Personal Travel Unit (PTU) Development and Initial Testing

FINAL REPORT

to

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by

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EXECUTIVE SUMMARY

The Federal Highway Administration has been conducting research on incorporating Global Positioning System (GPS) data (i.e., location and speed) as part of travel survey data since 1995. This report describes a research project to develop a small, lightweight person-based data collection device including GPS data that will allow recording of walk, bike, and other trips that do not involve using a motor vehicle. The biggest motivations to incorporate GPS data into household travel surveys are to improve data quality and to reduce respondent burden during the survey process.

This research was spurred by the fact that GPS receivers and Personal Digital Assistants (PDAs, or hand-held computers) are becoming more affordable and more commonly used. GPS combined with PDAs offer the opportunity to capture accurate time, location, route choice, and travel speed, while simultaneously reducing the amount of time an individual spends completing a travel activity survey.

U.S. statistics indicate that the average distances in 1990 were 0.6 miles for walk trips and 2.0 miles for bicycle trips. Average trip times are on the order of 10 to 15 minutes, assuming an average walking speed of 3 miles per hour and bicycle speed of 10 miles per hour. Respondent burden and acceptance during walk and bike trips is of critical importance and is reflected primarily in the weight and size of the data collection unit.

The Personal Travel Unit (PTU) as configured in this research task weighs approximately 454 g (1 lb.) and is carried in a lightweight pouch with a GPS receiver mounted on a shoulder strap.   Respondent survey questions are posed through a touch-screen user interface. The PTU is powered by on-board batteries (2 AA alkaline batteries in the PDA and 4 AAA alkaline batteries in the GPS unit) and can provide approximately eight hours of available data collection time.

A small group of test subjects used the PTU in actual travel. These test subjects found the PTU easy to use and the burden for entering data before a trip and for changing travel modes were in the expected time ranges, generally one minute or less. The PTU offers a preferred alternative to other forms of travel diaries and there was no hesitation among the test subjects to use this type of equipment for future studies.

While bench tests of the unit clearly demonstrate the capabilities of the equipment to capture the desired data, collected data from the test subject trials were unfortunately incomplete.   The PTU prototype deployed for test subject use experienced operational problems that limited the usefulness of the test subject data. The overall robustness of the PTU must be improved to eliminate the issues experienced during the test subject trials before more general field use.

While hardware issues hindered the successful data collection in this prototype, newer and more recently available products will considerably lessen or perhaps even eliminate these issues. Because the test subjects offered no complaints about the weight of the system or the user interface software, similar systems with more robust data collection capabilities can certainly be implemented in the near future.

1. Introduction

1.1 Background

The Federal Highway Administration has been conducting research on incorporating Global Positioning System (GPS) data (i.e., location and speed) as part of travel survey data since 1995. This research was spurred by the fact that GPS receivers and Personal Digital Assistants (PDAs, or hand-held computers) were becoming more affordable and more commonly used. The biggest motivation to incorporate GPS and PDAs for household travel surveys are to improve data quality and to reduce respondent burden during the survey process. GPS combined with PDAs offer the opportunity to capture accurate time, location, route choice, and travel speed, while simultaneously reducing the amount of time an individual spends completing a travel activity survey.

1.2 Previous Research

Proof of the concept for incorporating GPS into travel surveys was accomplished in the Lexington study[1], funded by FHWA and executed in 1996 – 1997. This study deployed a hand-held computer and GPS receiver to collect survey data on vehicle-based trips for 100 households in Lexington, KY. The respondents used the hand-held computer to enter driver, passenger, and trip purpose information for each trip via the touch-screen user interface. The hand-held computer recorded GPS data associated with each respondent-defined trip from an attached, integrated GPS receiver-antenna. The Lexington study was limited to vehicle-based trips because the data collection equipment relied on the vehicle to power the GPS receiver and recharge the batteries in the hand-held computer.

A second study including collection of GPS travel data focused on heavy-duty truck activity and was sponsored by the California Air Resources Board (CARB) and FHWA[2]. This study incorporated auto-start and autonomous operation features into the data collection equipment. GPS travel data were collected automatically and did not depend on the respondent to initiate the trip record. This application further confirmed the feasibility of collecting GPS-related travel data. Again, this study was restricted to vehicle-based travel.

While privately owned vehicles (POV) account for the majority of travel in the United States (86 percent of all person trips and 91 percent of all person miles[3]), other travel modes are of increasing interest to travel researchers. Walking, biking, and public transportation trips account for a significant portion of person trips in the U. S. and are receiving increasing scrutiny by travel researchers. Researchers suspect that walking and biking trips, in particular, suffer from significant inaccuracies in travel time and distance measures that are normally associated with a recall survey. Collecting GPS data associated with these trips will provide accurate data for the study of walking and biking travel modes.

The Dutch Ministry of Transport has completed a person-based survey including GPS data. The Netherlands survey included 150 persons with a data collection unit that was carried for 4 days to capture all modes of travel including bike, walk, public transit, and private vehicle trips[4]. The weight of the equipment used in the Dutch study was 2 kg, of which 20 percent was the battery (380 of 2,020 g), and the equipment carrying case was approximately 12 inches (length) by 6.4 inches (width) by 6 inches (height) (300 mm L x 160 mm W x 150 mm H). Survey participants were told that they were not required to use the equipment for every trip, but to use a paper diary to record those trips when they did not use the equipment. Later, they were asked about the times when they chose NOT to carry the equipment with them. The most frequent occasions mentioned were when participants made shopping trips, and carrying the equipment was described as being "too much burden" for biking, walking, and public transport trips. Despite the size and weight of the equipment, 70 percent of the respondents evaluated the project as "positive" and 65 percent said they would be willing to participate again. In general, the size of the equipment was rated more negatively than the weight[5].

When GPS data collection equipment is used to track vehicle trips only, the weight and size of the equipment is not a significant concern. However, if the survey research intends to include walk and bike trips, then the weight and size of the data collection unit is of critical importance with respect to respondent burden and acceptance.

1.3 Project Objective

This research task continues FHWA's development of travel data collection methods using GPS technology to supplement traditional travel data collection techniques. The objective of the research was to develop a small, lightweight person-based data collection device that will allow recording of walk, bike, and other trips that do not involve using a motor vehicle.

