GPS Pilot Project

PHASE ONE: LITERATURE AND PRODUCT REVIEW

Prepared for:

New York Metropolitan Transportation Council

December 2007

Contractor – STV

Principal

Dr. Catherine T. Lawson, PhD – University at Albany
Dr. Cynthia Chen, PhD – City College New York
Dr. Hongmian Gong, PhD – Hunter College
Sowmya Karthikeyan, Alain Kornhauser – ALK Technologies

Graduate Research Assistants:
Jamie Cepler, Maria Chau, University at Albany, SUNY
Haiyun Lin, CC CUNY, Salvatore Dziekan, Hunter College CUNY

Table of Contents

Project Overview

The **GPS Pilot Project** is designed as a "Proof-of-Concept" experiment to determine whether incorporating Global Positioning Systems (GPS) technologies into the upcoming NYMTC Household Travel Survey efforts will provide a cost-effective person-based strategy for collecting both passive and active travel behavior data. The primary objectives are to:

1. ***Determine the feasibility of using GPS technologies*** to collect "passive" data on travel behavior and integration into household travel survey efforts. The initial experiment will use "off-the-shelf" GPS hardware, currently available software, and existing GIS data in the Manhattan region.
2. ***Determine the feasibility of collecting data for "mixed mode" travel*** in the Manhattan region, considering the costs associated with any upgrades to the GPS devices, software programming and/or GIS data to support integration into the Best Practices Model (BPM) and collect data of sufficient quality for household travel survey efforts.
3. ***Determine the feasibility of collecting data for previously "misreported" trips*** as described in the review of the 1997 Regional Household Travel Survey (RHTS), particularly those trips that included transit.
4. ***Determine the feasibility of incorporating GPS data in future household travel survey efforts with a sample population*** based on the ease of use and acceptability of specific users.

Executive Summary

This report - **GPS Pilot Project: Phase One** addresses the first part of primary objective '***1. Determine the feasibility of using GPS technologies***'. In this phase the research team examines how GPS technology collects 'passive' data on travel behavior and how this technology is integrated into household travel survey efforts by (1) conducting a scan of various agencies and organizations that have used GPS technology in their travel surveys and review the existing literature on their experience; (2) evaluating the most recent 'off-the-shelf' person-based GPS units available, and (3) researching GPS and GIS software interface and hardware data exchange. The first three sections of this document concentrate on these areas and are titled - *Section One: Use of GPS for Regional Travel Surveys*; *Section Two: Review of Available GPS Technologies*; and *Section Three: GPS/GIS Interface*. Each of these sections includes an introduction on the segment being covered, descriptions and definitions used in the review and a table summarizing the findings/comparisons for the particular section. The last section, *Section Four: Discussion* - (1) focuses on issues related to this research, (2) summarizes phase one in the *Conclusion* and (3) presents the *Next Step* outlining the subsequent initiatives in phase two.

Section One: Use of GPS in Regional Travel Surveys

Introduction

To determine the feasibility of using Global Positioning Systems (GPS) in the New York Metropolitan region, the research team conducted a scan of government agencies and organizations that previously used GPS technologies as a method of collecting data for their travel surveys. From the Lexington study conducted in 1996 to the most recent Oregon household travel survey conducted in 2005, there have been 13 regional or statewide travel surveys that have used GPS technologies in the United States, of which 3 used person-based GPS technology. Literature is available for 6 of these surveys, including 2 of the 3 person-based GPS studies. In addition to the U.S. experience, the research team also reviewed person-based GPS surveys in other countries. These overseas studies were conducted in Europe and Australia and 4 of them are included in this report.

Factors Used to Evaluate GPS Feasibility

A number of factors were considered in evaluating GPS feasibility. These factors include: *Data Accuracy and Reliability*; weight of *Person-based GPS unit*; *Ease of Use/Respondent Burden*; *Costs*; *Public Response*; *Advantages of Implementing GPS in Travel Survey*; and *Major Findings* from the review of the GPS survey studies. This section provides a definition and synopsis of the factors used to evaluate GPS feasibility from the literature review. Table 1 then lists each study and summarizes these factors which evaluate the potential use of GPS as a tool for regional travel surveys.

Data Accuracy and Reliability

'Data Accuracy' measures the precision of the data generated by the GPS unit and includes: time, speed, and longitude and latitude. 'Reliability' examines the range of accuracy under a variety of circumstances. These circumstances may consist of different conditions for travel mode-choice (i.e. *subway, bus, walk/bike, and ferry*), transportation infrastructure (i.e. *bridge, highway*), building type (i.e. *steel, brick, high-rise*) and environmental factors (i.e. *trees, terrain, topology*).

The existing literature suggests that the accuracy of the newest GPS units can detect a point within 10 - 50 meters of a location and record data continuously per second for several hours (Wagner et. al 1996; Bradley et. al 2005; Wolf et. al 2006). The most advanced person-based GPS unit has up to 12 - 16 hours of battery life or 466,000 points of recording (NuStats et. al 2005, Stopher et. al 2005). In terms of 'reliability', the literature implies that loss of signal for GPS units could be caused by the 'urban canyon' effect (caused by high-rise buildings) or being underground (Ohmori et. al 2000, Wermuth et. al 2003; Wolf 2004). In the past, areas covered by trees were also problematic; however, recent upgrades in GPS technologies seem to have overcome this issue (Stopher et. al 2005). Another 'reliability' concern for GPS units is with 'cold starting' which is the amount of time it takes for a GPS unit to lock on to a satellite signal when it is initially turned on. The literature indicates that during a cold start, data generated by the GPS units might be unpredictable. The optimal condition for the GPS unit to acquire signal when it is initially turned on is when the unit is motionless in an open space; otherwise, it can be very difficult or even impossible for the GPS unit to obtain a stable signal (Ohmori et. al 2000, Stopher et. al 2002).

