methodology for Matching Recall Trips

Thus a technique for matching recall trips with the corresponding machine-recorded trips is subject to many uncertainties that makes a distinct match for all recall trips improbable. This study used a three-step approach to the matching process. First, the interview trip start times and durations were compared to the PDA trip start times and durations. Since the PDA time markers are essentially set by the respondent, analysts reasoned that the PDA times were more likely to resemble the "remembered" trip characteristics. The criteria used was as follows. If the machine-recorded trip start time was within 30 minutes (before or after) of a recall trip start time, and the machine-recorded trip duration was within 40% (higher or lower) of the recall trip duration, then that pair of trips was considered a possible match. Secondly, analysts reviewed all available trip characteristics and made a judgement about which of the possible matches would be considered valid. Thirdly, the analysts reviewed all available trip characteristics for the remaining unmatched trips and made judgements on additional matches as the trip information indicated.

The results of this approach to matching recall trips with the corresponding machine-recorded trips are as follows.

- The 100 households reported 473 recall trips on the recall days, approximately 4.7 recall trips per vehicle[5].
- 84 total households have valid machine-recorded travel data documenting 408 trips on the recall days, approximately 4.9 machine-recorded trips per vehicle.
- The same 84 households recorded 391 recall trips on the recall days, approximately 4.7 recall trips per primary driver.
- The remaining 16 households recorded 82 recall trips that cannot be matched because there are no corresponding machine-recorded trips.
- 240 of the recall trips (61.4%) have been reasonably matched to machine-recorded trips on the recall days.

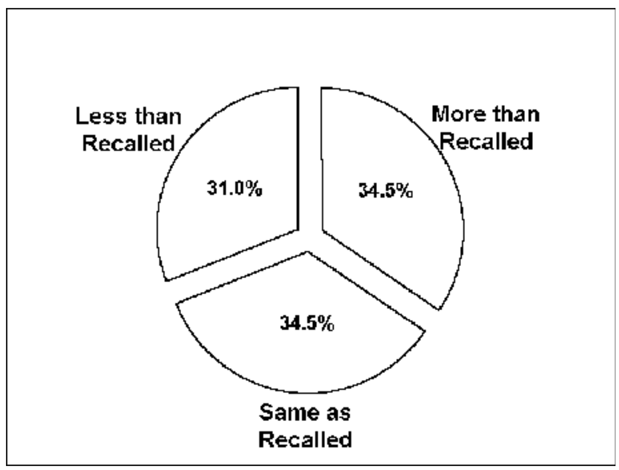


Figure 5.7 Comparison of Matched Machine-recorded Trips to Recall Trips in Lexington Households

Figure 5.7 illustrates the breakdown of the comparison of machine-recorded and recall

[5]The Lexington data do not represent a true household survey. The data result from a single vehicle in the household, most often controlled by a primary driver, thus the data more closely represent a per vehicle or per (primary) driver statistic.

trips for these 84 households[6]. 29 of the households (34.5%) had more machine-recorded trips than recall trips, with a total of 67 more machine-recorded trips than recall trips. In these cases, the household member has forgotten to report at least one or more trips during the recall interview. 29 of the households (34.5%) show the same number of machine-recorded trips and recall trips. 26 of the households (31.0%) show fewer machine-recorded trips than recall trips, with a total of 50 fewer machine-recorded trips than recall trips. These 50 recall trips cannot be matched because there are no corresponding machine-recorded trips for these households. This set of households represents those that did not use the equipment on a regular basis or, perhaps, some equipment problems were experienced.

5.3 Recall Comparisons

This section presents results for comparisons using the recall data. The recall data from the Lexington field test are compared with the machine-recorded Lexington data and national statistics to determine differences in the distributions of travel characteristics. The recall data are also compared directly to machine-recorded travel for the same trips to determine the differences between the recall descriptions and actual travel measurements.

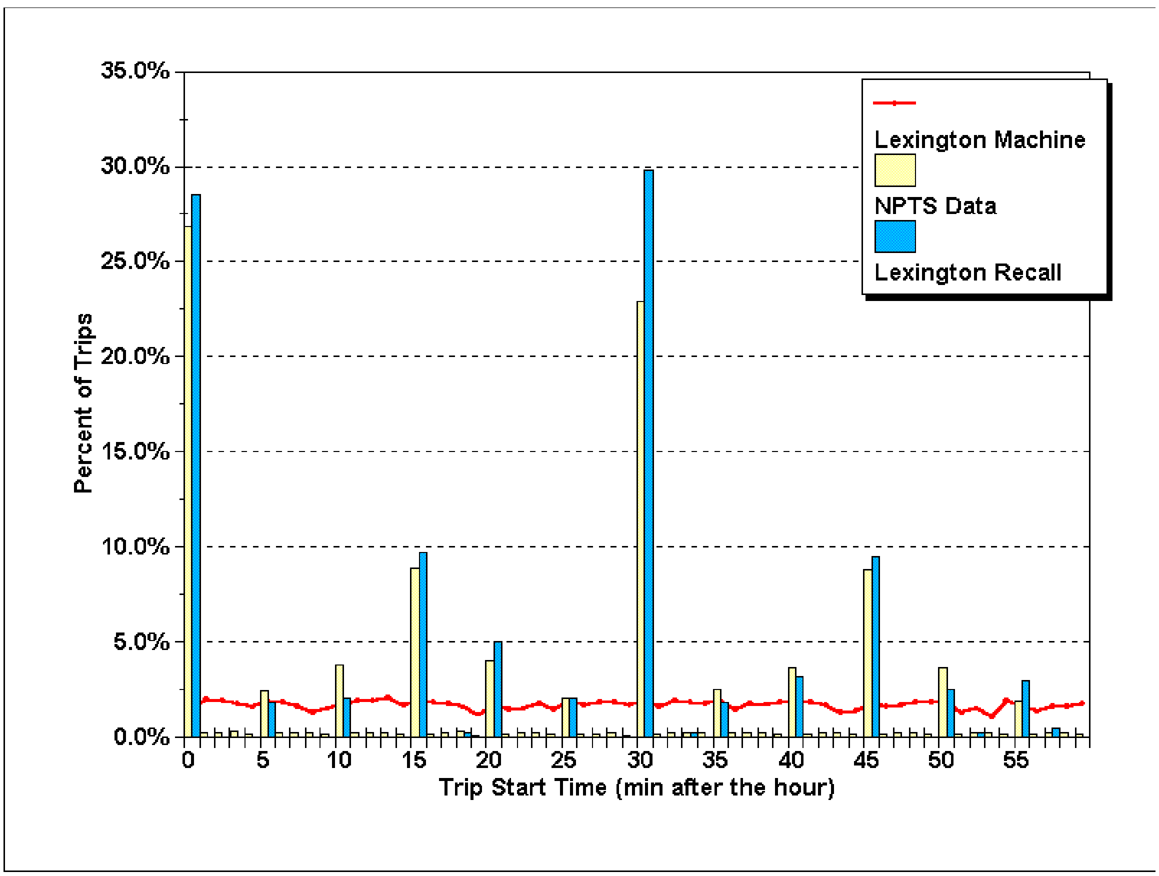
5.3.1 Trip Start Times and Trip Distances

The recall data are compared with the machine-recorded data and national statistics using reported trip start time, in minutes after the hour, and reported trip distances. The recall data are the answers of the Lexington respondents in a post-usage interview that mimicked the travel recall interviews used in the NPTS. These data are compared to the machine-recorded data from the Lexington field test, and a 1995 NPTS 6-month interim data set.

The results of the trip start time data are revealing. Trip start times reported in interviews are often rounded to nearest quarter-hour or half-hour—people simply do not report an accurate trip start time. This quarter-hour, half-hour distribution is evident in the NPTS data and the Lexington recall data as shown in Figure 5.8. For comparison, the Lexington field test equipment recorded these times automatically for each trip initiated by the respondents. Figure 5.8 shows the frequency distribution of trip start times for the Lexington data collected automatically during the field test compared to the recall data and the NPTS data set. The NPTS and recall data clearly show peaks at every quarter hour and lesser peaks at every five minute interval. The Lexington machine-recorded data have no such peaks, and is nearly a flat distribution over the entire sixty minute interval.

[6]The recall interview included trips by all modes (walking, transit, etc.) in addition to the equipped vehicle. Trips other than those made in the equipped vehicle have been removed from this comparison in order to directly compare the same set of trips in both data sets.

Figure 5.8. Distribution of Trip Start Times in Minutes after the Hour for NPTS (1995 6-month interim data set), Lexington Machine-recorded Data, and Lexington Recall Data.



Similar results can be seen in the reports of trip distances. Figure 5.9 shows the cumulative frequency distributions of reported trip distances for the 1995 NPTS 6-month interim data set, the Lexington data collected automatically during the field test, and the Lexington recall (interview) data. Again, the NPTS and Lexington recall data show many similarities in reported trip distance, with peaks occurring on the mile values (when travel distance is under 5 miles) or in 5 mile increments (when travel distance is greater than 5 miles). The automatically collected Lexington field test data reflect shorter average trip distances and produces a much smoother distribution of trip distances.

5.3.2 Trip to Trip Comparisons

Another comparison was made between the recall travel data and the machine-recorded data from the field test. This comparison focused on directly comparing the recall information with machine-recorded information for the same set of trips to observe the differences in the data. The sets of trips compared were determined by matching the recall trips with specific machine-recorded trips, based generally on trip start times and durations, as well as general comparisons of the trip characteristics. Comparisons are made for both travel time and travel distance.

The travel distance comparison (Figure 5.10) shows the variations in the measured distance for specific recall distances in the data set. The chart shown compares the recall distance with the travel distance measured from the GIS base map (MAP). A similar comparison used the measured distance from the GPS receiver, with similar results. The variations are shown as the median of the measured distance, bounded by the 25th and 75th percentile value of all the measured distances for the specific recall value. The straight line in the figure represents the curve where the recall and measured distances would be identical. An overall observation is that the median measured distances are consistently lower than the recall distances. That is, the recall distances consistently overstate the travel distance. For example, the recall distance of ten miles has a median measured distance value of 6.5 miles and 25th and 75th percentile values of four and 9 miles as measured by the GPS, and a median measured distance value of 6.48 miles and 25th and 75th percentile values of 3.95 and 8.91 miles as measured by the MAP.

Similar results are seen in the comparisons of travel times, shown in Figure 5.11. The chart shows the measured time from the PDA compared with the recall travel time. A second comparison was done using the measured time from the GPS with similar results. Again, the variations shown are the medians of the measured time, bounded by the 25th and 75th percentile value. While the median values for the PDA measurements are closer to the recall times for low values, the general trend is that the recall times generally exceed the median measured value. For example, the recall time of 10 minutes has a median measured time value of 10.4 minutes and 25th and 75th percentile values of 8 and 13.8 minutes as measured by the PDA. Another factor to consider is that the PDA time measurement includes the time required for the respondent to enter data into the computer. This activity generally consumed one to two minutes. Thus the actual travel time is likely one to two minutes less than measured by the PDA,

Figure 5.9. Distribution of Reported Trip Distance for NPTS (1995 6-month interim data set), Lexington Machine-recorded Data, and Lexington Recall Data.