In general, the basic requirements for the Personal Travel Unit (PTU) were:

- An overall weight less than 454 g (1 lb.)
- Ability to record GPS data at regular intervals
- Touch screen user interface
- Small enough to be easily carried while walking or biking.

These requirements were intended to reduce respondent burden in responding to the survey (via a touch screen user interface) as well as reduce the physical burden (size and weight) associated with carrying the PTU.

1.4 Organization of this Report

Section 2 of this report describes the equipment selected for this project and the rationale for the selection of specific equipment items. Section 3 describes the survey application software and user interface for the PTU. Section 4 provides the definition and results of the brief test period involving several test subjects. Test subject reactions to using the PTU are described via their response to survey questions in Section 5. Section 6 provides a summary of the project results and problem areas and identifies the next steps that are needed to expand the PTU test to a larger audience.

2. Equipment Identification and Selection

One primary objective was that the PTU equipment must be easily carried for walk and bike trips. The PTU concept includes a GPS receiver/antenna mounted on a shoulder strap to allow for good satellite visibility and a PDA contained in a small pouch at waist level. Alternatively, the carrying pouch (essentially a small camera case) can be attached to a belt.

2.1 Hardware Selection

Hardware associated with the PTU development consists of the hand-held computer, or PDA, and a GPS receiver and antenna. A self-contained power supply is necessary to support data collection during walk and bike trips. Since the first application in the Lexington proof-of-concept study, both the availability and variety of PDAs have substantially increased. A principal objective of hardware selection was to achieve an overall PTU weight of no more than 454 g (1 lb.) to reduce the respondent's physical burden during walk and bike trips. Commercial, off-the-shelf technology was a priority in the selection process in order to minimize development costs and the total costs of the completed PTU.

The weight of currently available PDAs ranges between 120 and 250 g (4 to 8 oz.). The Philips® Nino 200 PDA using the Windows CE operating system was selected as the hand-held equipment for the PTU prototype. The Nino 200 is approximately 134 x 87 x 20 mm (5.3 x 3.4 x 0.8 in.) and weighs approximately 220 g (8.0 oz.) including the two AA batteries that power the unit. The on/off switch is located on the front face of the case and the screen contrast can be adjusted with a contrast wheel located on the right-hand side of the case.

GPS receivers have become widely available and less expensive since the Lexington study. GPS receivers are currently available that weigh approximately 225 g (8 oz.) and antennae as small as 8 by 8 mm (0.3 by 0.3 in.) have been developed. However, most of these receivers are only available as original equipment manufacturer (OEM) kits, or circuit boards, that are intended to be installed as a component of another device. These OEM kits also required a separate power source and antenna to complete the GPS equipment. Few self-contained, commercially available GPS receivers were identified for possible inclusion in the PTU. The selected GPS equipment was an off-the-shelf DeLorme® EarthMate™ integrated GPS receiver and antenna. The EarthMate™ is a 12-channel, non-differential receiver[6] with horizontal accuracies between 10 to 15 meters[7]. The integrated receiver/antenna is approximately 12.2 x 7.1 x 1.8 cm (4.8 x 2.8 x 0.7 in.) and weighs approximately 198 g (7 oz.) including the four AAA batteries that power the receiver. The EarthMate™ is configured to refrain from collecting redundant position data when stationary or when the GPS data are not being used (i.e., retrieved by a mapping program or recorded) in order to conserve battery life.

Connecting cables are required between the PDA and the GPS unit to complete the PTU. The PTU as configured and tested included a GPS sentence translator (GST) module to convert the receiver's proprietary binary data output into a standard NEMA data stream. The combined weight of the PDA and GPS is approximately 406 g (14.3 oz.) including batteries. With cables and a small carrying case, the total package weighs approximately 454 g (1 lb.).

2.2 Operating System

The PDA equipment selected for this trial runs on a Microsoft Windows CE platform, the predecessor to the recently launched Microsoft Windows-based PocketPC operating system. This selection was not a requirement for configuring the PTU. The PDA operating system market has two major segments; the Palm operating system (Palm/OS) and Microsoft Windows-based operating systems. Approximately 75% of the PDA market uses Palm/OS, principally the popular Palm Pilot series of PDAs as well as the recently introduced Handspring Visor PDA. While Palm/OS currently has the market lead, there are still many popular PDAs from several manufacturers that utilize a Windows-based platform.

Off-the-shelf GPS receivers are available that work with either operating system. The commercially available interfaces for these GPS receivers generally are focused more toward navigation applications rather than survey tools. Typically they illustrate the user's position on an on-screen map and permit storage of GPS locations along the route for later recall or way-finding.

The PDA operating system used in the PTU is transparent to the survey respondent because it is hidden beneath the PDA survey application software. The PDA survey application can maintain essentially the same look and feel with either operating system. The survey application poses predefined questions and accepts respondent inputs through on-screen choice lists. Thus, the choice of an operating system for a survey application relies principally on the skills of the application developer in working with a particular operating system, including the benefits and limitations of the operating system with respect to the survey requirements.

2.3 Operational Factors

U.S. statistics indicate that the average distances in 1990 were 0.6 miles for walk trips and 2.0 miles for bicycle trips[8]. Average trip times are on the order of 10 to 15 minutes, assuming an average walking speed of 3 miles per hour and bicycle speed of 10 miles per hour. With a data collection time of up to 8 hours, up to 32 average walk or bike trips may be captured in theory. If trips by all travel modes are collected, as is planned, the number of trips and data collection time may be substantially less since vehicle-based trips tend to be significantly longer. The development process included specific tests to determine the actual data collection time that this configuration can support without additional power sources, and without replacing or recharging the system batteries.

The selected PDA has 8 MB of memory available to store collected data, which is believed to be more than adequate compared to the expected data collection times. A GPS data recording frequency of once every 5 seconds can be used due to the lower speeds associated with walk and bike travel. This recording interval should provide an adequate route track and will also conserve memory in the PDA.