Person-based GPS units: weight

'Weight' consists of the sum of the loads between the GPS receiver and any other accessories that are required to be carried when traveling. Previous studies conclude that people tend to take off their units during their walk or transit trips when the GPS unit weight more than 1 or 2 kilograms (Wolf 2004, Wolf et. al 2004). In recent years, the weight of a GPS unit has been reduced to 100 - 500 grams (e.g., the Neve Steplogger and the Geostat wearable Geologger) (Stopher et. al 2005, Wolf et. al 2006).

Ease of Use/Respondent Burden

'Ease of Use' and 'Respondent Burden' assesses the usability of the person-based GPS unit. 'Ease of Use' indicates how user-friendly the GPS unit is, while 'Respondent Burden' indicates the level of involvement the GPS unit places on a participant of a travel survey. Several dimensions were considered in measuring these criteria including the skills-level required by a participant to operate a computer and the GPS technology and the amount of time and the number of tasks required to report a trip. These tasks may include carrying the unit, filling out a paper diary, uploading data from the unit, and reporting the trip on a computer, etc.

The existing literature suggests that the use of GPS units can reduce respondent burden to some extent. For GPS survey participants the time typically spent on reporting each trips was approximately 1 minute (Battelle 1997, Battelle 2000, Wermuth et. al 2003). Several experimental GPS studies tested the possibility of requiring people to fill out an electronic travel diary, downloading data from GPS units, and verifying the routes of their trips through a GIS-inserted software interface. Studies from regional travel surveys suggest that it is more appropriate and common to limit the participants' burden by only requiring them to carry the GPS unit (Wolf et. al 2001, Wolf 2004, NuStats et. al 2005, Wolf et. al 2006), however, 80% of all the reviewed GPS surveys required the participants to fill out a traditional paper survey in addition to participating in the GPS survey.

Costs

'Costs' includes both the price of the equipment and cost in conducting a travel survey using GPS units. In the U.S. one source reported that the cost of conducting a survey in 2005 with a GPS unit only (no paper diary) was $1068 per household and $1198 per household for both GPS and paper diary survey (NuStats et. al 2005). At the same time, they suggest that the cost of GPS units were declining rapidly with advancement in the technology. For example, the cost of a GPS unit in 1996 was $1400 during the Lexington study. In 2005 the cost of a GPS unit dropped down to AU$950 (US$710) during the New South Wales Survey in Australia. The only person based GPS units cost reported were by researchers motivated in travel survey applications. (e.g., the Neve Steplogger and the Geostat wearable Geologger).

Public Response

'Public Response' refers to the public's willingness to participate in a GPS survey. The existing literature suggests that most people or households are willing to participate in GPS travel surveys (Battelle 1997, Battelle 2000, Wolf 2004, Bradley et. al 2005). Households who refuse to participate have demographic characteristics that are significantly different from those who agree to participate. Characteristics of these households are often associated with low income, non-English speaking, without driver license, couples with older children or heads of households younger than 30 years old (Hawkins et. al 2004, Bradley et. al 2005).

Advantages of implementing GPS in travel surveys

Implementing GPS in travel surveys has the advantage of gathering more accurate data on trip routes. Existing studies demonstrate the applicability of a GPS-equipped survey to various travel modes, the ability to be able to determine the route of the trip by using GIS or other software tools, and the ability to capture trips that would be missed in a traditional paper or telephone based survey.

The existing literature reveals that GPS units can be used independently and can capture a number of trip types that are typically missed in a traditional travel surveys. In particular, these missing trips include: single trips along a multi-trip journey and short duration trip late at night (Wolf et. al 2002). According to Doherty (Doherty et. al 1999), people tend to round off their travel times in 5, 10 or 15 minutes increments and report an approximate origins/destinations location rather than the actual location. Implementation of GPS in travel survey can overcome this limitation. Although in-vehicle GPS units only detect motorized trips, person-based GPS units can provide data on all types of travel modes (*automobile, walk, public transit*). Using both GIS the GPS technology in travel survey can generate accurate information on the participants travel time, route, intermediate stops, and origin and destination (Wermuth et. al 2003, Wolf 2004, Stopher 2007). Doherty and Wermuth (Doherty et. al 1999, Wermuth et. al 2003) suggest that a more effective method of obtaining mode information is to combine the GPS survey with the traditional paper diary. Assumptions of the mode of travel can be inferred by using trip speeds. Trips with higher speed tend to be automobile trips; trips with stops on location of each bus station tend to be bus trips; trips of lower speeds with stops at intersections tend to be walking trips; trips with origin and destination located near subway stations where signal is lost (underground) and reestablished tend to be subway trips. These assumptions may seem valid however under various situations they can also be wrong. For instance, trip speeds are affected when there is congestion, or when applied to people with physical disabilities.

Summary of Findings

There are several important findings from the existing literature on the 'Use of GPS in Regional Travel Surveys'. These include:

- GPS improves survey data quality
    - Using person-based GPS in travel survey can generate more accurate information on a participant's travel time, duration, route, intermediate stops, and origin and destination.
    - The accuracy of GPS-generated information for travel modes still needs to be verified.

- GPS captures trips that used to be underreported or missing
    - GPS data reports trips along a multi-trip travel journey including short duration trips late at night.
    - The literature reveals that GPS survey participants report more trips than paper diary survey participants.

- Characteristics of households who do not participate in GPS travel survey
    - Households who typically refuse participation in combined GPS and paper diary survey tend to be households that are:
        - larger
        - low income
        - non-English speaking
        - without a vehicle
        - couples with older children, or
        - where the head of the household is younger than age 30
    - In particular, households with older vehicles, older children/young adults in large households typically are not willing to participate in GPS travel surveys. These households tend to be under-reported for GPS surveys and should be considered a "special group" which requires additional attention in a GPS survey effort.

- Reasons for refusal
    - In order to compare data, regional travel surveys involving GPS technology usually require participants to partake in both the GPS survey and paper diary survey. The most common reason households refuse to participate in GPS surveys was because of data duplication. In other words, they felt that they had already filled out a paper survey and it was unnecessary to partake in the GPS survey and vice versa.
    - Another reason of refusal to participate in GPS surveys relates to privacy. However some studies, such as London 2002, concluded that it is not an issue among their participants.