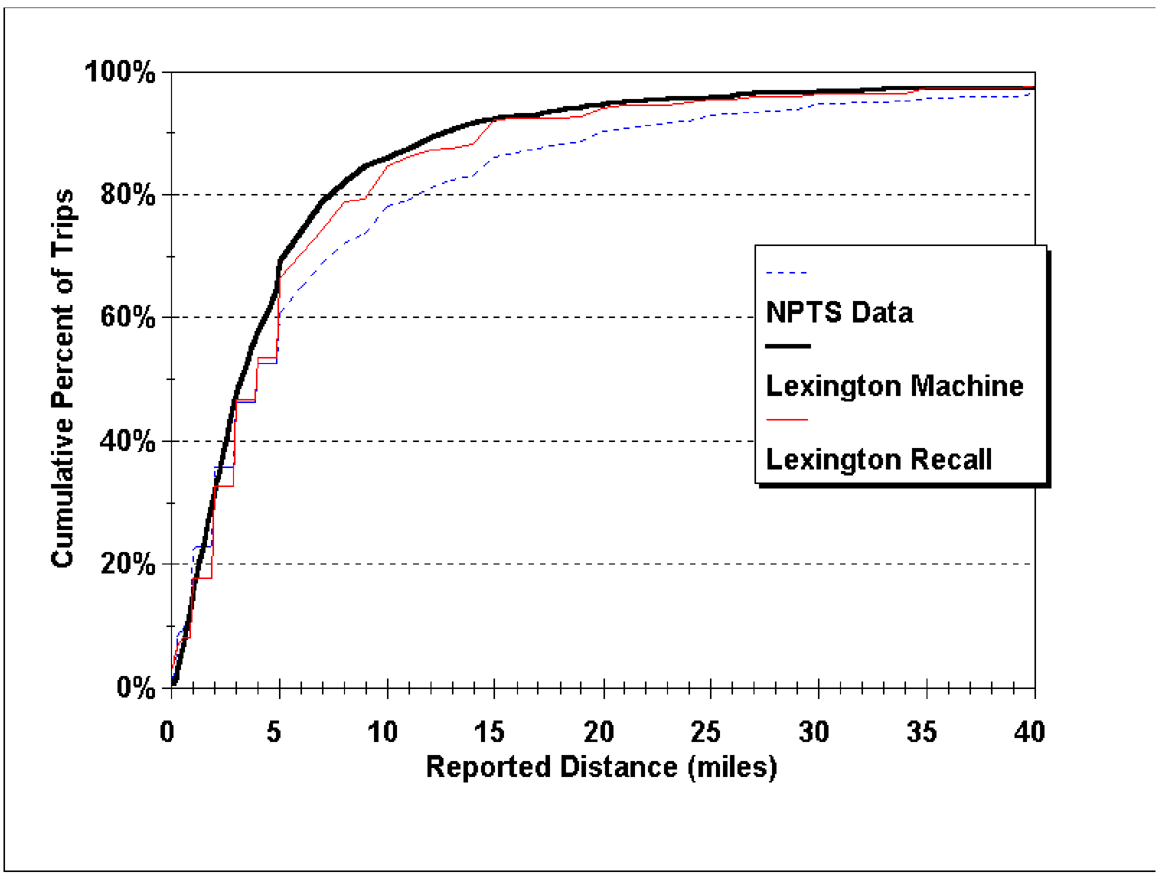


Figure 5.10 Comparison of Lexington Recall and Measured Travel Distances.

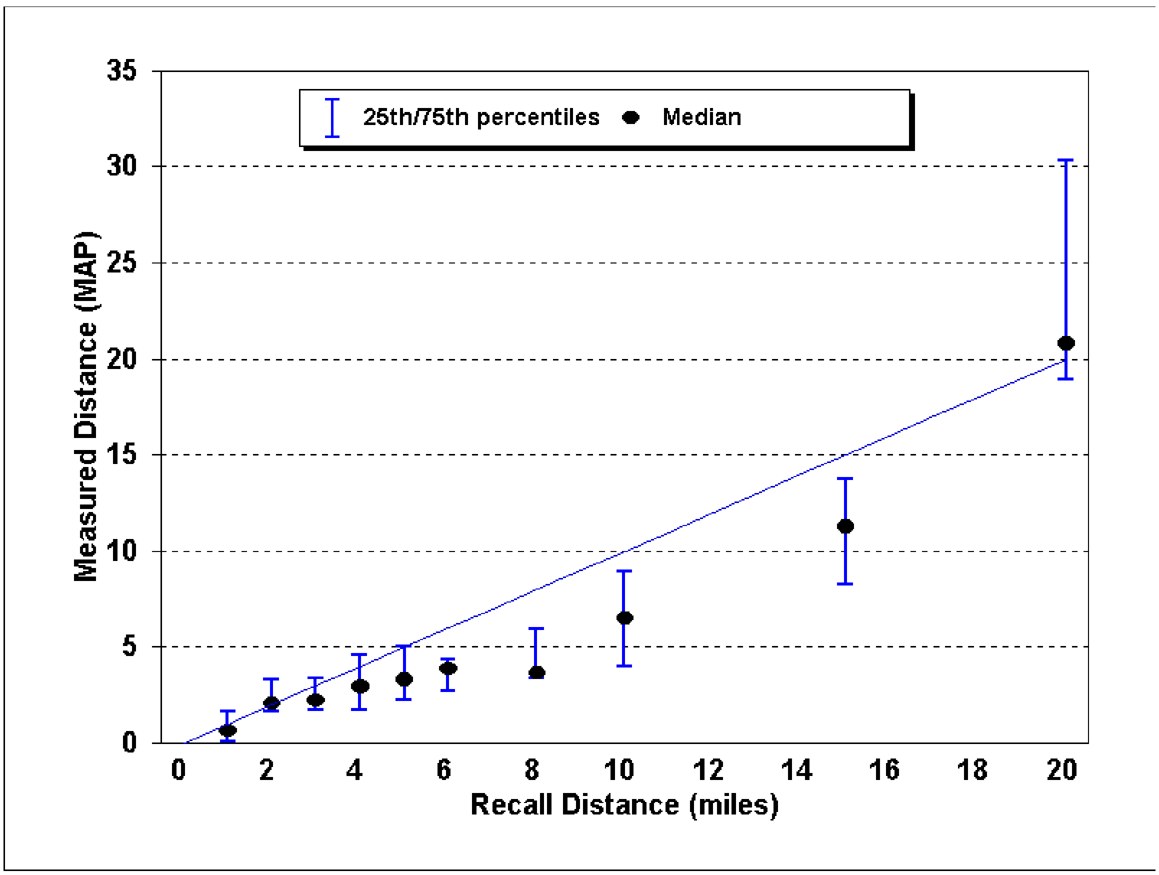
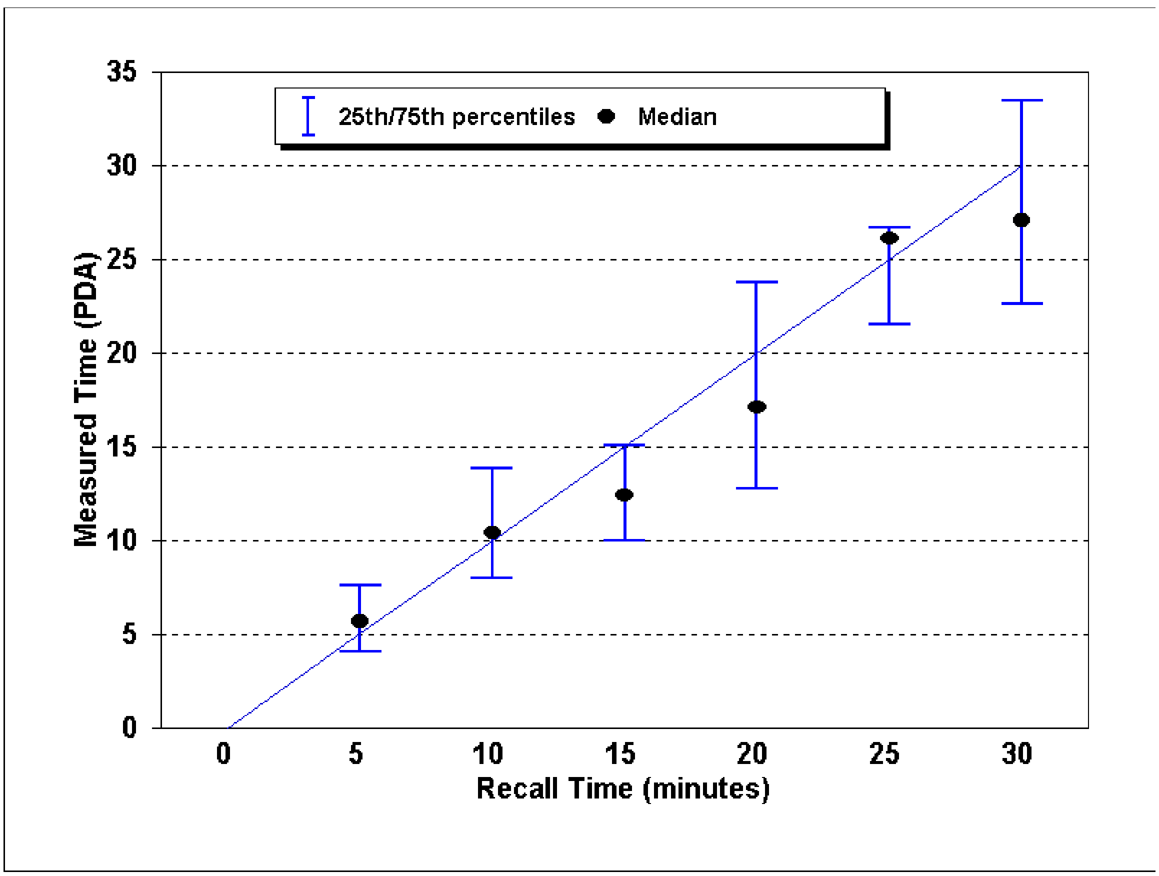


Figure 5.11 Comparison of Lexington Recall and Measured Travel Times.



which would result in larger differences between the recall times and actual times than are indicated in the figure.

5.4 Benefit of Multiple Days of Travel Recorded

Recording multiple days of travel allows study of day-of-week variations and other insights into travel behavior. With the GPS equipment, vehicle miles of travel (VMT) and travel speed become easily accessible data within the travel survey.

Table 5.4 shows that even with a very small sample of 100 household vehicles, using a 6-day survey period, information on more than 2,700 vehicle trips are captured with a good distribution of trips by day of week. Even this small a data set will permit limited exploration of variability of vehicle travel over the survey period and the relationship between the stability or variability by personal or household characteristics.