2.4 Equipment Configuration Summary

The configured PTU is illustrated in Figure 2.1. The PTU is comprised of a Philips® Nino 200 PDA and a DeLorme® EarthMate™ integrated GPS receiver and antenna. The PDA uses the Windows CE operating system. The PTU survey application software is described in Section 3. The PTU weighs approximately 454 g (1 lb.) and is carried in a lightweight pouch with the GPS receiver mounted on the shoulder strap. The PTU is completely powered by on-board batteries (2 AA alkaline batteries in the PDA and 4 AAA alkaline batteries in the

GPS unit). The PDA batteries are expected to provide up to 8 hours of use during data collection activities. The GPS unit is rated for up to 10 hours of use on one set of batteries.

3. PTU Survey Application Software

The survey application is an individual-based survey that incorporates trips using various travel modes. The respondent initiates the trip record (and GPS data recording) using the PDA and identifies the travel mode for the trip. When the respondent later indicates the end of the trip using the PDA, they are asked to identify the trip purpose from a predefined choice list. The survey application has options for continuing the next trip as part of a chain (e.g., walk to bus stop, then ride bus for commuting to work), or indicating that a final destination has been reached to close the trip record. The trip chaining option, which was not a part of the Lexington project, is included to capture multiple mode travel and sequential trips segments that are a part of normal, daily travel. The survey application is fully described in the following discussion.

3.1 Administrative Features

The PTU application software has several administrative features that are used to set up the survey tool for each respondent and control data recording. Access to the administrative features is password protected to prevent the respondent from inadvertently altering the settings of the survey during use. The principal administrative features include personalizing the survey tool and setting the data recording parameters.

The survey tool can be personalized with the respondent's name to make the user interface seem more friendly to the individual respondents, to facilitate use by multiple respondents, and to reduce confusion as to who was making a trip. A numeric code for the respondent is also provided to protect the respondent's identity in subsequent data manipulations. During data exporting and data reporting, the respondent's name can be stripped from the data file and the data will remain associated only with the numeric code.

Administrative settings that can be manipulated include specification of participant name(s), setting of the current date and time, selection of a GPS sample rate, identification of the device name, and entry of the device owner. Additionally, the System Administration screens facilitate uploading collected data and initializing the PTU for data collection. GPS sample rate is the time interval for recording GPS data records. Sampling as frequently as once per second is possible. However, due to the slower speeds associated with walk and bike trips, longer recording intervals can be used to conserve memory used for data storage.

3.2 Respondent Interface and PTU Operation

Figure 3.1 illustrates the scenarios for use of the PTU survey tool in flowchart form. Written use and installation instructions were provided to the respondents that describe the PTU operation and emphasize that that the GPS unit should be afforded an unobstructed view of the sky whenever possible (e.g., if travelling by car, the GPS unit should be placed on the dashboard or near a window). The respondent must initiate PTU operation by pressing the PDA "on" switch and indicating a start trip by selecting the "Start Button" in the touch-screen userinterface. The survey process steps and the respondent selections in each step are described in the following subsections.

3.2.1 Study Participant Name

The respondent's first selection, after beginning a trip, is to indicate the name of the person actually making the trip. This is accomplished by touching and highlighting the person name and touching "Continue" at the bottom of the screen. The default name selected is the name of the respondent who made the last trip.

3.2.2 Travel Mode

Next, the travel mode for this trip must be selected (Figure 3.2). The choice list includes most available travel modes and an "other" designation for trips not otherwise captured by the choice list. The respondent selects the travel mode by touching the appropriate mode, which highlights the selection, and then touching the "Continue" button at the bottom of the screen.

3.2.3 Car/Motorcycle Mode Questions

If the respondent specified that the travel mode is a car or a motorcycle (Figure 3.2), the respondent will be asked to enter the total number of persons in the vehicle to capture vehicle occupancy (Figure 3.3). If the travel mode is not car or motorcycle, the survey application moves directly to the "Collecting Trip Data" mode. For car trips, the respondent may specify up to 19 occupants. For motorcycle trips, the respondent can specify up to two (2) occupants. In either case, if more than one occupant was specified, the respondent will be asked if they are the driver.

3.2.4 Collecting Trip Data

The "Collecting Trip Data" screen indicates to the respondent that data are being recorded and no more entries are required. The PDA can be stored in the carrying pouch until the respondent reaches their destination. The PDA screen must remain "on" in order to operate the application while using internal batteries.

3.2.5 Arrive at Destination

The respondent indicates arrival at the destination by touching the "End Trip" button on the screen. A verification screen will then display to allow the respondent to confirm the end trip command. Verification that the respondent has reached a destination terminates GPS data recording for the trip.

3.2.6 Trip Purpose

The PTU asks the respondent to indicate the trip purpose for the travel from a predefined choice list (Figure 3.4, Table 3.1). The trip purpose may consist of a primary trip purpose and a secondary trip purpose (i.e., some trip purposes are further defined through secondary choices). The respondent selects a primary trip purpose by touching and highlighting the primary trip purpose choice (scrolling the list if necessary), and then touching "Continue" at the bottom of the screen. If the primary trip purpose choice is further defined by secondary choices, the secondary trip purpose choices will appear on the screen. The secondary trip purpose choice is selected by touching and highlighting the secondary trip purpose choice and then touching "Continue" at the bottom of the screen. Following the declaration of trip purpose, a confirmation screen is presented for review, from which the trip purpose may be accepted or modified.

Table 3.1 Trip Purpose Predefined Choices

Trip Purpose:	**Specific Purpose:**
Change Travel Mode	**None**
Social or Recreational	*None*
Personal or Household Business	- Shopping

	- Errands and other personal business (e.g., bank, post office, dry cleaner, video rental, barber, car repair, etc.)
Return Home	*None*
Work or School	- Workplace - Work-related Business - School, College, or University
Pick Up or Drop Off Passengers	- Pick Up Passenger - Drop Off Passenger
Eat Out	*None*
Medical or Dental	*None*
Other	- Religious Activities - Volunteer Work - Community Meetings - Other

3.2.7 Final Destination

After confirming the trip purpose selection, the respondent is asked if the present destination is their final destination (Figure 3.5). If the respondent responds "Yes", then the trip file is concluded and the respondent is informed that the trip has been completed successfully. When the respondent selects "OK," the PTU returns to the "Start Trip" configuration in preparation for the next travel. If the respondent responds "No" to the final destination question, the PTU saves the data file as a segment of a trip chain and prepares to capture the next travel as the subsequent segment of the trip chain. The PDA screen moves to the "Start Next Trip" screen.