Table 1. Previous Studies Using GPS for Regional Travel Surveys

Study	Data Accuracy and Reliability	Weight (person-based GPS only)	Ease of Use / Respondent Burden	Costs	Public Response to GPS Survey	Advantage of Implementing GPS in Travel Survey	Major Findings
Lexington, KY 1996 ***Participants:*** *100 Households with 216 individual drivers*	**Unit:** PCMCIA *Improving accuracy on trip begin/end: time and location, providing valid data on the actual routes and highway functional class*	N/A	Reduce respondent burden : 74% of trip take 1 minute or less to report; 95% of 2 min or less.	$1400 per unit; also suggested as reduce to $800 one year later	Willing to participate	▪ On-vehicle GPS system power source from car ▪ Visible user interface on hand-held computer ▪ GPS appears sufficient to plot most 'roadway network' trips	▪ No real problem from GPS application in large-scale deployment was found. ▪ Additional techniques may be needed to accurately track vehicle in urban canyons, tree covered areas, or underground. ▪ GPS produces a higher percentage of short-distance trips: 5.14 vs. 4.63 trips/day
Atlanta, GA 2000 ***Participants:*** *550 Households out of total 4,000 sample size*	**Unit:** unknown **Signal interval:** 1 second **Dwell time:** first 120 second **Cold Start issue:** First 20 - 120 seconds of trip may not be recorded by the GPS	N/A	N/A	N/A	N/A	▪ Trips using other modes, such as walking, N/A by in-vehicle GPS system (basically non-motorized mode users)	▪ Most trips that are often omitted in travel diary can be identified by GPS, such as short duration trip which is part of a journey or short "out-and-back" round trips. However, trips do not involve the vehicle leaving path can not be identified by the GPS. ▪ Sampling strategy: Identify certain strata: transit user, non-motorized mode users, atypical housing inhabitants
Kansas City, MO 2004 ***Participants:*** *228 Households out of 3,049 sample size, with 426 vehicles*	**Unit:** GeoStats Geologger **Signal interval:** 1 second *Log all points where speed is greater than 1 MPH;* **Dwell time:** 120 seconds	N/A	Passive on-vehicle GPS logger: Least burden for the users if the researcher will do the data exportation instead of the users.	N/A	Statistically significant differences between the socio-economic characteristics between GPS households and non-GPS households. (See findings in right.)	▪ Misreported trips when using GPS: most are a single stop among a journey and have the average duration of 5.7 minutes; most missing trips are later in the day. (See findings in right.)	▪ GPS households report higher trip rates: 5.15 trip/ person vs. 4.18 of others ▪ Self-selection bias: people who are willing to be in GPS samples tend to use their vehicle more. ▪ Survey instrument bias: using GPS encourage people report trip on diary more. ▪ Follow-up interview can help identify typical missing transit trips when doing personal-based survey. **Public Response:** 1) GPS Households are larger, own more vehicles, and has higher income. 2) For non-response: vehicle in low income households, or households with a head younger than 30 has more missing trips, older vehicle in multiple vehicle households has more missing trips. Drivers who do not use paper diary are related to missing trips, particularly when their trips are reported by others on proxy.

Table 1. Previous Studies Using GPS for Regional Travel Surveys

Study	Data Accuracy and Reliability	Weight (person-based GPS only)	Ease of Use / Respondent Burden	Costs	Public Response to GPS Survey	Advantage of Implementing GPS in Travel Survey	Major Findings
California State 2001 ***Participants:*** *At least 200 Households out of 16,500 sample size*	**Unit:** GeoStats Geologger **Signal interval:** 1 second *Log all points where speed is greater than 1 MPH;* **Dwell time:** 120 seconds	N/A	N/A	N/A	N/A	▪ Match rate between the GPS trip and CATI trip is 67% for the first 15 HH.s.	▪ The average trip rate for GPS households is 8.47 per household vs. 6.93 for the diary.
Oregon State 2005 (COSMO) ***Participants:*** *299 Households*	**Unit:** GeoStats GeoLogger *(wearable)* **Battery / Power Drain:** Lithium Ion, rechargeable; **Capacity:** 466,000 points; **Valid points:** speed greater than 1 MPH	N/A	N/A	Total survey cost per Household: CATI only- $425; GPS only - $1068; CATI & GPS - $1198.	GPS part of survey has higher refusal rate by household comparing with diary.	N/A	▪ Rather than replace traditional diary survey with GPS, report in this study recommends continuing with mixed-frame sample (both GPS and diary) for full study.
Battelle Memorial Institute 2000 ***Participants:*** *6 Battelle Staff Members*	**Unit:** Personal Travel Unit (PTU): *GPS & PDA*	454 grams shoulder strap, touch-screen user interface	Easy to use, response burden generally 1 minute or less.	N/A	All test subjects preferred this approach to written travel diaries.	N/A	▪ Data quality was poor: PTU system "time-out" as missing connection between GPS receiver and the PDA.
Quebec City, Canada 1999 ***Participants:*** *3 vehicles in a 1 to 2 week period (In total, 49 days of travel is monitored , with 913 km and 164 stops)*	**Unit:** Trimble Geoexplorer receiver *(with differential correction module)* **Signal interval:** 5 seconds **Unit:** Garmin GPS48 receiver *(low-cost, with differential correction module): DBR21* **Signal interval:** 4 seconds	N/A	Lower respondent burden	N/A	N/A	▪ GPS receivers can be used to support descriptive and in-depth studies on travel behavior. ▪ GPS can collect detail multiple data on vehicle and can be used to automatically detect the real roadway segment.	▪ Major problem encountered: Collecting data problem --- delay in start up of GPS; ▪ Data storage problem --- lack of enough storage space for multiple day survey.