Table 5.4 Vehicle Trips and Vehicle Miles of Travel (VMT) by Day of Week

Day	Vehicle Trips	VMT	
		GPS	MAP
Monday	415	1,255	1,258
Tuesday	437	1,690	1,590
Wednesday	449	1,445	1,453
Thursday	472	2,604	1,946
Friday	377	1,653	1,653
Saturday	327	1,749	1,717
Sunday	281	1,236	1,090

The issue of whether or not there was trip reporting fatigue using this method is still being explored. Drivers reported that it typically took them one minute or less to enter the information into the computer each time they made a trip. 62% said they remembered to use the equipment every time, and 36% said they used the equipment most of the time (Section 7 of this report). When examining the number of trips per day, defining Day 1 as the date of first recorded information (Table 5.5, column a), there is no apparent reporting fatigue, with the number of trips from Day 2 through Day 6 all between 330 to 380 trips per day. However, if Day 1 is defined as the first day for which there is a valid trip record (Table 5.5, column b), the distribution changes substantially. There may be evidence of reporting fatigue, with a decline from about 450 trips to 350 trips. However, changing the Day 1 definition may be overly skewing the distribution by removing non-driving days that occurred at the beginning of the household test period. This issue needs further exploration, with controls for day-of-week. A hardware solution that eliminates the need for the driver to actively turn the equipment "on" each time a trip is made would help answer the reporting fatigue problem. This hardware solution has been implemented in a subsequent GPS survey effort.

Table 5.5 Vehicle Trips by Time in the Survey Period

Day of Usage	Number of Trips per Day (all households)	
	(a)	(b)
Day 1	269	464
Day 2	333	456
Day 3	379	425
Day 4	350	360
Day 5	379	363
Day 6	338	342
Day 7	274	191
Day 8	153	87
Day 9	92	29

(a) Day 1 of usage defined as date of 1st recorded information (practice trip, error, or other)
(b) Day 1 of usage defined as date of 1st valid trip record (at least one minute and 15 GPS data points)

5.5 Summary

The average daily statistics, the travel time distribution, and trip length distributions from the Lexington field test all indicate shorter average trip distances than in NPTS. The measures associated with the Lexington data were collected by the data collection devices and the NPTS measures are based chiefly on recall interviews. Overall, the results suggest that personal travel length is shorter than past estimates based solely on recall interviews.

Trip start times, in minutes past the hour, and trip distances both show radically different distributions when measured by the data collection device versus recall interviews. These results provide insight to the real distributions of personal travel start times and trip distances, which vary substantially from the distributions based on recall interviews.

Matching recall trips to machine-recorded trips for trip-to-trip comparison is a difficult task due to a number of factors. Variations in travel start times, durations, distances, and destination addresses between machine-recorded data and recall data all serve to confound the process. The methodology employed here matched approximately 61% of the recall trips with machine-recorded trips. Overall, the data suggest that the number of machine-recorded trips exceeds the number of recall trips; that is, the recall data likely underestimate the total number of trips.

Trip-to-trip comparison of recall and machine-recorded data shows that the recall estimates generally overstate both travel time and travel distance as compared to the travel measurements recorded by the data collection device.

Recording multiple days of travel allows study of day-of-week variations and other insights into travel behavior. With the GPS equipment, even with a very small sample of 100 household vehicles, using a 6-day survey period, captured information on more than 2,700 vehicle trips with a good distribution of trips by day of week. The issue of whether or not there was trip reporting fatigue using this method is unresolved and still being explored. Additional controls on usage by day-of-week and equipment modifications will help address this issue.

6. GPS Data

A principal objective of the field data collection effort was to capture Global Positioning System (GPS) positional data for the individual trips made by the respondent households. These data, used in combination with the Lexington area base map, permit analysis of the individual trips based on the information that is part of the map database. A key part of the assessment was matching the collected GPS data points with the individual links in the base map for this analysis. Both the accuracy and continuity of the collected GPS data influence the outcomes of this process.

6.1 GPS Data Accuracy

The accuracy of the GPS data collected during the field test is dependent on the receiver design, the status of the Navstar GPS satellites, and the location of travel. The GPS data are "absolute" GPS points, that is, they have not been differentially corrected for the affects of selective availability. The absolute GPS data positional accuracy depends on the implementation of selective availability. Selective availability, controlled by the Department of Defense, is a purposeful degradation of the signals transmitted by the GPS satellites so that unauthorized users cannot achieve the full military accuracy of the system[1]. With selective availability on, receiver accuracy is within ±100 meters (328 feet) with 95% probability and a most probable error of approximately 50 meters (165 feet). With selective availability off, receiver accuracy improves to within ±15 meters (49 feet) with 95% probability.

Differential GPS (DGPS) can reduce these errors substantially in many applications. The Garmin receiver used here is differentially correctable to less than 10 meters (33 feet), and some receivers in the literature boast of centimeter accuracy in some applications. DGPS was evaluated as a possible option for this program and was not employed for several reasons. The DGPS tested in early trials (see Appendix A) did not represent a clear advantage versus the objectives of the test. Secondly, a source of a differential correction signal in the Lexington test area was not readily available during the planned time of the field test. Third, using DGPS required additional equipment and costs for each field unit.

At some point in the future the issue of DGPS is expected to be moot. The Government has announced a policy of reduced use of selective availability and eventual phase out of its use altogether. By that time, newer technology GPS receivers will likely out perform any of the low-cost receivers available today.

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[1] Logsdon Tom, *The Navstar Global Positioning System*, Van Nostrand Reinhold, 1992.

6.2 GPS Data Continuity

The continuity of the GPS data collected during the field test was influenced by two factors. First, there are gaps in the data stream due to receiver operation. These gaps are the time segments necessary for the receiver to establish a positional solution when it is first turned on (known as time to first fix) or after there has been a loss of signal, such as when the vehicle moves into a parking garage, into a tunnel, or for some other reason the signal is blocked from reaching the receiver.

The second factor affecting the data continuity is that the GPS data collected during the field test were also recorded at irregular time intervals due to a fault in the data collection equipment. This irregular spacing of the GPS data points in time added to the complexity of assessing which segments within the base map were actually traveled by the respondents.

6.3 The Lexington Area Base Map

The Lexington area base map (Figure 6.1) used in this study was composed from several sources in 1995. The map database contains over 10,200 roadway segments or links covering over 1,930 kilometers (1,200 miles) with street centerline accuracy from 2.1 meters (7 feet) to 4.5 meters (15 feet). The roadway database also includes designation of six highway functional classes — freeway, arterial highway, major arterial, minor arterial, collector, and local thru-street (functional classes are shown in the figure). Non-intersecting segments and overpasses are properly handled because there are no node definitions at their graphical intersections and one-way streets and on- and off-ramps have proper directional indications.

This Lexington base map includes only Fayette County, Kentucky. Since the local planning area, and thus the field test area, included both Fayette and Jessamine counties, the Lexington base map was supplemented by the TIGER data set for Jessamine County for the subsequent analysis. Figure 6.2 illustrates the complete planning area that was included in the field test.

6.4 Map-Matching Analysis

The map-matching analysis uses the collected GPS points to identify the specific roadway nodes and links that were traveled in the Lexington area network. The results of the map-matching process allow a more accurate description of the trip distance based on the link length contained in the database, as well as summaries of travel by highway functional class. Identifying trip origins and destinations are also feasible by address-matching in the base map database.

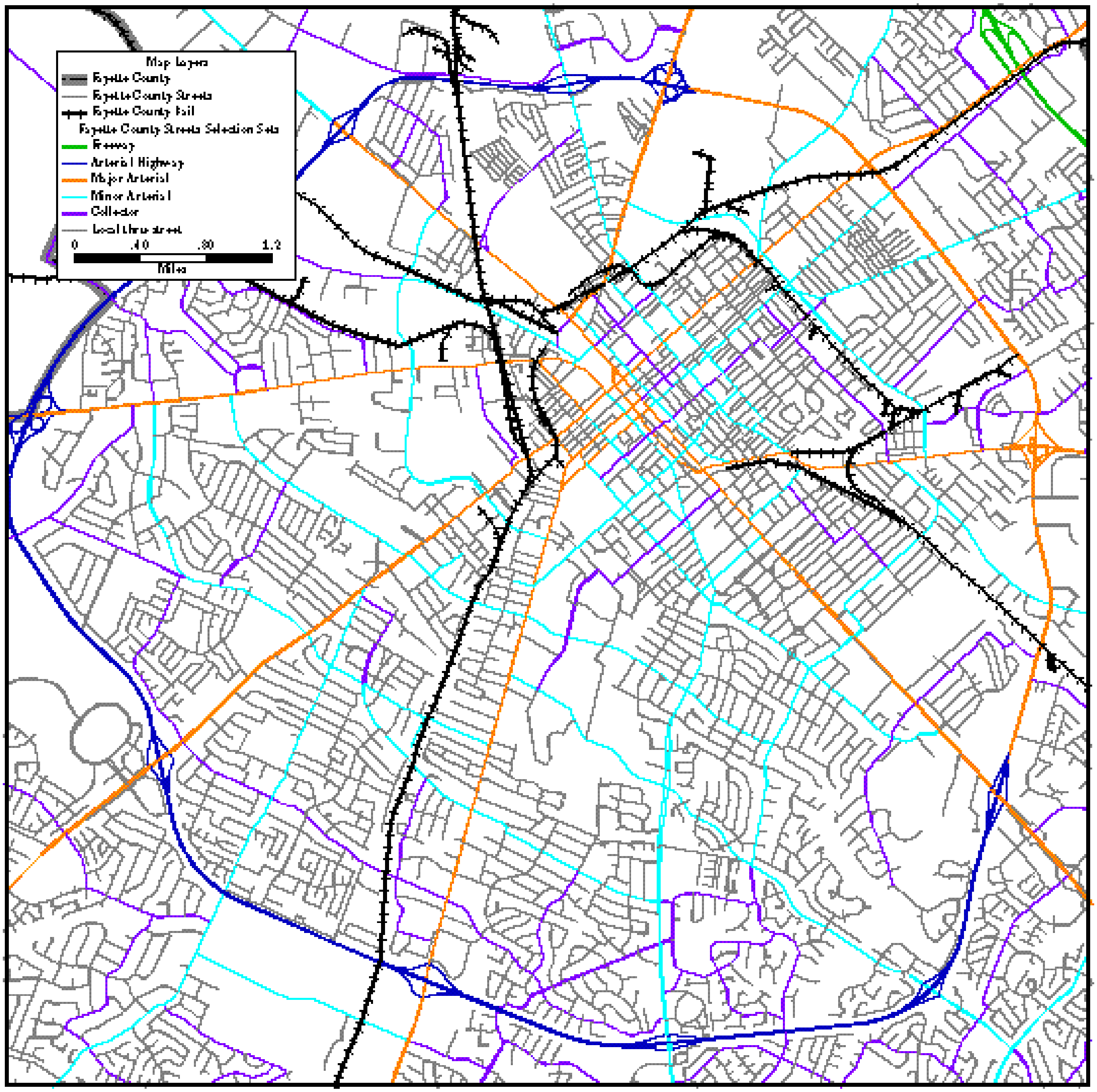

Figure 6.1 Portion of the Lexington Area Base Map Illustrating Highway Functional Class.