3.2.8 Start Next Trip (Trip Chaining)

When the respondent is ready to resume travel, the respondent touches the "Start Next Trip" button and the PTU begins the data record for the next segment of the trip chain. The respondent is asked if the travel mode is the same as for the previous travel. If the respondent responds "No", the PTU will prompt the user to select a travel mode (see section 3.2.2 above), and may also ask car/motorcycle mode questions (see section 3.2.3 above) if one of those modes is selected. After these selections, GPS data collection resumes for the next trip.

If the travel mode has not changed the respondent should respond “Yes.” In this case the “Select Travel Mode” screen is skipped. Otherwise, the process is the same as if the respondent had selected “No.” Upon arriving at the “Collecting Trip Data” screen, the PDA can be stowed and travel may resume.

3.3 Survey Application Summary

The PTU individual survey application allows for the collection of travel data indicating traveler name, travel mode, and vehicle occupancy if the travel mode is car or motorcycle. Additionally, a response as to whether the respondent is also the driver is obtained for car or motorcycle trips with two or more occupants. The survey tool also allows trip chaining to be indicated, with changes of travel mode between segments of the trip chain. Trip purposes and GPS data are associated with each segment of the trip chain to allow detailed description of the travel.

4. PTU Testing

PTU testing was conducted to evaluate PTU general operation, data collection capacity, and test subject response to use of the PTU to collect travel data. Data collection capacity contains two elements; (1) the data storage limits imposed by available memory in the PTU and (2) the data recording time as constrained by battery life of the PTU. The objectives of these tests were to establish the general operating limits for the PTU and to gauge the general response of test subjects to actual use of the device.

4.1 Scope of Tests

PTU tests consisted of two types; (1) bench tests and (2) test subject usage. Bench tests were conducted to establish general operational parameters and theoretical operation limits for the PTU. Test subjects who used the PTU for two to three days during actual travel provided further testing of the PTU. Data collected by the test subjects were uploaded and examined to determine the GPS data capture rate and the general usefulness of the data for describing walk, bike, and other trips. Test subjects were also asked to complete a questionnaire describing their general response to using the PTU (Appendix A).

The PTU tests examined general characteristics of PTU operation and were not exhaustive. While general characteristics of collected data and operational limits are described from the test results, these conclusions must be considered preliminary due to the limited scope of the tests. The principal constraints on PTU testing were the resources available to support test subject data collection and evaluation.

4.2 Bench Testing

Bench testing focused on the individual equipment components and their ability to perform their function in the context of PTU operation. Substantial experience exists with the hand-held computer in similar data collection applications, thus the bench tests focused principally on the EarthMate™ GPS receiver.

These tests were conducted using the EarthMate™ GPS receiver in a configuration where the data stream from the receiver could be monitored on a second-by-second basis. These tests also focused on walking trips. Walking trips were believed to be the most challenging for the receiver for two reasons.

- The EarthMate™ GPS receiver must detect movement or else the receiver shuts down to conserve power
- Walking trips are more likely to include obstructed views for the receiver (e.g., nearby buildings or tree cover over sidewalks)

These characteristics are more important in walk and bike trips where the speed of travel is significantly less than in car trips.

These controlled tests verified the EarthMate™ GPS receiver's capability to acquire and maintain a position fix during walk trips, and to support one-second position and speed data collection associated with the walk trips. Figures 4.1 and 4.2 illustrate the results of a controlled walk trip test of the GPS receiver. This test first verified that a position fix had been acquired prior to beginning the walk trip. This test clearly illustrates the capability to collect the desired information using the GPS receiver. Figure 4.3 shows an additional walk test and Figure 4.4 illustrates a vehicle trip. Both of the examples were the results of bench test conditions.

However, bench tests also indicated that the receiver may require substantial time periods to acquire an initial position fix during a walking trip. Walking tests with the receiver required nearly four (4) minutes to achieve and maintain a position fix that would allow sustained collection of both position and speed data.

4.3 PTU Usage by Test Subjects

The PTU tests included six test subjects that used the PTU equipment in walk, bike, and car trips. Test subjects were Battelle staff who volunteered to use the PTU during normal travel activities. While some of the test subjects had a general familiarity with the PTU development project and other travel data collection efforts underway at Battelle, only one was directly involved in the PTU development effort. Three of the six test subjects had no prior experience in using Battelle-developed travel survey equipment that includes GPS data collection.

The test subjects were provided short oral briefings (approximately 5 minutes) and written instructions on the installation and use of the PTU equipment. All test subjects were encouraged to use the PTU for all trips over a two or three day period. Table 4.1 provides a summary of the PTU usage by the six test subjects.

Table 4.1. Summary of PTU Equipment Usage by the Test Subjects

Test Subject	Number of Days Used	Number of Trips	Travel Modes		
			Walk	Bike	Car
1	3	7		X	
2	1	3	X		
3	3	4		X	X
4	2	4			X
5	3	10	X		X
6	3	5		X	X
Totals	15	33			

4.3.1 Test Focus

The emphasis of these tests was on PTU usability and data quality. PTU usability is judged from test subject reactions to the PTU and their ability to use the PTU in everyday travel activities. These results were captured through a test subject questionnaire. The results from the questionnaire and discussion of test subject responses are contained in Section 5 of this report.

Data quality, for this test, was defined in two parts. First, are data collected consistently throughout the data collection period as defined by a trip start and trip end parameters? This is a system measure that accounts for proper communication between the GPS receiver and the hand-held computer. This communication is necessary for the GPS data to be consistently recorded into the unit's memory.

Secondly, are the collected GPS data of sufficient completeness and detail to allow description of the route of travel? This question measures the GPS receiver's performance under the field conditions of the test.

4.3.2 Test Results

Data quality from the test subject data collection was poor. Data was not consistently collected throughout the data collection period as defined by the trip start and trip stop parameters.

The PTU application software recorded trip start and end and the associated trip purpose as entered by the test subject, with only a few exceptions. However, there were numerous trips where the PTU application software "timed out" and indicated an error rather than recording GPS data. This occurrence can result from several conditions.