Table 1. Previous Studies Using GPS for Regional Travel Surveys

Study	Data Accuracy and Reliability	Weight (person-based GPS only)	Ease of Use / Respondent Burden	Costs	Public Response to GPS Survey	Advantage of Implementing GPS in Travel Survey	Major Findings
Netherland 1997 ***Participants:*** *151 Individuals*	**Unit:** unknown	2kg	N/A	N/A	Equipment considered too heavy and may have contributed to lost data.	▪ Researchers conclude that it is possible to use GPS to monitor various mode of travel.	▪ The equipment was considered as too heavy and thus reported to be left behind on significant number of walk, cycling or transit trips.
London, England 2002 ***Participants:*** *154 Individuals* *(3 days data)*	**Unit:** GeoStats GeoLogger *(wearable)*	1 kg with Palm PDA	N/A	Equipment price: US$875 / £475 (British market, year 2006)	Participants in London receptive to technology. Concerns about security and privacy were less than expected.	▪ 82% of all the GPS data are usable.	▪ Participants appeared not to be overly concerned about security and privacy issues.
New South Wales, Australia 2003 ***Participants:*** *82 Individuals from 48 Households*	**Unit:** Neve-Steplogger **Battery life:** 12-16 hours, rechargeable;	103 grams	Easy to wear compared with previous ones. Entails some degree of respondent burden.	Equipment price: US$724 / AU$950 (2005)	Response rate of 53.9%; there were statistically significant differences between participants and non-participants in GPS study	▪ Provide the time, speed, and position of the user, as well as information on participant's mode, purpose, duration, route, and accurate origin and destination locations.	▪ The two main reasons for refusal were the burden (already agreed to in diary survey) and concern on privacy. ▪ Non-response people (may be under estimated in the GPS survey) are more likely to be: from non-English speaking countries; Couple households with older children; low income; large household size (*author suggest needs further study on this point*).

Section Two: Review of Available GPS Technologies

Introduction

The review of existing literature suggests GPS technology can be successfully implemented in regional travel surveys. A particular concern of this technology for a New York City deployment is the ability of the GPS hardware and software components to function properly. The research team reviewed the most recent "off-the-shelf" GPS units on a set of performance features.

"Off-the-shelf" Product Review

The fast-moving nature of technological developments in the GPS market is an advantage for research in this area. The GPS technology has been integrated into three different applications: the GPS receiver, the GPS logger, and the GPS tracker.

- A GPS receiver is linked to Personal Computer (PC) or a pocket PC. These units can archive spatial data and/or send the data to PDA for location information.
- A GPS logger is the same equipment as a receiver, but also includes memory within the unit. Records are generated from a process signal, with recordings occurring every second in comma-delimited format. The data fields can include latitude, longitude, altitudes and speed. The storage capacity varies depending on the intervals designated for data collection. For example, data captured every second would require more storage than if captured every 30 seconds.
- GPS trackers are similar to the logger however they also include a telecommunications component using a SIM card to transmit information in real time through a phone line. This method is more expensive to use since the GPS tracker needs to be "called" – 'where are you now'. Calling to report the data would require a study using 200 units to have 200 phone lines.

Since the cost of using a GPS tracker would be prohibitive with the current technological requirements, only GPS loggers are being considered. Table 2 provides a listing of the units available at the time of this review, according to the manufacturing specs. The features reviewed include: datalogger type; name; receiver; number of positions stored; data recorded; data format; power; run hours; price; supplier; and URL.

Datalogger

The datalogger is a battery-powered unit that contains a GPS receiver and has the ability to internally store data captured and processed by the receiver, where the data is then available to download on to a PC for further processing. Nine types were reviewed.

Receiver

The receiver is the chipset used by the datalogger to receive and process a satellite signal. There are a number of chipsets available with different characteristics to better handle poor signal reception in conditions such as an urban environment. The two most important factors to consider are 'sensitivity' and 'multipath rejection'.

- Sensitivity is measured in dBm. dBm is the measurement of power loss in decibels using 1 milliwatt as the reference point. A signal received at 1 milliwatt yields 0 dBm where a signal at .1 milliwatt is a loss of 10 dBm. For GPS receivers sensitivity is always designated as a negative number; the lower the number the higher the unit's sensitivity.
- Multipath rejection is the ability of the chipset to reject GPS signals that are bounced off the sides of buildings, or other obstructions which create false position readings because their time of arrival at the datalogger has been prolonged by the bounced path. There is no measurement for this and multipath rejection is generally determined by field experimentation.

Number of Positions Stored

The datalogger records data points as latitude/longitude coordinates. Each recorded position uses memory in the datalogger's storage space. It is important to determine the memory capacity or length of time a unit can record data before the datalogger's storage space is full and the data needs to be uploaded on to a computer. Generally, a datalogger with a greater memory capacity is preferable.

Data Recorded

The data recorded in a datalogger typically includes latitude, longitude, time and speed. Additional data-variables are offered on more advanced GPS models. The data output can be conveyed differently from different manufacturers.

Data Format

Data format is the file format of the data recorded. This is relevant since data must be downloaded from the unit and further processed. If the datalogger uses a proprietary file format then its usefulness may be limited. Preferred file formats for data processing are .txt or .csv.

Power

Typically dataloggers have portable self-contained power unit such as a rechargeable or single use battery. Some units have the ability to be powered from a car charger outlet.

Run Hours

Run hours are the length of time the unit can operate before a recharge or battery replacement is necessary. Generally a longer length of time a unit can operate without battery recharge or replacement is preferred.

Purchase Recommendations

To determine the best unit for the New York City environment, the most important selection criteria is the receiver chipset quality and the capability of the unit to function in urban canyons. After reviewing available GPS units, the research team selected two: the 'i-Blue 747' and 'GlobalSat DG-100'. 'i-Blue' contains a MTK chipset and 'GlobalSat' contains a SiRF III chipset. The selection of these two chipsets was based on the GPS expertise of Paul Biba (ALK), a research team member who specializes in testing GPS units. Compared to other 'off-the-shelf' consumer-level GPS units, the chipsets on these unit's appear to be most effective ones available to date. The published sensitivity of 'i-Blue' is -158 dBm and 'GlobalSat' is -159 dBm (manufacturer's published specifications).