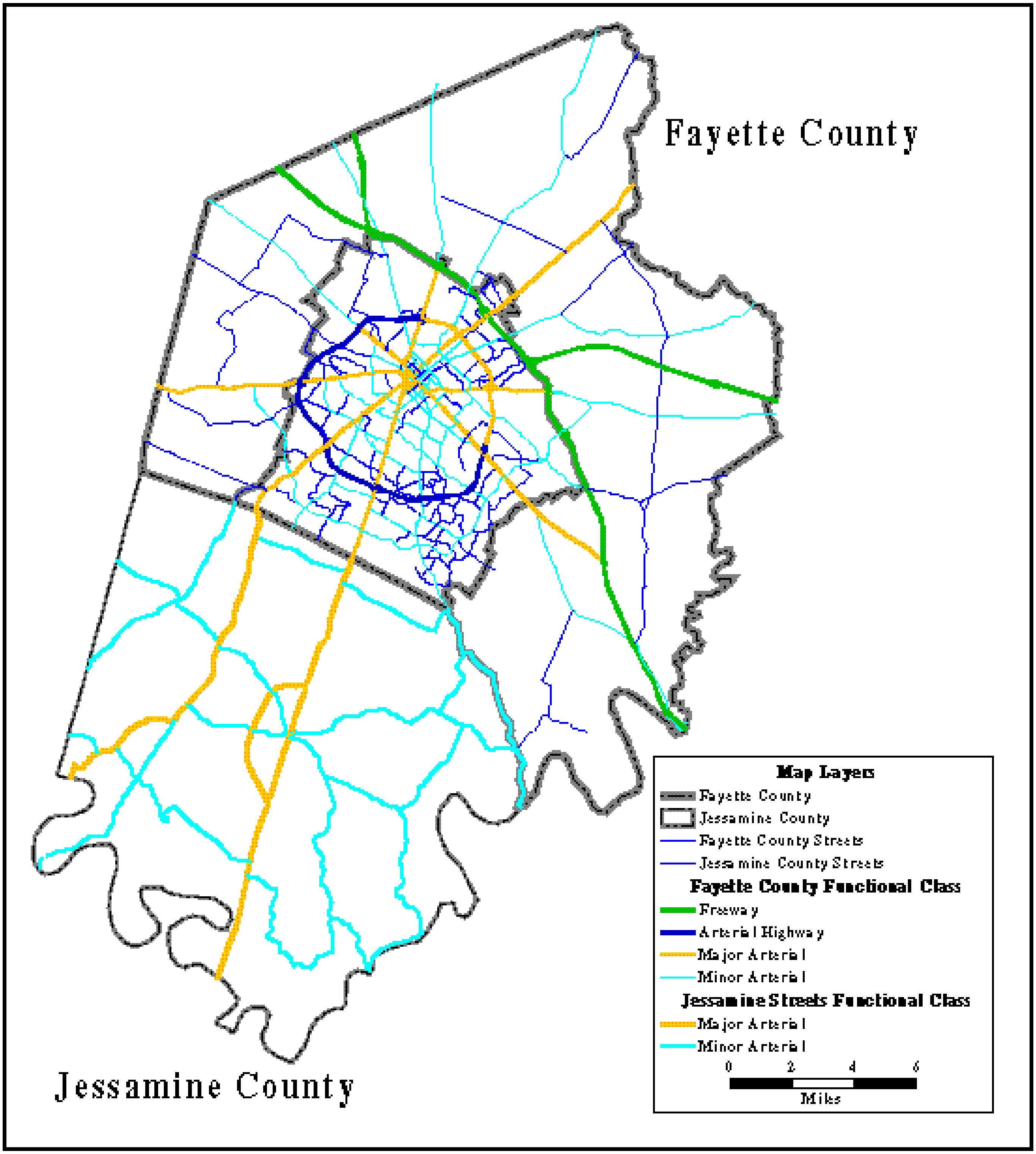

Figure 6.2 Lexington Area MPO Planning Area and Field Test Area.

The map-matching analysis was performed using software developed by TransCore[2]. This automated process is based on a GPS matching algorithm that uses a network database (Link, Node, Shape, and Street Name files) to convert a raw GPS data file to:

- a GPS Match database with coordinate adjusted and link referenced time points,
- a GPS Trip database with trip summary and origin-destination information, and
- a GPS User database with general user identification information.

These results completely describe the collected GPS data points in terms of the network defined by the Lexington map base file.

The principal difficulty in performing the map-matching analysis for the Lexington GPS data file was overcoming the continuity problems related to the irregular time intervals when the data were recorded. These sometimes sparse data points led to poor performance of the matching algorithm, which attempts to identify corners, stops, and curves in the raw GPS data file as features that are recognizable in the map network. These problems were overcome by the logical addition of synthetic data points between the original GPS data points, creating a synthetic data file that approximated one-second data collection. This approach led to much improved performance in the matching algorithm and the resultant matched file for the Lexington field test.

6.5 Summary of Map-Matching Results

Figure 6.3 shows some example trip segments including both the raw GPS data as collected in Lexington and the corresponding matched data after the analysis. In all cases, the trip trace with the single points represents the raw GPS data that was collected in Lexington, and the trip trace where the points are circles represent the matched data. The examples in Figure 6.3 are as follows.

- Figure 6.3(a) - a vehicle exiting a freeway via the off ramp and making a left-turn onto the intersecting highway,

- Figure 6.3(b) - illustrates "wandering" associated with GPS data collection at the beginning of a trip.

- Figure 6.3(c) - illustrates a route with two closely spaced 90-degree turns.

- Figure 6.3(d) - illustrates a wide radius turn.

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[2]TransCore (formerly JHK & Associates), 1900 North Beauregard Street, Alexandria, VA 22311.

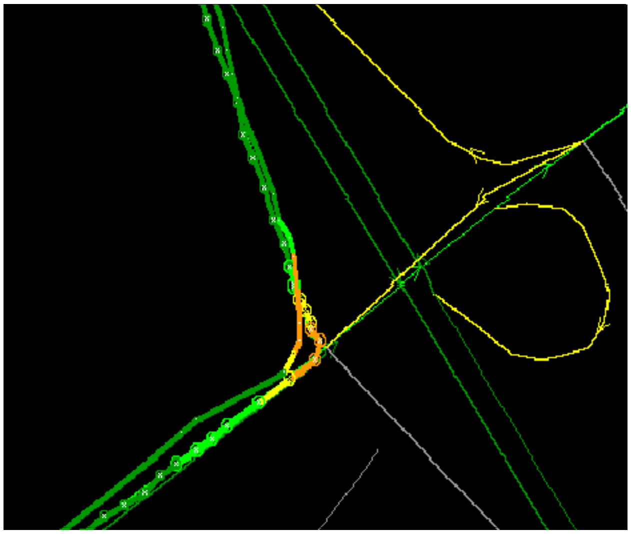

Figure 6.3(a) shows a vehicle exiting a freeway via the off ramp and making a left-turn onto the intersecting highway. The unmatched trace does not hold the tight radius of the turn and does not align with the highway after the vehicle has turned. The matched data set for this segment adheres to the turn radius and the highway after the turn.

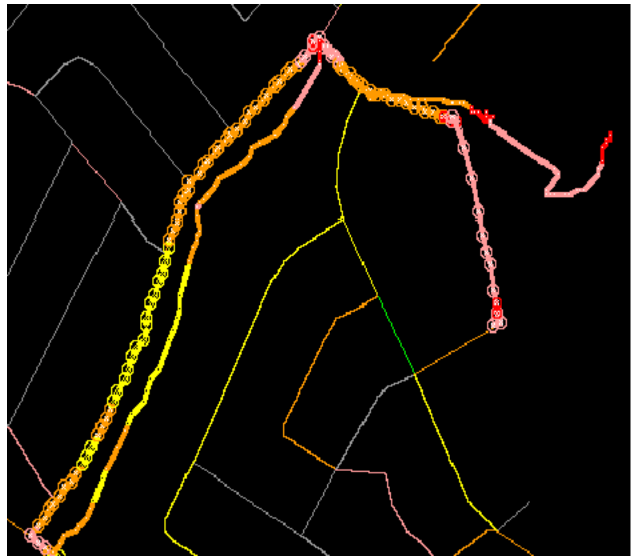

Figure 6.3(b) illustrates one issue associated with GPS data collection at the beginning of a trip. The raw GPS data show some evidence of "wandering" in an area where no roadways are apparent. This initial period occurs as the GPS receiver improves on the position solution and the trace comes close to the established roadway. The matched file adheres to the roadway but, on the other hand, may have "overmatched" the points at the beginning of the trip. The trip apparently starts about mid-way along the first segment instead of at the lower end of the segment as indicated by the matched file.

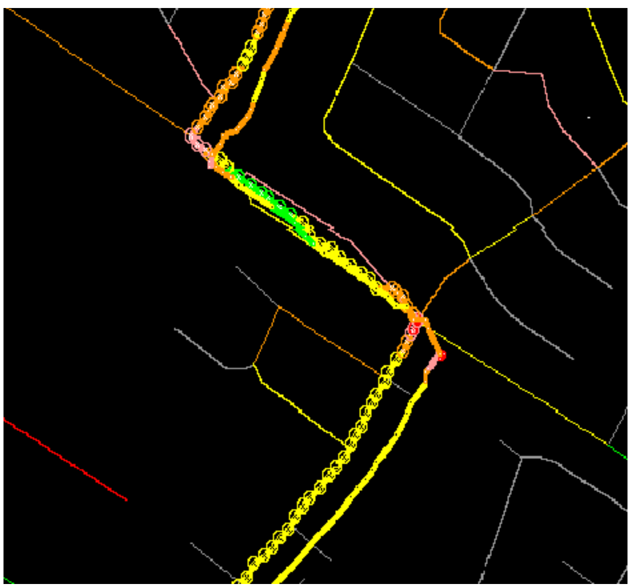

Figure 6.3(c) illustrates a raw data file and matched data file along a route with two closely spaced 90-degree turns. Both traces are fairly consistent, only the matched file approximates the roadway while the raw data file is clearly offset from the roadway.

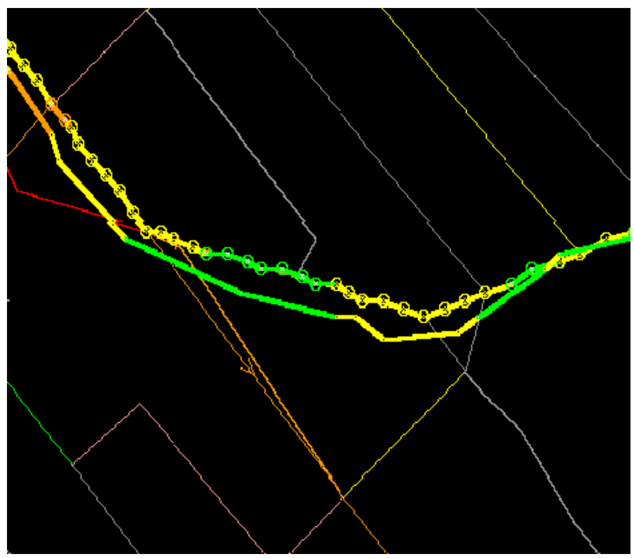

Figure 6.3(d) shows data sets for a wide radius turn. The actual GPS data track a path that has a larger radius than the roadway. The matched data set adheres to the roadway segments.

Figure 6.3 Examples of Raw GPS Data and Matched GPS Data from the Lexington Field Test.