- Communications timing errors between the hand-held computer and the GPS receiver
- Frequent route direction changes or obstructions, preventing the GPS receiver from achieving a position fix during the trip
- GPS receiver failure to recognize movement and thus remaining in an "off" state[9]
- Errors introduced via inadvertent activation of the touch screen interface or the unit's on/off button
- Memory allocation errors in the application software (observed in bench tests)
- Communications errors between the GPS receiver and the GST module, resulting in unreadable GPS data
- Poor integrity of the cabling connections between the hand-held computer and the GPS receiver, aggravated by "jostling" of these connections during trips, especially walk and bike trips
- Weak or discharged batteries in the hand-held computer or GPS receiver.

Approximately 80% of the recorded trips experienced some “time out” or other system error during the test period and thus are subject to incomplete or missing GPS data.

Those trip files that contain GPS data are inconsistent in the amount of GPS data. Most of the trips taken by the test subjects had insufficient GPS data to allow description of the route of travel. The data indicate that prolonged delays were experienced in achieving a position fix during travel. Time to first fix varied significantly among the trip files. Initial acquisition for a test subject (i.e., the first usage by the test subject) ranged up to 17 minutes to acquire a sustained position fix. Reacquisition for subsequent trips (i.e., by the same test subject) ranged from approximately five (5) to six (6) minutes for walking trips to as little as two (2) minutes for vehicle trips. In fact, some trip files never achieved a valid position fix although a continuous stream of information was observed from the GPS receiver.

When a position fix was achieved, position updates were inconsistent and often did not occur at regular intervals. Portions of some trip data files show regular one-second position updates as anticipated. However, other trip data files show regular position updates for short periods (a few seconds to minutes), separated by similar time periods of unchanging position or missing data. Figure 4.5 illustrates the inconsistent nature of collected GPS position data during a test subject walk trip. Except for car trips, speed data is missing from many files. None of the trip files contain GPS data sufficient to provide a complete route description from start to end of a trip due to the time variations in achieving and maintaining a GPS position fix.

The GPS data performance was likely influenced by the following factors.

- Inconsistent positioning and/or frequent repositioning of the GPS receiver with respect to a full view of the sky
- Frequent route direction changes or obstructions, preventing the GPS receiver from achieving a position fix during the trip
- GPS receiver failure to recognize movement and thus remaining in an “off” state
- Communications errors between the GPS receiver and the GST module, resulting in unreadable GPS data
- Weak or discharged batteries in the GPS receiver.

The GPS receiver requires an adequate view of the sky to acquire a position fix and subsequently update that position as the receiver moves. The equipment configuration, as deployed, placed the GPS receiver on the PTU shoulder strap. Due to the bulk of the GPS receiver, its position would usually be in front of or behind the shoulder rather than on top of the shoulder. While the GPS receiver is capable of acquiring and maintaining a position fix in these positions, shifting the position of the shoulder strap for comfort during the trip can alter the GPS receiver's satellite view and result in a loss of fix.

4.4 Evaluation and Recommendations

The results of the test subject use of the PTU were disappointing, given the fact that both the GPS receiver and the hand held-computer have been demonstrated to meet the needs of the data collection. However, the integrated system did not consistently capture trip and GPS data sufficient to describe the travel and travel route characteristics.

The PTU must be made more robust for frequent everyday use in a data collection environment. Discussions with the test subjects indicate that the jostling of walk and bike trips often results in activating the touch screen interface inadvertently, prematurely ending trips and GPS data recording or, in some cases, turning the unit off via inadvertent activation of the on/off switch.

The PTU application software must be made more error resistant to ensure the greatest opportunity to record GPS and other trip data. The high percentage of "time out" errors experienced with the test subjects is unacceptable in the data collection tool. Some of these errors may have been associated with poor communications between the GPS receiver and the GST module. Eliminating the need for this module by including the translation in the software would eliminate one possible source of error and simplify the cabling arrangement.

The GPS receiver performance should also be upgraded. Although the EarthMate™ receiver performed well in bench tests, it also demonstrated a slower than anticipated "time to first fix" response under the conditions provided by the test subjects, particularly for walk and bike trips. This response may in large part be due to the variable position of the receiver, thus frequently changing the receiver's view of available satellites, and the tendency of walk trips to be closer to obstructions (e.g., buildings). However, the time-to-first-fix response is critical because most walk and bike trips are far shorter in duration than car trips.

5. Test Subject Survey Responses

The volunteer test subjects that used the PTU equipment were asked to complete a brief survey after they had completed their travel using the equipment. This survey covered four general areas of interest:

- Equipment Installation (questions 1 through 6)

- Use of the PDA (Hand-held Computer) (questions 7 through 11)
- Data Collection Activities (questions 12 through 15)
- Potential Problem Areas and User Suggestions (questions 16 through 23).

The survey form is included as Appendix A. The following sections provide the test subject responses and comments from this survey.

5.1 Equipment Installation

Test subjects were given both an oral briefing and written instructions for installation of the PTU equipment. This section of the questionnaire addressed the effectiveness of the installation instructions. The tally of these responses is provided in Table 5.1.

Table 5.1. Survey Questions and Responses related to PTU Equipment Installation.

No.	Survey Question	Responses
1	Which of the following installation instructions did you utilize (circle all that apply)?	Briefing = 6 Written Guide = 4
2	Which installation instructions did you find the most helpful (circle only one)?	Briefing = 6 Written Guide = 0
3	How clear were the installation instructions in the written guide?	Very Clear = 2 Somewhat Clear = 3 Somewhat Unclear = 1 Very Unclear = 0
4	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 (on your person and in your vehicle).	Strongly Agree = 1 Agree = 4 Disagree = 1 Strongly Disagree = 0 Note: one subject indicated that they would have answered "Strongly Agree" if there were more pictures.

No.	Survey Question	Responses
5	Did you experience any problems in installing the GPS device (on your person or in your vehicle)?	Yes = 0 No = 6 Note: one subject commented that they used the PTU in their car by placing the entire unit on the dashboard, without using the suction cup mount (for the GPS receiver) or the vehicle power cord. (Note: a suction cup mount was provided to aid in securing the GPS receiver in the vehicle.)
6	How could the installation process be improved?	§ The power cable that plugs into the car lighter was a bit time consuming to hook up. § The instructions contain too much detail and could use more pictures.