Table 2. Global Positioning Systems (GPS) Unit Comparison

Datalogger	Name	Receiver	Sensitivity (dBm)	# of Positions Stored	Data Recorded	Data Format	Power	Run Hours	Price	Supplier	URL
Deluo	Bluetooth Datalogger	N/A	N/A	170,000	GPS time, latitude, longitude, driving speed	HTML, CSV, NMEA	Battery/ Car charger	N/A	$159.95	Deluo	deluoelectronics.com
Wintec	WBT-201	Atmel-uBlox ATR 0625	N/A	131,072	timing, latitude, longitude	N/A	Battery/ Car charger	12-15	$94.99	Semsons	Semsons.com
	WBT-200	u-Nav	N/A	12,680	timing, latitude, longitude	N/A	Battery/ Car charger	10	$89.99	Semsons	Semsons.com
	WBT-100	u-Nav	N/A	12,680	timing, latitude, longitude	N/A	Battery/ Car charger	10	$94.99	Semsons	Semsons.com
Royaltek	RBT-1100	N/A	N/A	30,000	N/A	N/A	Battery/ Car charger	N/A	$94.99	Semsons	Semsons.com
	RBT-3000	N/A	N/A	N/A	N/A	N/A	Battery/ Car charger	10	$99.99	Semsons	Semsons.com
I.Trek	Z1	MTK	-158	50,000	N/A	N/A	Battery/ Car charger	N/A	$79.99	Semsons	Semsons.com
GlobalSat	DG-100	SiRF III	-159	60,000	time, date, speed, altitude, GPS location	TXT, XLS, NMEA183	Battery/ Car charger	20	$89.99	Semsons	Semsons.com
i-Blue	747	MTK	-158	100,000	GGA, GSA, GSV, RMC, VTG, GLL	NMEA 0183	Battery/ Car charger	N/A	$74.99	Semsons	Semsons.com
	757 Pro	N/A	N/A	50,000	GGA, GSA, GSV, RMC, VTG, GLL	N/A	Battery/ Car charger/ solar	30/100	$84.99	Semsons	Semsons.com
EverMore	DL-200BT	N/A	N/A	28,000	GCA, GLL, GSA, GSV, RMC, VTG	N/A	Battery/ Car charger	6	$69.99	Semsons	Semsons.com
GeoStats	GeoLogger	N/A	N/A	N/A	N/A	N/A	Car charger	N/A	N/A	Geostats	geostats.com
Qstarz	BTQ 1000	MTK	-158	100,000	N/A	N/A	Battery/ Car charger	32	$99.95	BuyGPSNow	buygpsnow.com

Section Three: GPS/GIS Interface

Introduction

With evidence that GPS could be used to enhance data quality for regional travel surveys and claims that off-the-shelf GPS units have sufficient capacity to function in the New York environment, it is also important to investigate the interface with geographic information systems (GIS) spatial representations available for the region. The data generated by the GPS units requires a downloading processing strategy. The output data must be geocoded in order to use it in mapping software, such as ESRI ArcMap.

Table 3 provides a summary of the recent research addressing the interface between GPS and GIS. The elements reviewed include: the purpose of the study; the role of GPS; the role of GIS; how GIS assists GPS gaps; issues addressed and recommendations from the study.

Purpose of the Study

The research team reviewed five studies. Most of the articles pertain to real-time vehicle tracking (Bonnifait et al. 2007, Wolf et al. 1999). Some studies have been conducted that use GPS as a supplement or replacement to traditional travel diaries (Duncan 2007), however many do not consider the use of GIS.

Role of GPS

The role of GPS ranged from real-time tracking of vehicles, tracking walking routes and the recording characteristics of travel behavior including: travel time; routes; speed; mode; and origins and destinations (Bonnifait et al. 2007, Duncan and Mummery 2007, Chung and Shalaby 2005).

Role of GIS

The role of GIS included map matching, determining routes and processing the GPS data (Bonnifait et al. 2007, Wolf et al. 1999). No studies or articles were found that used GIS to fill gaps from travel in tunnels or underground subways.

How GIS assists GPS gaps

The most common use of both GPS and GIS was loading GPS data to a GIS road map and running algorithms to determine the exact route taken by linking GPS points to specific road segments (Chung and Shalaby 2005, Bonnifait et al. 2007, Wolf et al. 1999).

In certain instances of signal interruption, GIS was used to determine routes taken where GPS was unable to provide adequate data. Most articles indicate that more research needs to be conducted with regards to this issue and Wolf (1999) completely omitted all data from downtown areas since recording GPS data is interfered by the ‘urban canyon’ effect.

Issues Addressed

The most common issues that have arisen relate to GPS receivers not functioning properly due to loss of satellite signal resulting from tree canopies, urban canyons or weather conditions and issues relating to the margin of error in readings which can be up to 100m depending on the quality of the GPS receiver. Academic literature about travel through tunnels and the role of GPS and GIS to record these trips was not found.

U-blox (2004) specifically addressed GPS tracking in tunnels and other areas without direct contact with GPS satellites. This situation resulted in a test conducted by u-blox on their SBR-LS vehicle navigation system. The system uses dead reckoning ("DR") methods to determine the vehicle's location in the absence of a direct satellite connection. 'DR' relies on hardware that measures distance and direction traveled. This system works because contact with a satellite is not needed to record this data. This system, however, was devised to serve individuals and would most likely require too much setup work to be useful in a study.

Recommendations

Two of the studies provided recommendation for further study. Wolf et al. (1999) suggested conducting test routes to verify the GPS unit's accuracy under different conditions (e.g., tree canopies). U-blox (2004) recommended outfitting vehicles with odometers and other types of hardware, in addition to the GPS units.

Summary of findings

The findings from the existing literature addressing GIS, GPS and the interface between GIS and GPS are limited at this time. The primary issue impacting the effectiveness of GPS as a source of travel data relates to the satellite signal. Hardware improves, particularly with respect to the chipsets used in the available units may or may not solve some of the identified problems. The recommendation to conduct test routes prior to relying on the data is very important.