Overall, there were 1,984 respondent-defined trips that had valid GPS data and were subjected to the map-matching analyses[3]. Of these, 1,921 (97%) trips were successfully matched to the network. 39 of the 63 trip files that could not be matched to the network (62%) generally had few valid GPS points in the file (approximately 90% had fewer than 20 valid GPS points), and represented very short distances based on the GPS points that were available (approximately 87% had distances less than 0.16 kilometer (0.10 mile)).

6.6 Benefit of Having GPS Component

There are two distinct benefits to a survey method which includes a GPS component.

- Data are available that may provide information on route choice by the respondents.
- Data can be accurately organized by highway functional class usage and travel speed.

Route choice behavior is complex and not well understood. Most modeling techniques, when dealing with route choice decisions, rely on a shortest path method in the absence of more definitive information. Figure 6.4 provides an example of route choice behavior observed during the Lexington field test. This set of trips, from a single household, illustrates the complexity of route choice decisions that may be made on a daily basis. Clearly a shortest path approach does not capture the travel indicated by these data.

The second distinct difference between using a survey method which includes GPS compared to self-reporting with a telephone interview is that utilization of different classes of roads and travel speeds are available. Traffic counts provide information along specific routes, days and times, but have no corresponding information to vehicle occupancy and trip purpose. Having the elements of trip purpose, occupancy, together with route choice and travel speed, would provide planners with information that could be used in evaluating management systems, designing intelligent transportation systems, and addressing other issues. In the 1990 Nationwide Personal Transportation Survey (NPTS), respondents were asked to identify the number of miles by different road types for a specific trip.[4] This was nearly impossible for most respondents and resulted in poor data quality. The following tables show how the vehicle trip information can be tabulated across roadway functional class.

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[3]The matching analysis considered all trip records with no restriction on duration or number of GPS points. Previous discussions (Sections 4 & 5) do not consider trip records with durations less than one minute or with fewer than 15 valid GPS points.

[4]Research Triangle Institute. "1990 Nationwide Personal Transportation Survey, User's Guide to the Public Use Tapes." Appendix E. Report FHWA-PL-92-007, FHWA, U.S. Department of Transportation, 1991.

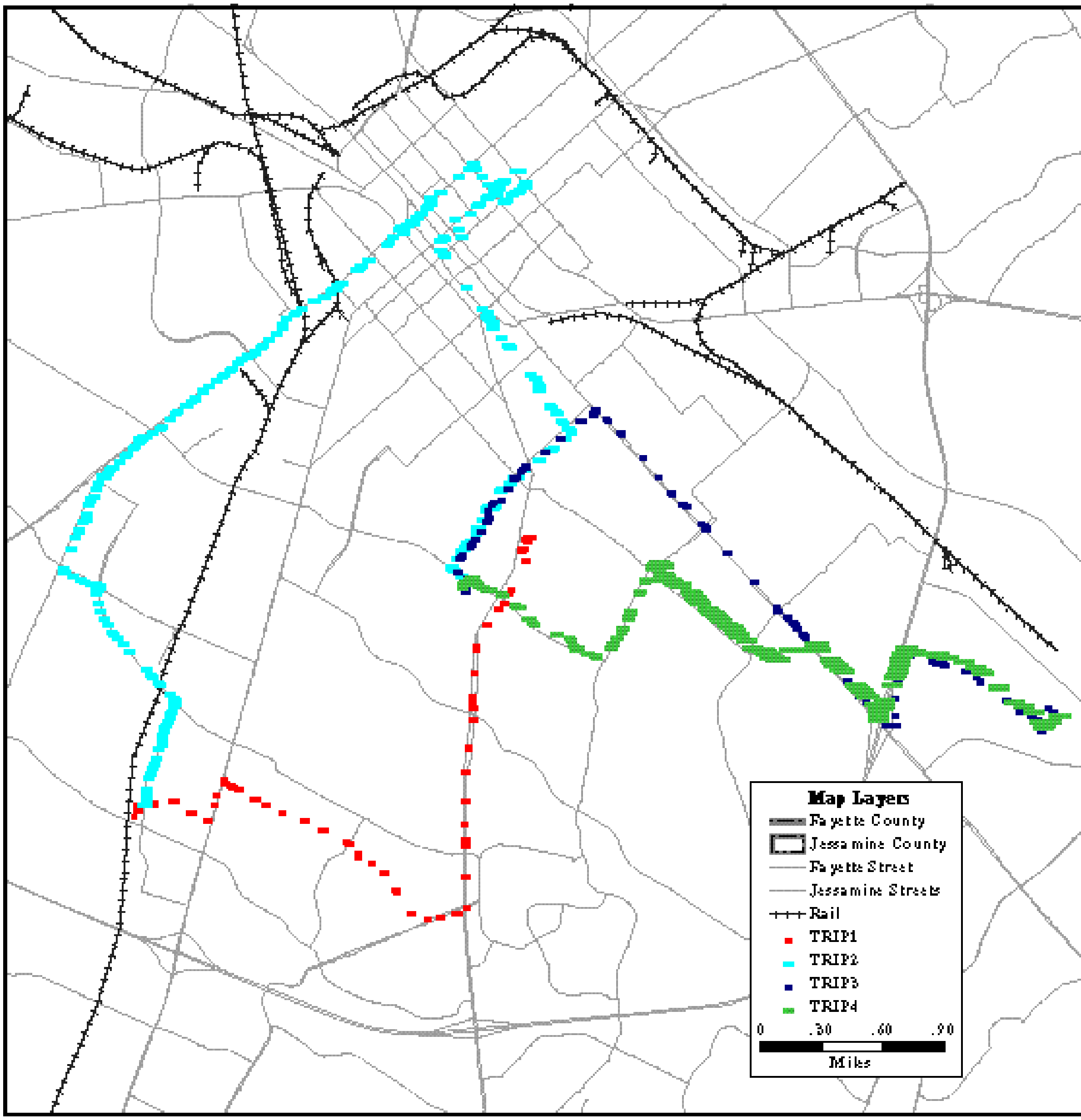

Figure 6.4 Example of Complex Route Choice Behavior.

Table 6.1 presents an overall breakdown of the travel in the Lexington data set by highway functional class.[5] In addition to overall miles traveled, the travel distribution is shown for the AM and PM peak travel periods in the Lexington area.

Table 6.2 presents a breakdown of travel for specific trip purposes as a function of highway functional class. Table 6.3 present travel speeds by highway functional class, including separate breakdowns for the AM and PM peak travel periods.

Table 6.1 Breakdown of Travel by Highway Functional Class and Time of Day.

Highway Functional Class	% of Highway Miles	Miles Traveled	AM Peak 7 - 9 am	PM Peak 4 - 6 pm	Off Peak
Freeway	4.27%	2.87%	0.67%	2.69%	3.36%
Arterial Highway	2.01%	10.45%	16.79%	10.65%	9.03%
Major Arterial	7.19%	32.78%	29.10%	31.29%	33.97%
Minor Arterial	16.91%	29.54%	30.76%	28.15%	29.64%
Collector	8.31%	8.85%	8.33%	9.64%	8.72%
Local thru-street	61.30%	15.50%	14.31%	17.52%	15.27%

6.7 Summary

The ability to use map-matching techniques to transform the collected GPS data into the proper network link segments expands the usefulness of the collected data. Data summaries can be generated by highway functional class or other function that may be contained in the database. GPS data accuracy and data stream continuity are important contributors to the success of the map-matching algorithms. The more important of these is to have a continuous stream of position points, preferably at one-second intervals.

A second issue related to the map analysis is the possibility of detecting undeclared trips among the data. An undeclared trip may be represented by a long dwell time in the data stream, indicating the vehicle is stationary, but the respondent has not indicated a stop through user input. A second type of undeclared trip could be represented by a large discontinuity in the mapped route. In these cases, the start of a trip would be some distance from the end of the previous trip, indicating that the respondent forgot (or refused) to enter the proper trip information. An autonomous device (requiring no user interaction) may resolve those trips

[5]The highway functional class designators in the tables are derived directly from the base files used in the study, and are not necessarily equivalent to the official FHWA highway functional class designators.

where the respondent forgot to enter proper data, but the other undeclared trip issues are still to be examined.

Table 6.2 Breakdown of Travel by Highway Functional Class and Trip Purpose.

Highway Functional Class	Trip Purpose(a)			
	To Work Place	To Social or Recreational Activity	To Eat Out	To Shopping
Freeway	4.0%	3.4%	0.0%	2.0%
Arterial Highway	18.0%	7.8%	13.9%	7.7%
Major Arterial	33.0%	39.1%	33.0%	36.0%
Minor Arterial	27.0%	28.7%	29.2%	30.4%
Collector	8.0%	7.1%	8.1%	9.1%
Local thru-street	10.0%	13.8%	15.8%	14.9%

(a) Trip purpose breakdown includes only trips to an activity. Return trips are not included.

Table 6.3 Breakdown of Travel Speed by Highway Functional Class and Time of Day.

Highway Functional Class	Average Speed (MPH)		
	Mon - Fri all times	AM Peak 7 - 9 am	PM Peak 4 - 6 pm
Freeway	57.3	54.0	56.6
Arterial Highway	49.0	53.7	49.7
Major Arterial	27.3	33.7	27.0
Minor Arterial	24.3	23.6	24.9
Collector	21.0	19.7	21.5
Local thru-street	12.7	14.1	14.1

7. Respondent Attitude Data

As a part of the post-usage interview, the household respondents were queried about their experiences when installing and learning to use the data collection device, their experiences in using the instructional materials and data collection equipment, and specific concerns about this type of data collection effort. These query areas were all conducted as a part of the post-usage interview for each household, after the travel recall portion of the interview was completed. Appendix B of this report contains all questionnaires used during the field test.

The post-usage questions were asked of everyone that had driven the equipped vehicle on the recall day. Within the 100 households, six had two people who had both driven the equipped vehicle on the recall day. All 106 individuals who had driven an equipped vehicle on the recall day participated in the post-usage interviews.

The objectives of these questions focused on issues related to ease-of-use of the data collection device, both at installation and for day-to-day use, the respondents' general impressions about the device and preferences versus other data collection techniques, and any fears or concerns that the respondents expressed with respect to using the device. These areas are all important for deciding if this type of data collection device might be feasible for future, more wide-spread use to supplement existing data collection techniques.

The results of these respondent attitude queries are discussed in the following sections.

7.1 Installation of the Data Collection Equipment

An important issue in using the data collection equipment is the ability of the respondent to install the equipment properly without the assistance of a technician. The design of the equipment was focused on easy installation, and both an illustrated, written guide and an instructional video tape were provided to the respondents to assist in the installation process. Respondents could also call the project "hotline" (operated by the MPO) if they were having problems.

This series of questions in the post-usage interview focused on the installation process and the instructions that were provided to assist the respondent in the installation process.

Question B1.	Did you yourself install the GPS device? A. Who installed the device for you? B. Why did you not install the device yourself?					
GPS device installed by...	Male	Female	18-24	25-49	50-64	65+
Self	47	37	25	33	14	12
Household Member	5	14	2	9	5	3
Other	0	3	0	0	1	2

Most respondents (approximately 80%) installed the GPS equipment themselves. Males were more likely (90%) to have installed the equipment themselves than females (69%). For both males and females, assistance was generally provided by another household member. Overall, members of the households accounted for 97% of the equipment installations.