Most subjects (4 out of 6) used both the written and oral instructions for installation of the PTU equipment. However, the subjects unanimously agreed that the oral briefing was the most helpful form of instruction (The oral briefing was always provided prior to the written instructions). Only one of the subjects disagreed that the written instructions were sufficient to complete the PTU equipment installation.

No problems were experienced during the installation process. Improvements that were suggested included adding more illustrations in the written instruction materials and reducing the amount of wiring associated with the PTU equipment.

5.2 Use of the PDA (Hand-held Computer)

Test subjects were given both an oral briefing and written instructions for operating the PTU equipment. This portion of the test subject survey focused on these instructions and ease of use of the PDA. The tally of these responses is provided in Table 5.2.

Table 5.2. Survey Questions and Responses related to Use of the PDA.

No.	Survey Question	Responses
7	Did you ever use the hand-held computer?	Yes = 6 No = 0
8	How did you learn to use the hand-held computer?	Briefing = 5 Written Guide = 3 Past Experience = 1
9	How clear were the use instructions in the written guide?	Very Clear = 4 Somewhat Clear = 2 Somewhat Unclear = 0 Very Unclear = 0
10	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 are sufficient to allow me to successfully teach others how to use the hand-held computer.	Strongly Agree = 3 Agree = 3 Disagree = 0 Strongly Disagree = 0
11	Overall, how easy was it for you to use the hand-held computer before each trip?	Very Easy = 5 Somewhat Easy = 1 Somewhat Difficult = 0 Very Difficult = 0

All subjects used the PDA (hand-held computer). Most subjects favored the oral briefing for learning to use the PDA, although some relied on both the oral and written instructions. One subject had prior experience in using the PDA in a similar format.

The test subjects agreed, with differing levels of enthusiasm, that the written instructions were clear and were sufficient to use the PDA or to teach others to use the PDA. Overall, five of the six test subjects rated the PDA "very easy" to use before making a trip.

5.3 Data Collection Activities

This portion of the test subject survey focused on how the PTU equipment was used during data collection activities. The tally of these responses is provided in Table 5.3.

Table 5.3. Survey Questions and Responses related to PTU Data Collection Activities.

No.	Survey Question	Responses
12	How often were you able to enter trip data into the hand-held computer?	All of the Time = 3 Most of the Time = 3 Some of the Time = 0 Almost Never or Never = 0 Note: one subject that responded "Most of the Time" stated that the unit quit working (dead batteries), but otherwise experienced no problems.
13	How much time was needed, on average, to set up the equipment when changing to a new mode of travel?	Car: 1 minute 2 minutes 3 minutes 5 minutes (first time) Bicycle: 1 minute <1 minute 2 minutes Walk: 1 minute 2 minutes (first time) Bike to Car: <1 minute Bike to Walk: instantaneous Car to Walk: <1 minute
14	How much time was needed, on average, for data entry before each trip?	¼ minute = 1

No.	Survey Question	Responses
		½ minute = 2 <1 minute = 1 1 minute = 2
15	How easy was it to read the screen on the hand-held computer?	Very Easy = 3 Somewhat Easy = 3 Somewhat Difficult = 0 Very Difficult = 0

Three of the test subjects entered trip data for all trips they made during their test period. Of the three that did not enter data “all the time”, one test subject experienced a failure of the PTU equipment that prevented entering data (dead batteries). The other subjects that responded “most of the time” did not comment on situations when the PTU equipment was not used.

The time required to set up the equipment for a change of travel mode varied from instantaneous to approximately three (3) minutes (one subject responded that five (5) minutes were required for the initial set up for use in their car). Most responses were two (2) minutes or less for all travel modes indicated. In retrospect, this question should have specified the specific travel mode change associated with the time estimate (for example, from bike to walk, or from bike to car). One subject responded in this manner and their responses are consistent with the anticipated result. That is, some time is necessary when converting to or from the car travel mode, but much less time is required to change travel modes if a car is not involved[10].

All test subjects responded that only one minute or less was required to perform data entry before each trip, and half of the subjects indicated one-half (½) minute or less for this activity. The test subjects were evenly divided between “very easy” and somewhat easy” when commenting on their ability to read the PDA screen.

5.4 Potential Problem Areas and User Suggestions

This portion of the test subject survey focused on potential usage problem areas that were observed in the Lexington study and other studies that incorporated GPS equipment. Test subjects were also asked their opinions on how the PTU equipment could be improved. The tally of these responses is provided in Table 5.4.

Table 5.4. Survey Questions and Responses related to Potential Problem Areas and User Suggestions.

No.	Survey Question	Responses
16	What problems did you have in using the hand-held computer?	§ It crashed once, but mostly no problem. § Too easy to accidentally turn off and on. § Bumping on bicycle caused accidental data entry. § The "debug" messages: there was a debug message at the start screen that said to see the Administrator; there was another debug message indicating file size.
17	Was the use of the hand-held easier or harder than you thought it would be?	Easier = 3 Harder = 0 About as Expected = 3 Comment: Quick and simple, starts collecting data right away (quick set up process).
18	Were there occasions, such as quick trips or when you were running late, when you did not have time to input trip data?	Yes = 1 No = 4
19	Would you have preferred keeping a written log of driving instead of using the hand-held computer?	Yes = 0 No = 5
20	Would you be willing to use this device again in a similar study?	Yes = 6 No = 0

21	While you were driving your vehicle (all modes where you were an operator), how much of a distraction was created by having the device in use?	Great Deal = 0 Some = 0 Very Little = 2 None = 3
22	Did you change your driving habits in any way because the device was with you?	Yes = 1 (tried to collect more data) No = 4 Note: one subject never drove with the unit.
23	In what way could we improve this device and its usage?	§ Make PDA use possible without removal from pouch, smaller and lighter. Use backpack (or add belt) for bike travel. § Smaller and easier to wear. § Go wireless where possible, combine GPS and PDA into one package and run a lightweight small GPS antenna to the shoulder strap and/or dashboard. § Needs to be more robust to physical movement, especially for bicyclists. § A picture or diagram showing the change to the car cable would be helpful. § Make the software select a person. § Make the hardware smaller. § Needs to turn itself off. § Ideally, it would beep when car turned on or off. § The GPS device on the shoulder was a bit big. § The wire coming out of the bag to the GPS device sometimes got in the way.