The review of the literatures revealed gaps in recent GPS/GIS research, including dealing with travel through tunnels and in subways. There was also very little information on the software used to generate and download the data to a computer for analysis. The durability of the GPS units during survey conditions is also of concern as the concept of using GPS to enhance regional travel surveys moves from the research lab to practice.

Table 3. The Relationship between Geographic Information Systems (GIS) and Global Positioning Systems (GPS)

Study	Purpose of Study	Role of GPS	Role of GIS	How GIS assists GPS gaps	Issues addressed	Recommendation
Versailles, France 2007 *Bonnifait et al.*	Fusion approach merging GPS, Dead Reckoning and GIS in tracking intelligent vehicles.	Real-time tracking location of vehicles.	Map matching to determine vehicle location on road network.	An algorithm is applied to GPS data to determine road selection. During GPS gaps, GIS road networks are examined to determine the most probable path taken when GPS data is restored.	Road matching, gap filling.	N/A
Toronto, Canada 2005 *Chung & Shalaby*	Feasibility of GPS as a replacement for travel diaries. How accurate are algorithms for determining routes and modes?	Record travel times, routes, speed, mode, and beginning and end points. Road links and modes.	Link GPS data to a map to determine routes traveled and locations of mode transfers	Determine routes and mode of transportation transfer points.	Inaccurate GIS map. Breaks in GPS data – "by connecting ends of broken GPS traces using appropriate estimation rules like shortest path algorithm, the full path can be identified." (p. 400)	N/A
Rockhampton, Australia 2007 *Duncan & Mummery*	Comparison of routes predicted by GIS and actual routes from GPS data by students walking to school.	Tracking route taken on walk to school.	Route predicted by running an algorithm using the home address and school address.	N/A	Routes taken varied between predictions and actual routes. However, distances traveled were similar.	N/A
Atlanta, Georgia 1999 *Wolf, Hallmark, Oliveira, Guensler, & Sarasua*	Examination of usefulness and accuracy of GPS data for travel studies. Comparison of GPS hardware.	Recording travel routes.	Process GPS data and interpreting results	Linking GPS data to road segments.	Loss of lock and time needed to regain useful readings and data (p. 69). Accuracy of base map. Spatial accuracy errors of TIGER maps 30 – 50 m errors are common and contribute to GPS points missing center buffers. Omitted urban canyons from analysis due to poor GPS performance.	Representative test route to verify GPS unit's accuracy in areas with different types of potential interference (ex. Trees canopies, etc.).
New York City, New York 2004 *U-Blox*	Product (SBR-LS) that uses dead-reckoning to determine location in areas where GPS service is not available.	Vehicle navigation system.	The product has a base map, but the article does not go into much info.	N/A	Determining vehicle location in tunnels and other areas with no GPS availability by measuring speed and direction traveled.	Vehicles need to be outfitted with odometers and other hardware and not just a portable GPS unit.

Section Four: Discussion

From the review of the literature on the use of GPS technology for household travel surveys, off-the-shelf GPS units, and the emerging GIS/GPS interface, the research team is able to provide preliminary responses to some of the issues highlighted for this research project:

Issues Relate to Research

Should a person-based-GPS survey be a part of the upcoming regional household travel survey?

In the review of the available materials, the research team found primarily positive responses to the potential use of GPS in future regional household travel survey deployments. However, most of the uses have been for research using small numbers of participants. As a result, there is no guidance for MPOs on whether they should include GPS and if so, how to integrate the new technology into current practice. If the GPS methodology is a substitute for travel surveys then there are no completed studies for guidance (no full deployment conducted with GPS). The methodology is yet to be described. Where GPS is a complement, it has been used to try and adjust the difference between traditionally reported travel patterns and the evidence from GPS data mapping. The statistical validity of whether GPS is sufficient (or even more accurate) is yet to be established for correction factor applications.

There are concerns regarding the inherent redundancy of asking people to complete a traditional paper-based travel survey and asking them to carry a GPS unit for the passive collection of their travel patterns. In several of the applications reviewed by the research team, respondents were asked to list locations they often visited. It might be possible to eliminate the travel diary and ask survey participants a set of standard questions about their typical destinations. For example, such information could include: their home address; their work address; their school address; their most often used grocery store; and their most frequent "other" destination (e.g., "In the course of a week, what location other than work and home are you the most likely to visit?") (Murakami 2007).

Perhaps the most hopeful use of GPS in travel survey efforts is described by Bradley et al. (2005. They suggest the role of GPS data, with supplementary diaries, as a full replacement for paper-based diary data collection. Not only would it be possible to change the instrument suite for travel data collection, but also to establish a continuous surveying strategy of small samples rather than the traditional large-scale survey. There could bring substantial cost savings by redeploying a "fleet" of GPS units to numerous households over a particular time period. They also look to the future use of multi-functional cell phone technologies capable of collecting GPS location data and verbal supplemental data on trip purpose, etc. Moving forward with new concepts and techniques could introduce unknown biases and deployment risks.

The risks for an MPO include:

- Sufficient knowledge to evaluate consultants claiming to be able to deploy GPS;
- The functionality of the GPS equipment to meet the demands of the region and the risk that the equipment fails because of internal chipset capabilities; risk of equipment failure for no apparent reason; and/or data generation failure because the participants fails to use the equipment correctly;
- Increased reduction in participation of particular household types because of the level of sophistication of the participants required to use GPS units at this time.

The rush to implement GPS for travel surveys could result in spoiled surveying efforts if MPOs are left without guidance on how to determine the appropriateness of the methodology to their needs and populations. A set of testing procedures to reduce these risks are important to continue the momentum towards using new technologies and reducing outright failures.

What would be the minimum recommended sample size of the person-based GPS component of the regional household travel survey?