Of the respondents that did not install the equipment themselves, only four or five expressed reluctance or some doubt about installing the equipment. Two respondents indicated some degree of physically disability and thus needed some assistance with the installation. Most responses to question B1B stated that a husband, brother, or grandson wanted to install the device and the respondents simply did not decline the assistance.

Question B2.	Which of the following installation instructions did you utilize when installing the GPS device into your vehicle?					
Instruction...	Male	Female	18-24	25-49	50-64	65+
Written Guide	33	23	13	22	10	11
Video	35	23	19	21	12	7
Hotline	3	1	1	1	1	1
In-person Help	0	1	0	0	0	1
Other	1	0	0	1	0	0

As expected, both the written instructions and instructional video were used extensively (95%) in the installation process, with responses about evenly split between the written instructions and the instructional video. Younger respondents were more likely to have used the instructional video tape, and older respondents[1] were more likely to have used the written instructions.

Question B3. Which installation instructions did you consult first?						
Instruction...	Male	Female	18-24	25-49	50-64	65+
Written Guide	10	8	4	6	4	4
Video	13	3	4	5	4	3

Responses were also evenly split between the written instructions and the instructional video among those respondents that used more than one instructional material in the installation process. Within this group, males were more likely to have first used the instructional video, and females were more likely to have first used the written instructions. First usage was evenly split across the age groups in this study.

Question B4. Which installation instructions did you find most helpful?						
Instruction...	Male	Female	18-24	25-49	50-64	65+
Written Guide	5	6	2	2	3	4
Video	17	4	6	9	4	2

Again, males preferred the instructional video and females preferred the written instructions, however the instructional video was preferred by a larger margin than the first usage question addressed above. Also, there appear to be differences across the age groups. The youngest age groups clearly preferred the instructional video by a margin of almost 4 to 1, however the oldest group preferred the written instructions by about a 2 to 1 margin.

[1]Many respondents indicated that they used both of the instructional materials in the installation process.

Question B5.	How clear were the installation instructions in the written guide? Would you say very clear, somewhat clear, somewhat unclear, or very unclear?					
Written Guide...	Male	Female	18-24	25-49	50-64	65+
Very Clear	26	19	11	13	10	11
Somewhat Clear	7	4	2	9	0	0
Somewhat Unclear	0	0	0	0	0	0
Very Unclear	0	0	0	0	0	0

Users of the written instructions generally agreed that the written instructions were very clear (80%), however the 25-49 age group was less enthusiastic with a response of 59% very clear and 41% somewhat clear.

Question B6.	Do you strongly agree, agree, disagree, or strongly disagree with the following statement? The written instructions alone were sufficient to allow me to successfully install the GPS device.					
Written Guide sufficient?...	Male	Female	18-24	25-49	50-64	65+
Strongly Agree	19	15	9	11	6	8
Agree	14	8	4	11	4	3
Disagree	0	0	0	0	0	0
Strongly Disagree	0	0	0	0	0	0

While a large proportion of the written instruction users thought the instructions were very clear, a smaller proportion expressed strong agreement that the written instructions alone were sufficient to install the GPS equipment. Approximately 61% of these users strongly agreed, and the remaining users agreed with the statement. The oldest age group (73%) and the youngest age group (69%) were the strongest supporters of the written instructions. None of the users of the written instructions disagreed with the statement in Question B6.

Question B7.	How clear were the installation instructions in the video tape? Would you say very clear, somewhat clear, somewhat unclear, or very unclear?

Video Tape...	Male	Female	18-24	25-49	50-64	65+
Very Clear	32	19	17	17	11	6
Somewhat Clear	3	3	2	3	0	1
Somewhat Unclear	0	1	0	1	0	0
Very Unclear	0	0	0	0	0	0

Users of the instructional video agreed that the instructional video was very clear (88%). All age groups responded with greater than 80% of the responses being "very clear". Only one female in the 25-49 age group rated the instructional video as "somewhat unclear".

Question B8.	Do you strongly agree, agree, disagree, or strongly disagree with the following statement? The video tape alone was sufficient to allow me to successfully install the GPS device.

Video Tape...	Male	Female	18-24	25-49	50-64	65+
Strongly Agree	26	14	12	16	8	4
Agree	9	4	7	3	1	2
Disagree	0	5	0	2	2	1
Strongly Disagree	0	0	0	0	0	0

Users of the instructional video remained confident that the instructional video was sufficient for the installation with an overall response of 70% strongly agree, 22% agree, and 8% disagree. The middle two age groups were the biggest supporters of the instructional video tape with 76% and 73% "strongly agree". These age groups also had some dissenters with responses of "disagree" to the above question. All of the disagree responses were female, spread over all age groups except the youngest age group (ages 18-24).

Questions B9, B11.	Was the hotline staff or the person who came to your home able to answer you questions clearly? Would you say their answers were very clear, somewhat clear, somewhat unclear, or very unclear?
Questions B10, B12.	Do you strongly agree, agree, disagree, or strongly disagree with the following statement? The GPS device cannot be installed without hotline answers or the people coming to your home.

Few respondents required hotline staff or personal assistance for installation of the GPS equipment. In all cases, the instructions or answers they received were judged to be very clear, and all of the respondents disagreed with the statement that the GPS equipment cannot be installed without this assistance.

Question B13. Did you experience any problems in installing the GPS device?

Problems installing?...	Male	Female	18-24	25-49	50-64	65+
Yes	6	1	2	1	2	2
No	41	36	23	32	12	10

Few problems were experienced when installing the GPS equipment. Approximately 92% of the respondents reported no problems when installing the GPS equipment. Of those that did report problems (approximately 8%), all but one were males.

Question B14. Did you use anyone else's help to install the device?
A. Who helped you?
B. How did the other (person/people) give you assistance?
C. Could you have installed the device without assistance from others?

Help installing?...	Male	Female	18-24	25-49	50-64	65+
Yes	1	2	1	2	0	0
No	46	35	24	31	14	12

Few of the respondents (4%) had someone help them install the GPS equipment. All received assistance from someone in the household, and all stated that they could have installed the GPS equipment without assistance from others. The primary assistance received was help in connecting or manipulating the cables and wires connecting the various pieces of equipment.

Question B15. How could the installation process be improved?

Most respondents complimented the ease of installation and offered no suggestions for improving the process. Most suggestions received related to making the cables shorter so that there would be less excess cable in the car, or making the cables more flexible so that they would be easier to manipulate. Also, several respondents suggested mounting the GPS receiver inside the windshield of the vehicle instead of outside on the roof.

7.2 Use of the Data Collection Equipment

This series of questions in the post-usage interview focused on the use of the data collection equipment and the instructions that were provided to assist the respondent in using the equipment.

Question C1.	Did you ever use the hand-held computer?

All respondents except one used the hand-held computer. No explanation was recorded explaining the reason for this exception.

Question C2.	How did you learn to use the hand-held computer? Did you read the written guide, watch the videotape, call the hotline, have project staff teach you in-person, or did you learn from someone else?

Instruction...	Male	Female	18-24	25-49	50-64	65+
Written Guide	30	30	12	23	13	12
Video	39	35	20	28	16	10
Hotline	1	0	0	0	0	0
In-person Help	0	2	0	0	0	2
Other	1	1	0	2	0	0

Overall, 53% of the responses credit the instructional video and 43% of the responses credit the written instructions. The remaining responses are spread among the hotline and personal assistance categories. Again, the younger respondents were more likely to cite the instructional video as they learned to use the hand-held computer, and older respondents were more likely to cite the written instructions.

Question C3.	Which instructions did you consult first to learn to use the hand-held computer?

Instruction...	Male	Female	18-24	25-49	50-64	65+
Written Guide	12	4	3	6	4	3
Video	8	10	3	1	5	3

Overall, respondents consulted both the instructional video and written instructions at approximately the same frequency. Males were more likely to consult the written instructions first, and females were more likely to consult the instructional video first. The age groups showed about a 50/50 split between the written instructions and the instructional video, except for the 25-49 age group which had a clear preference for consulting the written instructions first (86%).

Question C4. Which usage instructions did you find most helpful?						
Instruction...	Male	Female	18-24	25-49	50-64	65+
Written Guide	7	6	3	6	1	3
Video	11	8	3	7	7	2

For those respondents that consulted both sets of instructions, the instructional video was believed to be more helpful to using the hand-held computer by both males (61%) and females (57%). Only the oldest age group preferred the written instructions, by a 3 to 2 margin.

Question C5. How clear were the usage instructions in the written guide? Would you say very clear, somewhat clear, somewhat unclear, or very unclear?						
Written Guide...	Male	Female	18-24	25-49	50-64	65+
Very Clear	22	23	11	16	8	10
Somewhat Clear	8	6	1	6	5	2
Somewhat Unclear	0	1	0	1	0	0
Very Unclear	0	0	0	0	0	0

Of the respondents that used the written instructions to learn how to use the equipment, 75% rated the written instructions as very clear and 23% gave a rating of somewhat clear. Both males and females had similar overall responses. Only one respondent rated the written instructions as somewhat unclear. The youngest and the oldest age groups appeared to be the most receptive to the written instructions, giving very clear ratings of 92% and 83% respectively.

Question C6. Do you strongly agree, agree, disagree, or strongly disagree with the following statements? a. The written instructions alone were sufficient to allow me to successfully learn how to use the hand-held computer b. The written instructions alone were sufficient to allow me to successfully teach other drivers how to use the hand-held computer						
Written Guide (C6a)...	Male	Female	18-24	25-49	50-64	65+
Strongly Agree	20	12	7	12	6	7
Agree	9	16	5	9	6	5

Disagree	1	2	0	2	1	0
Strongly Disagree	0	0	0	0	0	0

Users of the written instructions gave an overall 95% in the strongly agree and agree ratings when asked if the written instructions alone were sufficient for learning how to use the equipment. However, the strongly agree category received only a 53% rating overall, with females being noticeably lower than males with only a 40% strongly agree rating. Overall, 5% of the respondents disagreed with the statement. The youngest and the oldest age groups again appeared to be the most receptive to the written instructions, with both groups giving strongly agree ratings of 58%.

Responses were slightly more favorable when respondents were asked if the written instructions alone were sufficient for them to teach other drivers how to use the equipment, with an overall strongly agree rating of 57%.

Question C7. How clear were the usage instructions in the video tape? Would you say very clear, somewhat clear, somewhat unclear, or very unclear?

Video Tape...	Male	Female	18-24	25-49	50-64	65+
Very Clear	34	25	17	18	15	9
Somewhat Clear	5	10	3	10	1	1
Somewhat Unclear	0	0	0	0	0	0
Very Unclear	0	0	0	0	0	0

Of the respondents that used the instructional video to learn how to use the equipment, 80% rated the instructional video as very clear and 20% gave a rating of somewhat clear. Males rated the instructional video more favorably than females with a very clear rating or 87%. No respondents rated the instructional video less than somewhat clear. Among the age groups, only the 25-49 age group gave the instructional video a very clear rating of less than 85%, with a rating of 64%.