While all of the test subjects found the PTU equipment fairly easy to use, some problems were encountered. One subject responded that the PTU was too easily turned on and/or off and one bicycle user noted that the jostling and bumping of the bicycle ride caused inadvertent data entry through the touch-screen interface. Also, some software and communication problems were encountered. At least one system crash was experienced and another test subject encountered “debug” messages from the user software that made use more difficult.

None of the test subjects expressed a preference to keep a written travel diary instead of using the PTU equipment and all test subjects expressed willingness to use the equipment again for similar studies. Only one test subject admitted a change of driving habits in order to collect more data for this study when using the PTU. None of the test subjects thought the PTU was a distraction when driving a vehicle.

The test subjects offered several suggestions for improvements in the PTU equipment and its use. Several suggestions focused on smaller and lighter equipment, including reducing or eliminating the wiring associated with the PTU equipment. Several suggestions related to the robustness of the PTU equipment for bicycle trips, including a better or more secure manner of wearing the equipment compared to the shoulder bag that was used. Suggestions were also provided for improving the instruction materials (more illustrations) and operational features (automatic on/off in a vehicle and aural cues).

5.5 Summary

From a user viewpoint, the survey responses indicate that the PTU equipment and test use were successful. Overall the installation and use instructions were deemed adequate and the PTU itself was found easy to use. Respondent burden for entering data before a trip and for changing travel modes were in the expected time ranges, generally one minute or less, and these time requirements can be expected to drop as the user gains experience over the course a travel survey. The PTU offers a preferred alternative to other forms of travel diaries and there is no hesitation among the test group to use this type of equipment for future studies.

The test group also provided several useful suggestions for improving the PTU. While many of these issues were anticipated, the experience gained through actual use under survey conditions will only benefit the next generation of PTU equipment.

6. Results, Recommendations, and Next Steps

These preliminary tests of the Personal Travel Unit (PTU) provided valuable insights to the design and operation of a PTU for travel data collection during walk, bike, and other trips. While these tests were limited and perhaps did not answer all questions, use of a PTU for travel data collection in multiple travel modes is certainly feasible from both a technical and respondent perspective. The following discussions provide overall conclusions from this project and lessons learned for future PTU applications.

6.1 Respondent Burden and Comfort

The PTU as used in the tests met the size and weight goals established for the project. The total unit weighs approximately one pound (454 g) including batteries contained in both the hand-held computer and the GPS receiver. The PTU can be easily carried in a small carrying case with either a shoulder strap or on a belt. The only drawback experienced with the selected equipment is the relative bulk of the GPS receiver. When mounted on the shoulder strap, the GPS receiver tends to rest in front of or behind the shoulder, rather than on top of the shoulder. This is a comfort issue for the user and also impacts the GPS receiver's view relative to the GPS satellites. Since the receiver may be shifted from one position to another to achieve better user comfort, this may impact GPS receiver performance in achieving and maintaining a position fix.

Our test subjects were consistently favorable with respect to using the PTU during walk and bike trips. All test subjects preferred this approach to written travel diaries. The size and weight of the PTU did not cause a physical burden and the straightforward survey tool required minimal time for response using the touch-screen interface.

6.2 Technical Issues

The PTU as provided for the tests demonstrates all the capabilities necessary for the travel data collection task. The hand-held computer and touch-screen user interface are easy to use and the GPS receiver is capable of providing position and speed information for walk trips, which is believed to be the most challenging of the travel modes for GPS data collection.

However, the test subject trials demonstrated that the robustness of the PTU must be improved before more general use. Some of the general issues observed when using the PTU include the following.

- The carrying case must be made more secure and, if possible, smaller. Users during bike trips complained of the carrying case shifting during travel when secured only by the shoulder strap.
- The cabling associated with the experimental PTU was excessive and bothersome to users. Less cabling and perhaps a coiled cable to the PDA should address these issues. Secure cable connections must also be assured.
- The PDA touch-screen and on/off switch are essentially unprotected in the carrying case. The jostling of normal travel activities, especially during walk and bike trips, sometimes activated the touch-screen or on/off switch, prematurely ending or otherwise interrupting the data collection activity. PDAs exist in the marketplace that have a hard cover for the touch-screen when it is not in use. This approach is a viable fix for this issue.
- The GPS receiver/antenna was relatively bulky compared to the shoulder strap of the carrying case. This resulted in a comfort issue and caused shifting of the receiver, impacting receiver performance in achieving and maintaining a position fix.

Other technology options are now available since the PTU was first configured in late 1999. The PDA market continues to provide more options and several models now available have a hard case that protects the touch-screen interface when it is not in use. Also, more GPS receiver options are possible. GPS receivers are now being marketed that are plug-in modules for use with a PDA. Using a plug-in GPS receiver would require only a small patch antenna to be placed on a shoulder strap, rather than the integrated receiver/antenna used in the current test. Using a plug-in GPS module with a smaller antenna would reduce power consumption, address the user comfort issue, and also reduce the overall weight of the PTU.

The user interface as presented by the survey application proved easy to use and contained the appropriate questions for the travel data collection activity. However, there were some underlying issues related to internal communications and data storage that were experienced during test subject usage. These communication issues sometimes presented the test subjects with unexpected error messages and interfered with proper recording of the travel data. While it is unclear how much of the data recording problems were related to physical design issues (e.g., inadvertent activation of the touch-screen due to jostling) versus software communication issues, the software must be more robust for general use. When a member of the general public uses the PTU, the appearance of unanticipated messages in the user interface is simply unacceptable.

The GPS receiver time-to-first-fix must improve to ensure more accurate trip route descriptions in the collected travel data. This is especially important for walk and bike trips that are significantly shorter in duration than vehicle trips. For example, a two to three minute time-to-first-fix on a walk trip may account for 20% to 30% or more of the trip being lost since walk trips average only 10 to 12 minutes in duration. Improving time-to-first-fix is somewhat problematic because it depends on number of factors, including GPS receiver performance, time elapsed since the last valid position fix, and the receiver's view of the sky. However, this feature of a GPS receiver's performance must be an important consideration when selecting equipment.