Without a clear decision on whether the GPS technologies should substitute or complement a traditional or a modified survey deployment effort, the minimum number of households necessary to ensure a successful deployment can not be determined. The original plans for the metropolitan Washington 2007 Household Travel Survey considered using person-based GPS as an add-on instead of an in-vehicle GPS only add-on. The decision to not include person-based GPS was based on concerns that the technology was not sufficient for practice due to issues with battery life, the size and make-up of the equipment available, user resistance in carrying a person-based GPS for an entire day, and the quality and reliability of the person-based GPS units for actual capture of transit and pedestrian trips (Griffiths 2007). Provided these issues can be overcome, if all participants are equipped with inexpensive GPS units, then the number of units would be the entire sample (e.g., 15,000 participants). Most of the previous uses of GPS relied upon volunteers who were willing to try the new technology (self-selection bias). Any improvements in the collected data with respect to origins, destinations, travel times, etc., however, is of value, even if households providing improved data are not randomly sampled. The research team intends to contact other household travel surveying deployment programs currently in the field or in the process of being reported (e.g., Chicago surveying effort), to understand their decision-making process for including or excluding person-based GPS data, including decisions on sample size, in the next phase of this research.

How could the person-based GPS survey be used to improve and / or enhance current travel survey processes that have been used in the NYMTC Region?

The expected value-added from a person-based GPS survey in the NYMTC Region would be similar to other deployments, only if the GPS equipment can perform adequately within the conditions across the Region. This is being addressed with the purchase of two GPS unit types (the i-Blue 747 and the GlobalSat) that carry claims from the manufacturers of being capable of functioning in dense urban areas. These units will be tested in the next phase of this research project with respect to the following performance parameters:

- Quality and quantity of GPS data collected in a dense built environment (e.g., Wall Street area)
- Quality and quantity of GPS data collected in typical Manhattan street environments (e.g. mid-town and downtown areas)
- Ability of the GPS equipment to function on a variety of alternative modes including: bus, above-ground rail, ferries, and locations where subway cars surface, etc.
- Ease of use
- Durability of GPS equipment to actual field conditions
- Software interface for data downloading
- Ease of use in a GIS environment
- Overall accuracy of the GPS equipment in each of the test-bed environments

If the GPS units fail to function in the urban canyon environment, the research team will investigate current research using GPS-enabled cell phones. Application of this type of technology is underway in Japan by Eiji Hato and Yasuo Asakura (Murakami 2007). Cell phone GPS applications are also commercially available for monitoring children's activities (e.g., the "Chaperone" phone service offered by Verizon). Cell phone units may cost more than the GPS loggers initially. They may also be very expensive to use (similar to GPS trackers) if the service requires constant communication with a server. These issues will be addressed in subsequent phases of this project.

How could the person-based GPS survey help in addressing non-reported trips in the travel diaries?

Several previous studies attempted to use GPS to develop adjustment factors for non-reported trips (e.g. Oregon 2005). However, as Bradley (Bradley et. al 2005) pointed out, those participants willing to use GPS were actually more likely to report their trips more accurately. It is also possible that the GPS, not the participant, is appearing to "report" stops that are actually incidents of satellite "confusion". Knowing more about the number of satellites working at the time of the "non-reported" trip would help analysts understand the data and to make more appropriate conclusions.

According to Murakami (2007), using GPS tends to identify many more trips, but that these "stops" are often chains (e.g., stopping for coffee on the way to work), and therefore do not add significantly to the estimated vehicle miles traveled (VMT) for a region. At the same time, these identified stops could be very important for air quality analysis for vehicle stops.

How could the person-based GPS survey help in addressing the rounding of travel times, imprecise departure and arrival times reported in the travel diaries, and bad recollection of O-D locations by respondents for geocoding?

Traditional efforts to capture data with sufficient quality for modeling purposes have been plagued with rounding of travel times, poor recall by survey respondents on just when and where they were traveling, etc. The promise of more spatial and temporal accuracy from the use of person-based GPS in a large scale surveying effort has yet to be fulfilled. In addition to having equipment with sufficient capabilities to capture the data, the types of data generated and archived by the equipment software interface and the quality of the available GIS shape files will determine whether accurate travel times, departure and arrival times, and exact origins and destinations could be useful outputs from person-based GPS.

The information available for review of the manufactures of the GPS equipment lacked detail on the effectiveness of the software interface. The actual field tests of the equipment purchased for this research will be reviewed for functionality with respect to the software interface. Decisions made by the manufacturers on the length of time between readings could impact the usefulness of the data. For example, if the equipment user is unable to control the rate at which the data is collected, it may impact the quality of the data and the storage capacity of the units. A review of the software functions, archiving and data storage capabilities, and GIS interface will be crucial to addressing these concerns. The next phase of this research will address these areas of concern.

Would the person-based GPS survey help to improve the response rate from low response groups, such as young males?

Although no studies attempt to boost participation of particular groups (such as young males), some evidence was revealed that traditionally low-reporting groups also had lower levels of participating in GPS deployments. At the same time, there is a growing commercial market for GPS units for the public to use the equipment for leisure activities. The target market for these units appears to be young males with an interest in technology (e.g., Garmin retail displays in Chicago, Illinois store front).

How could the person-based GPS help in improving the BPM modeling process?

After the research team determines the viability of the person-based GPS units to function properly in a dense urban environment and on a variety of modes, it will be important to bring these results to the modeling community for their review. Without a dialogue with the modeling community, we can not understand the true nature of the improvements that person-based GPS will bring to the BPM modeling process. On the one-hand, person-based GPS may be limited to mimicking the data formats currently available from traditional household travel surveying efforts, with some improvement in the accuracy of the spatial and temporal data. On the other hand, the software interface and ability to convert the data to GIS shape files could generate tremendous new uses for modeling purposes. For example, the actual routings and travel behaviors could be used for validating models, including transit elements.

How would it be possible to track complex bus/subway transit rider paths in Manhattan?

The GPS units purchased for testing in the NYMTC Region appear to have the capability to provide data during trips on buses and just before entering and just after exiting the subway system. Specific tests are being designed to verify the usefulness of GPS for better understanding and recording complex trips. These field tests will include:

- Trips on buses
- Trips on subway routes with above ground segments
- Trips on ferries (e.g., the Staten Island ferry)
- Trips on other rail lines

How to address "acquisition time" for GPS devices to start registering lat/long coordinates upon being turned on, as well as related "no signal" and "inconsistent signal" issues related to being near tall buildings, being within structures, and cloudy days?