Question C8. Do you strongly agree, agree, disagree, or strongly disagree with the following statements?

a. The video tape alone was sufficient to allow me to successfully learn how to use the hand-held computer
b. The video tape alone was sufficient to allow me to successfully teach other drivers how to use the hand-held computer

Video Tape (C8a)...	Male	Female	18-24	25-49	50-64	65+

Strongly Agree	30	22	13	21	11	7
Agree	8	8	6	5	2	3
Disagree	1	4	1	1	3	0
Strongly Disagree	0	1	0	1	0	0

Users of the instructional video gave an overall 92% in the strongly agree and agree ratings when asked if the instructional video alone was sufficient for learning how to use the equipment. The strongly agree category received a 70% rating overall, with females being lower than males with a 63% strongly agree rating. Overall, 8% of the respondents disagreed or strongly disagreed with the statement. The three oldest age groups appeared to be the most receptive to the instructional video, giving strongly agree ratings of 69% to 75%.

Responses were slightly less favorable when respondents were asked if the instructional video alone was sufficient for them to teach other drivers how to use the equipment, with an overall strongly agree rating of 68%.

Questions C9, C11.	Were the hotline staff or the person who came to your home able to clearly answer your questions about using the hand-held computer? Would you say their answers were very clear, somewhat clear, somewhat unclear, or very unclear?
Questions C10, C12.	Do you strongly agree, agree, disagree, or strongly disagree with the following statement? The hand-held computer cannot be used correctly without hotline advice or without people coming to your home.

Few respondents required hotline staff or personal assistance to learn how to use the GPS equipment. In all cases, the instructions or answers they received were judged to be very clear or somewhat clear, and all but one of the respondents disagreed with the statement that the GPS equipment cannot be installed without this assistance. This single respondent agreed with the statement that the equipment cannot be used correctly without people coming to your home.

Question C13.	Overall, how easy was it for you to use the hand-held computer before each trip? Would you say very easy, somewhat easy, somewhat difficult or very difficult?

Use before each trip?...	Male	Female	18-24	25-49	50-64	65+
Very Easy	39	36	26	30	13	6
Somewhat Easy	10	17	1	11	6	9

Somewhat Difficult	2	0	0	0	1	1
Very Difficult	1	0	0	0	0	1

Overall, over 97% of the respondents said it was very easy or somewhat easy to use the hand-held computer before each trip. Younger people were more likely to find the hand-held computer easier to use than older people. Three males, one 50-64 age and two 65+ age, stated it was somewhat difficult or very difficult to use the hand-held computer before each trip.

Question C14.	How often were you able to enter trip data into the hand-held computer? Would you say all the time, most of the time, some of the time, almost never or never at all?

Enter data...	Male	Female	18-24	25-49	50-64	65+
All the Time	35	34	16	28	14	11
Most of the Time	17	17	11	12	6	5
Some of the Time	0	2	0	1	0	1
Almost Never or Never	0	0	0	0	0	0

Over 65% of the respondents reported that they entered trip data all of the time, and about 32% reported entering trip data most of the time. Overall responses were consistent for males and females, and generally consistent across age groups. The age group 50-64 gave the highest response of 70% for reporting trip data all the time.

Question C15.	How much time was needed, on average, for data entry before each trip?

Figure 7.1 shows the cumulative distribution of the time required to input data into the hand-held computer at the start of a trip. Approximately 74% of the respondents reported that entering trip information took 1.0 minute or less per trip, and over 95% reported 2 minutes or less.

Question C16.	How easy was it for you to read the screen on the hand-held computer? Would you say very easy, somewhat easy, somewhat difficult or very difficult?

Read the Screen?...	Male	Female	18-24	25-49	50-64	65+
Very Easy	31	26	24	19	8	6
Somewhat Easy	15	22	3	17	8	9
Somewhat Difficult	4	5	0	5	3	1

Very Difficult	2	0	0	0	1	1

Almost 90% of the respondents reported that it was very easy or somewhat easy to read the screen on the hand-held computer. However, only the youngest age group had no responses that indicated some difficulty in reading the screen. Difficulties associated with reading the screen increased with age group, with the oldest age group (65+) reporting only 35% "very easy" and approximately 12% in the "somewhat difficult" or "very difficult" response categories.

Question C17.	What problems did you have in using the hand-held computer?

Anecdotal data collected during the post usage interviews indicate that reading the screen on the hand-held computer was an operating issue. The very smooth, liquid crystal display (LCD) screen has a back light and an adjustable contrast control. However, ambient lighting conditions, viewing angle, temperature of the screen, and glare conditions made the screen hard to read without frequent adjustment of the screen contrast control. The screen contrast often needed adjustment after only a short trip. This frequent need to adjust screen contrast was cited as the single largest operating problem in the field test.

A second operating issue relates to the menu choices available to the respondent. Several respondents indicated that they were unsure which options to select for particular situations, leading to confusion when selecting from the menu choices.

Software anomalies also occurred from time to time, creating confusion in specific cases. Where possible, those devices were replaced in the field until the software could be replaced. Examples

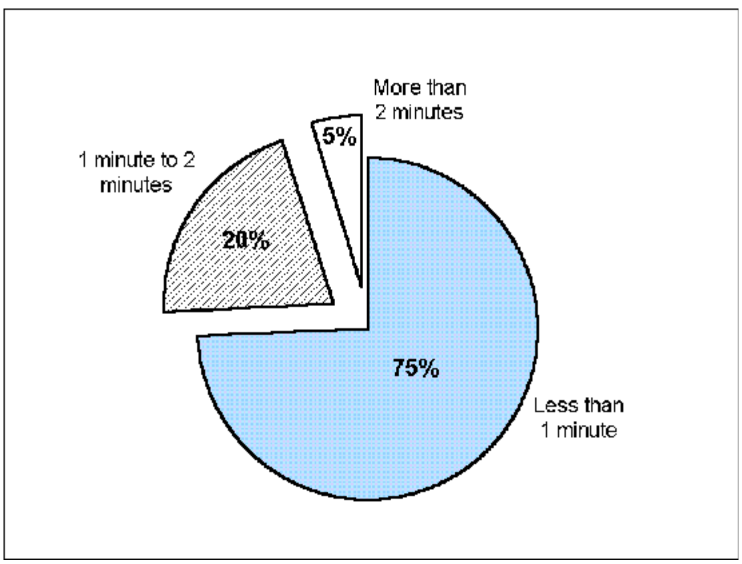

Figure 7.1 Estimated Time Required to Input Trip Data for One Trip

of software anomalies that appeared during the field test include the following.

- In one instance, the names associated with a previous user appeared in the place of the current user's household names in the menus. At some point during the previous user's time with the device, the software had been copied into the "permanent" memory of the device from the "temporary" memory associated with the PCMCIA card. Once this occurred, the software copy in "permanent" memory ultimately "overrode" the PCMCIA software and became the functioning copy of the software on the device, containing the household names of the previous user. Investigation revealed that the Magic Link® operating system was occasionally copying the software to the "permanent" memory.

- In several cases, the household names disappeared from the menus leaving "other" as the only selection for the driver and other household members. A specific cause for this occurrence was not identified, however reprogramming the household names appeared to solve this anomaly.

- Some user selections were lost from the database because the previous choice (as indicated by a highlight on the screen) was not "remembered". A specific cause for this occurrence was not identified. This occurrence was probably transparent to the users, however it resulted in blanks in data fields when it occurred. For example, a trip record may have a blank for the driver field, even though the appropriate driver name was highlighted on the selection screen.

- In one case the device would not turn on. This condition was attributed to a complete drain of the device's internal battery because the voltage from the vehicle cigarette lighter was too low to maintain the battery charge (either from a weak battery or an inadequate wiring connection). This device was replaced in the field. Once the battery was recharged, there was no indication of a continuing problem.

In a few cases, cabling was cited as being cumbersome. Some participants removed the equipment from their vehicles overnight to avoid theft, however they did not cite this as a problem.

Question C18. Did anyone else help you to use the hand-held computer?
A. Who helped you?
B. How did the other (person/people) give you assistance?
C. Could you have used the hand-held computer without assistance from others?

Did anyone help?...	Male	Female	18-24	25-49	50-64	65+
Yes	11	12	7	10	3	3
No	41	41	20	31	17	14

Approximately 22% of respondents reported that someone helped them use the hand-held computer. Males and females both received some help approximately 22% of the time. The younger two age groups were about 10% more likely to receive this kind of help. All of the assistance is reported to be from other household members and friends who generally were passengers in the vehicle. Assistance was usually entering trip data into the hand-held computer or reading the screen for the driver. All but two of the respondents indicated that they could have used the hand-held computer without assistance from others in the vehicle.

Question C19.	Was the use of the hand-held computer easier or harder than you thought it would be? A. In what ways was it harder?

Easier or harder?...	Male	Female	18-24	25-49	50-64	65+
Easier	31	40	22	27	14	8
Harder	3	4	1	2	1	3
About as expected	18	9	4	12	5	6

Overall, approximately 7% of the respondents reported the hand-held computer to be harder to operate than they expected, compared with almost 68% that reported that it was easier than they had expected. The youngest age group most frequently rated the hand-held computer easier than expected (82%), while the oldest age group represented the opposite end of the spectrum, with only 47% in the "easier" category and nearly 18% in the "harder" category.

Question C20.	Were there occasions, such as quick trips or when you were running late, when you did not have time to input trip data?

Did not have time?...	Male	Female	18-24	25-49	50-64	65+
Yes	15	18	15	14	2	2
No	36	33	11	26	17	15

Approximately one-third of the respondents reported occasions when they did not input trip data. These rates were about the same for both males and females. However, the younger age groups were much more likely to skip the data entry under these conditions. Nearly 58% of the youngest age group (18-24) reported skipping some data, and approximately 35% of the 25-49 age group reported skipping some data. The older two age groups were more reliable, with only 10% to 12% of their age groups reporting skipped data.

Question C21.	Would you have preferred keeping a written log of driving instead of using the hand-held computer?

Written diary instead?...	Male	Female	18-24	25-49	50-64	65+
Yes	7	4	4	1	2	4
No	45	49	23	40	18	13

Nearly 82% of males and 93% of females did not favor keeping a written driving log or diary over using the hand-held computer.

Question C22.	Would you be willing to use this device again in a similar study? A. Why would you not use it again?					
Use again?...	Male	Female	18-24	25-49	50-64	65+
Yes	50	53	26	41	20	16
No	2	0	1	0	0	1

Only 2 of the 105 respondents indicated that they would not be willing to use the hand-held computer again in similar conditions. One of the respondents reported that a physical handicap made the device inconvenient to use and thus they would choose not to participate again. The other declining respondent reported that they had become annoyed with the device by the end of their usage period and would likely not participate again.

Question C23.	While you were driving the vehicle, how much of a distraction was created by having the device in use? Would you say a great deal, some, very little or no distraction at all?					
Distraction?...	Male	Female	18-24	25-49	50-64	65+
Great Deal	0	0	0	0	0	0
Some	2	2	1	2	1	0
Very Little	9	10	8	6	5	0
None	41	42	18	34	14	17

Approximately 78% of the respondents reported no driving distraction while using the device and an additional 18% reported “very little” distraction. These response rates are approximately the same for both males and females. These response rates varied some across age groups, however no age group had over 5% response in the “some distraction” category, and no responses were received in the “great deal” of distraction while driving.

Question C24.	Did you change your driving habits in any way because the device was in the vehicle? A. In what way did your driving change?