Self-contained batteries powered the PTU and data collection time was limited by the estimated 8-hour life of the batteries in the PDA[11]. The PDA used in these tests was a relatively high user of power. Other PDAs currently on the market advertise longer operating times before needing battery replacement. None of the data collection tests exceeded the estimated 8-hour limit of the PDA and the PDA batteries were replaced frequently during the test period. Only one test subject reported that the PDA failed to perform in a manner that was consistent with dead batteries. Currently, the application software has no provision for announcing battery condition to the user or for properly terminating a data file when the PTU power is failing. This is a feature that should be incorporated into the application software to ensure data capture and inform the user when a low power condition exists.

6.3 Next Steps

The PTU needs several refinements before fielding for expanded use by general public respondents.

- The robustness of the equipment must be improved for walk and bike trips. These improvements must protect the touch-screen user interface and on/off switches to prevent inadvertent interruption of the data collection process.
- The application software must be refined to eliminate unanticipated messages to the user. As an alternate, the message set could be explained to the user in the user documentation, along with the proper response to the messages.
- GPS receiver time-to-first-fix should be examined to optimize performance for walk and bike trips. While complete origin to destination coverage is probably not possible, the contribution of the GPS receiver performance to this issue can be minimized.
- Comfort issues must continue to be addressed as the PTU is used. The principal issues relate to the relative bulk of the GPS receiver mounted on the shoulder strap, more efficient cabling design, and a more secure carrying case for the PDA.

Implementation of these improvements will further reduce the respondent burden associated with PTU use and improve the quality of the collected travel data. Although this prototype was perhaps “ahead of its time,” hardware improvements that have occurred within the last six months, as well as products to become available within the next six months, will make these improvements possible in the near future. GPS modules and smaller GPS chipsets are much more available, especially in anticipation of GPS integration with cellular telephones to meet the FCC mandates for E911 response.

Appendix A.

Test Subject Questionnaire

FHWA Walkabout Prototype Use Survey

<u>Installation</u>

1. Which of the following installation instructions did you utilize (circle all that apply)?

   Briefing   W**ritten Guide**

2. Which installation instructions did you find the most helpful (circle only one)?

   Briefing   **Written Guide**

3. How clear were the installation instructions in the written guide?

   Very Clear   **Somewhat Clear**   **Somewhat Unclear**   **Very Unclear**

4. 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 (on your person and in your vehicle).

   Strongly Agree   **Agree**   **Disagree**   **Strongly Disagree**

5. Did you experience any problems in installing the GPS device (on your person or in your vehicle)?

   YES   **NO**

DESCRIBE:

6. How could the installation process be improved?

DESCRIBE:

<u>Use of the Hand-held Computer</u>

7. Did you ever use the hand-held computer?

YES **NO**

8. How did you learn to use the hand-held computer?

Briefing **Written Guide**

9. How clear were the use instructions in the written guide?

Very Clear **Somewhat Clear** **Somewhat Unclear** **Very Unclear**

10. 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 are sufficient to allow me to successfully teach others how to use the hand-held computer.

Strongly Agree **Agree** **Disagree** **Strongly Disagree**

11. Overall, how easy was it for you to use the hand-held computer before each trip?

Very Easy **Somewhat Easy** **Somewhat Difficult** **Very Difficult**

12. How often were you able to enter trip data into the hand-held computer?

All of the time **Most of the time** **Some of the time** **Almost Never or Never**

13. How much time was needed, on average, to set up the equipment when changing to a new mode of travel?

Car ______ **min.**

Bicycle ______ **min.**

Walk ______ **min.**

_______ ______ **min.**

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

________ **min.**

15. How easy was it to read the screen on the hand-held computer?

Very Easy **Somewhat Easy** **Somewhat Difficult** **Very Difficult**

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

DESCRIBE:

17. Was the use of the hand-held easier or harder than you thought it would be?

Easier **Harder** **About as** Expected

DESCRIBE:

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

YES **NO**

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

YES **NO**

20. Would you be willing to use this device again in a similar study?

YES **NO**

21. While you were driving your vehicle (all modes where you were an operator), how much of a distraction was created by having the device in use?

Great Deal **Some** **Very Little** **None**

22. Did you change your driving habits in any way because the device was with you?

YES **NO**

DESCRIBE:

23. In what way could we improve this device and its usage?

DESCRIBE:

[1] Lexington Area Travel Data Collection Test – Global Positioning Systems for Personal Travel Surveys, USDOT, Federal Highway Administration, September 15, 1997.

[2] Heavy-Duty Truck Activity Data, USDOT, Federal Highway Administration, April 30, 1999.

[3] Our Nations Travel: 1995 NPTS Early Results Report, September 1997.

[4] Draijer et al, 2000; Perdok et al, 1998; Transport Research Centre of the Ministry of Transport, Public Works and Water Management, The Netherlands.

[5] Draijer, G.; N. Kalfs; and J. Perdok. (2000) GPS as a Data Collection Methods for Travel Research. 79th Annual Meeting of the Transportation Research Board, Washington, D.C., January 2000.

[6] At midnight on May 1, 2000, selective availability was discontinued by order of the President of the United States.

[7] DeLorme/Earthmate GPS Receiver Accuracy, http://www.delorme.com/earthmate/accuracy.htm, October 10, 2000.

[8] National Bicycling and Walking Study, FHWA, 1994.

[9] The EarthMate™ receiver turns off automatically if no movement is detected by the receiver. This is an internal feature of the EarthMate™ and is intended to conserve the receiver's batteries.

[10] The test protocol requested the test subject to change the PTU configuration by adding a power cable that allowed the PTU to be powered via the vehicle accessory port (cigarette lighter) when making vehicle-based trips.

[11] An option was provided for using the vehicle's power system to power the PDA for vehicle-based trips. This option allows more of the internal power resources to be focused on walk and bike trips. However, this option requires the user to disconnect and reconnect cables and is not preferred for general respondent use.