Only one individual reported a change in driving habits while using the device. This change was described as cutting out some short trips because they did not wish to enter the data.

Question C25.	In what way could we improve the device and its usage? Please consider the hand-held computer, the menus that appeared on the screens, the satellite receiver, the instructions and the help that was available.

While many respondents offered no suggestions for improving the equipment, many did offer suggestions that generally fall into three areas.

(1) Many respondents reported the cabling associated with the equipment to be excessive and somewhat difficult to deal with. Most suggested shorter cables, or perhaps a wireless connection between the GPS receiver and the hand-held computer.

(2) Many respondents were uncomfortable with the mounting options for the equipment. Many preferred that the GPS receiver be mounted inside the car rather than outside on the roof. The hand-held computer also caused some concern as it generally lay loose on the front seat of the vehicle. Some respondents suggested Velcro or suction cup mounts to the dashboard as a means to secure the equipment.

(3) A variety of suggestions were received regarding the menus or choices provided in the software. Some felt that the proper choices weren't available or that the selections that were available were too vague and confusing. One or two respondents suggested "voice" cues from the computer and voice recording capability so that the driver could simply state the required information.

7.3 General Concerns and Issues

This series of questions in the post-usage interview focused on the possible safety and security concerns of the respondents during the data collection phase of the field test.

Question D1.	Did you have any personal concerns about having your vehicle's movement recorded by the device?

Personal concerns?...	Male	Female	18-24	25-49	50-64	65+
Yes	2	5	0	5	1	1
No	50	49	27	37	19	16

Overall, less than 7% of the respondents expressed concerns about recording their vehicle's movements. More females than males expressed these concerns, and approximately 12% of the 25-49 age group expressed concerns. The anecdotal responses indicated that these concerns focused chiefly on personal privacy issues and whether or not the device could be used to reveal when the respondents were not at home.

Question D2.	Do you have any concerns about the government collecting personal travel data?					
Concerns over data?...	Male	Female	18-24	25-49	50-64	65+
Yes	2	3	0	4	1	0
No	50	51	27	38	19	17

Overall, less than 5% of the respondents expressed concerns about the government collecting personal travel data. Females and males expressed these concerns at approximately the same rate, and approximately 9.5% of the 25-49 age group expressed concerns, the largest fraction among the age groups. The anecdotal responses indicated that these concerns were exclusively focused on personal privacy issues, generally described as an uncomfortable feeling associated with knowing that your movements were being recorded.

Question D3.	Did you have any concerns about the safety of your vehicle while the device was installed?					
Concerns over safety?...	Male	Female	18-24	25-49	50-64	65+
Yes	13	15	8	8	5	7
No	39	39	19	34	15	10

Over a quarter of the respondents expressed concerns about the safety of their vehicle while the equipment was installed. Overall, rates of expressing these concerns were consistent between males and females, and among age groups, the oldest age groups had the highest rate at about 41%. Segregating the responses by age and sex, males in the youngest two age groups were the most frequent to express safety concerns, and females in the oldest two age groups were the most frequent to express safety concerns.

The anecdotal responses indicated that the majority of the concerns related to the potential for someone breaking into the car and stealing the equipment. Many respondents report that they took measures to counter this concern, such as removing the equipment from the vehicle at night or being careful to hide the hand-held computer when it was in the vehicle. Several respondents also expressed concerns about the equipment draining the vehicle's battery although no reports related to this issue were received during the field test.

8. Summary and Conclusions

The overall objectives of this research program focused on three areas.

- *Technology* - Develop a method and hardware to integrate GPS technology with self-reported travel behavior to improve travel behavior data.

- *Advantages & Disadvantages* - Document the differences between self-reported travel and GPS recorded travel and document the pros and cons of each method.

- *Future Potential* - Determine the potential for using GPS technology with regional and national travel behavior surveys, with particular regard to subjective responses to privacy.

Progress towards these objectives is described below.

8.1 Technology

Using GPS technology with small hand-held computers is a functional reality. Small, relatively light-weight, and relatively inexpensive equipment can be delivered to respondents for self-installation and use. The touch screen interface was easy to use, even for people over age 65. The general public is responsive to this technology and is willing to participate in multi-day surveys, given a financial incentive. This technology seems particularly suited for use in private vehicle surveys where the equipment must be very portable.

Absolute GPS data, by itself, appears sufficient to plot most trips on the roadway network. Also, matching the GPS data to the roadway network can be done sufficiently without a positionally accurate geographic base file. That is, map matching is possible, using only the TIGER/Line files available from the U.S. Census Bureau, although errors in some roads would be more likely in areas with parallel roads in close proximity.

Using differential correction, or GPS with additional equipment (such as gyroscopes or dead-reckoning), can provide additional accuracy and information for additional cost. These techniques may be needed to accurately track vehicles in urban canyons and in dense tree cover where absolute GPS technology alone may not be sufficient because the GPS signals are reflected or obscured.

8.2 Advantages & Disadvantages

The results have demonstrated that computer-assisted self-interviewing (CASI) combined with GPS technology can improve the quality of data from household travel surveys. Because the machine is tracking the start and end times, and the actual routes traveled, the respondent is no longer responsible for reporting these items. In particular, the reporting of destination addresses is long and time consuming, and often frustrating for the respondent. The frustration may be because the respondent does not know an actual address and may get to their destination using landmarks, or because the telephone interviewer cannot correctly spell or type in the street name.

In addition, the time taken for the respondent to begin each trip using this technology is about 1 minute. One minute of data entry time per trip, or five or six minutes of data entry time per day (assuming five or six trips per day) are not perceived to be as burdensome as spending 20 minutes on the telephone in one session to report one day's travel. This approach also helps eliminate the burden of the telephone interviewer contacting the respondents at a time that is not convenient for the respondent.

An ancillary objective was to identify the occurrence of missing (unreported) trips and therefore reduce the number of missing trips in the trip data record. A missing trip is generally described as a brief stop at the dry cleaner or the video store that is reported under a longer trip such as "return home".

In the field test, the respondent was required to turn the equipment on each time they began a trip. If the respondent failed to turn the equipment on (either deliberately or inadvertently), then no trip was recorded, and the data record thus contains a gap in the positional information that was recorded. However, when the equipment was on and the respondent made an intermediate stop, the time and positional record reflects those stops although there is no trip purpose assigned to the activity.

Thus the attempt to identify unreported trips remains incomplete. The equipment must activate automatically when the engine is operating to accomplish this objective. The machine can then collect time and position data, even if the respondent does not actively communicate with the device. The equipment is currently being modified for a truck activity survey to operate in this mode.

This CASI approach not only improves the quality of data that is traditionally collected using self-reported methods, such as paper diaries and telephone or mail-back retrieval, but information which was previously nearly impossible to obtain can be collected for routine analysis. For example, in the 1990 NPTS telephone interviews, one trip of each respondent was selected and the respondent was asked to estimate how many miles were traveled on what type of roadway (i.e., interstate, major arterial, collector, local road). Previous efforts to collect this type of information included asking respondents to draw their selected routes on paper maps. Route choice information is easily available using GPS/GIS components.

Neither of these methods captures accurate travel departure time or travel speed. Travel departure times and speed are easily available using a GPS component. Also, because the surveys can cover multiple days versus the single-day telephone interview, variability by day, by day of week, and departure time can be studied.

Table 8.1 compares the traditional telephone survey method with the potential resources available from the CASI approach described in this report. The advantages for travel data collection are clear. Data values that must be estimated in a telephone interview can be recorded more precisely in a CASI survey. Also, data values that are not accessible via telephone interviews can be collected using GPS and GIS techniques.

Table 8.1. Comparison of Traditional Telephone Survey with GPS/PTS Survey

Data Item	Traditional Telephone Survey	GPS/PTS Survey (CASI)
Trip start & end times	Estimated	Machine recorded
Trip distance	Estimated	Calculable from GPS trace Link distances from GIS
Route choice	Modeled "shortest path"	Actual path from GPS trace
Origin/destination	Recalled street address or intersection	GPS point Address/link match from GIS
Travel speed	Not available	Available from GPS Speed by link from GIS
Functional class	Not available	Available by link from GIS

8.3 Future Potential

This was a successful "proof of concept" project. Already, other projects in the field, and in the planning stages, have built on this project's experience. In particular, use of GPS with hand-held computers is gaining much wider acceptance in the field.

This approach for travel data collection has significant potential for future application in travel surveys. Although envisioned primarily as a supplement to traditional survey methods, the data from CASI surveys will provide insights that help shape the traditional methods, thus improving the overall process. This potential, demonstrated in the Lexington field test, will grow as the hardware and software tools continue to mature.

The greatest need in hardware advances in the near future will be better standardization of hand-held computer operating systems and GPS PCMCIA units. The operating system used in this project is implemented on only one hand-held unit currently in production. Improved standardization and continued proliferation of hand-held computers and their operating systems will make these techniques available to a wider range of users at lower costs.

The GPS receiver used in the field test transmits in NMEA 0183 ASCII format, and in a Garmin® proprietary format. Other GPS manufacturers typically have their own proprietary formats as well. These proprietary formats, and the difference computer operating systems, make it difficult for software developers to establish programs that work across a variety of GPS hardware. Also, newer GPS receivers, such as those using PCMCIA technology, may reduce the bulk of the equipment without sacrificing performance. These receivers were excluded from this field test because the power requirements were not compatible with the hand-held computer.

Because the transportation industry is just now seeing the value of GPS in transportation projects, there is little software available for automated post-processing of data. Typically, for transportation applications, map matching of GPS points to a roadway network would be a critical first step. The map-matching software used in this analysis of field test data is still under development, and several revisions were required to achieve the results shown here and to transport those results between software tools, such as a GIS. In general, more effort is needed to mesh the needs of transportation data users into the GPS and GIS products that are available.

Visibility of the screen, or any user interface, must be a strong consideration in future applications. Screen contrast caused some difficulties in this field test, however this was not overwhelming problem for the respondents. Visibility and ease of use are key factors in the respondent interface. In addition to a touch screen entry format, ease of use also refers to the types of questions asked and the choices that respondents have to select from. Some respondents admitted to confusion over how to respond during this field test, underling the importance of properly framed response sets in order to retrieve meaningful data.

The equipment, although compact, could be improved to further enhance its usefulness in this type of application. Excess cabling, a frequent suggestion for improvement, can be reduced, especially if the antenna for the GPS receiver can be brought inside the vehicle and still reliably produce results. Although the field test equipment survived intact, equipment that is sturdier, or hardened for field use, would be necessary for large-scale deployment.

Some people have suggested that the novelty of using a small computer elicited better participation and cooperation in the Lexington, KY survey, and that as hand-held computers became more common place, willingness to participate would decline. However, if computers can make the surveys less burdensome, then even if a novelty effect disappears, there should still be significant improvements to response rates and improvements in data quality.

In addition, not only are the size and weight of hand-held computers declining, but so are the prices. While the equipment costs for the Lexington, KY study were approximately $1400 per unit, approximately equivalent equipment one year later costs about $800. These changes in size, weight, and cost suggest that this type of equipment can be used for more than just vehicle-based surveys. When the total weight can be less than 0.5 lbs (225 gm) and battery operating capabilities are extended, then walk, bike, and transit trips might be recorded as well as private vehicle trips.