The evaluation criteria for the upcoming performance tests of the purchased GPS equipment will include acquisition time related to presence or absence of signal. The controlled experiments will be designed specifically to capture locations and situations where these issues can be adequately and repeatedly tested.

Conclusion

Although there is clear evidence that GPS units are being used by the research community to enhance regional travel surveying efforts, there are issues that still need attention. For example, the accuracy of the GPS-generated information is subject to various complications. Advancements in the technology being used for the GPS units appear to offer possible solutions to some of the issues regarding urban canyon effect, tree canopies, and other physical obstructions. With little materials available pertaining to the durability of the units under actual surveying conditions, additional tests need to be conducted under “field conditions”. Few details on the software used with various GPS units were available for review, suggesting another set of tests for actual surveying use.

The literature on the characteristics of the households missed or underestimated in previous GPS surveys suggests the need to better understand previously identified low quality response/high non-responding populations. These “special groups” need more investigation with respect to their response to the use of GPS to determine if their unwillingness to participate is related to the concept of surveying in general or GPS specifically.

Next Steps

Based on the findings and recommendations from previous research, the research team will be conducting a series of controlled experiments, testing the ‘i-Blue 747’ and the ‘GlobalSat’ GPS units under field conditions on specific routes. The review will include the accuracy of the data-generated; equipment durability; ease of data handling methodologies (e.g., installing software and downloading data); data quantity and quality; ease of conversion from GPS data format to GIS data; reliability of the units; and to address specific travel conditions in the New York environment.

Reference

Battelle, Transportation Division (1997) "Lexington Area Travel Data Collection Test: Final Report", Office of Highway Information Management and Office Technology Applications, Federal Highway Administration, Washington, D.C.

Battelle Memorial Institute (2000) "Personal Travel Unit (PTU) – Development and Initial Testing, Final Report", Battelle Transportation Division, Columbus, Ohio

Bonnifait, P, M. Jabbour, and G. Dherbomez. (2007) "Real-time implementation of a GIS-localization system for intelligent vehicles." *EURASIP Journal on Embedded Systems*. Vol. 2007

Bradley, M., J. Wolf, and S. Bricka (2005) "Using GPS Data to Investigate and Adjust for Household Diary Data Non-Response." Paper for the 10th TRB Application Conference, Portland, Oregon

'buy GPS now' (2007) http://www.buygpsnow.com Accessed July 2007

Chung, E., A. Shalaby. (2005) "A trip reconstruction tool for GPS-based personal travel surveys" *Transportation Planning and Technology* Vol. 28 (5), pp. 381-401

Deluo Electronics (2007) http://www.deluoelectronics.com Accessed July 2007

Doherty, S.T., N. Noel, M. Gosselin, C.Sirois, and M.Ueno (1999) "Moving Beyond Observed Outcomes: Integrating Global Positioning Systems and Interactive Computer-Based Travel Behavior Surveys" *Transportation Research Circular E-C026*, Transportation Research Board, National Research Council, Washington D.C.

Duncan, M. J. and W. K. Mummery (2007) "GIS or GPS? A Comparison of Two Methods for Assessing Route Taken During Active Transport" *American Journal of Preventative Medicine* Vol. 22(1), pp. 51-53

GeoStats (2007) http://www.geostats.com Accessed July 2007.

Griffiths, Robert. (2007). Personal communication with Jorge Argote.

Hawkins, R., and P. Stopher (2004) "Collecting Data with GPS: Those Who Reject, and Those Who Receive", paper presented at the 27th Australasian Transport Research Forum, Adelaide, September–October

Lawson, C., C. Fassman, and M. Chau (2007) "Household Travel Survey Research: Final Document." University at Albany, Albany, NY

NuStats, GeoStats, pbConsult, and Keith Lawton Consulting (2005) "Continuous Survey for Modeling in Oregon: Pilot Study Evaluation." Oregon Department of Transportation, Oregon Modeling Steering Committee, Oregon

Ohmori, N., Y.Muromachi, N. Harata, and K. Ohta (2000) "Travel Behavior Data Collected Using GPS and PHS", Traffic and Transportation Studies: Proceedings of ICTTS 2000, pp.851-858

Semsons (2007) http://www.semsons.com Accessed July 2007

Stopher, P., P. Bullock, and Q. Jiang (2002) “GPS, GIS and Personal Travel Surveys: An Exercise in Visualization”, presented at the 25th Australian Transport Research Forum, Canberra, Australia

Stopher, P., S. Greaves, and C. Fitzgerald (2005) “Developing and Deploying a New Wearable GPS Device for Transport Applications” 28th Australasian Transport Research Forum, Sydney, September

Stopher, P., and S. Greaves (2007) “Household Travel Surveys: Where are We Going?” Transportation Research, Part A - 41, pp 367-381

U-blox AG. (2004) “GPS and Dead-Reckoning in New York City with SBR-LS” http://www.u-blox.com/technology/White_Papers/GPS_DR_Test_Drive_NYC(GPS.G3-X-04001).pdf Accessed August 5, 2007

Wagner, D., D. Neumeister, and E. Murakami (1996) “Global Positioning Systems for Personal Travel Surveys” Paper presented at National Traffic Data Acquisition Conference (NATDAC), May 1996, Albuquerque, NM

Wermuth, M., C. Sommer, and M. Kreitz (2003) “Impact of new technologies in travel surveys”, In P. Stopher and P. Jones (eds.), Transport Survey Quality and Innovation, Pergamon, Oxford, pp.151-180

Wolf, J., (2004) “Applications of New Technologies in Travel Surveys”, Submitted to the International Conference on Transport Survey Quality and Innovation, Costa Rica, August 2004.

Wolf, J., P. Bonsall, M. Oliveira, L. Leary and M. Lee (2006) “Review of the Potential Role of 'New Technologies' in the National Travel Survey: Report of work conducted in Work package 1”, Department for Transport’s Research Project UG599, UK

Wolf, J., S. Bricka, T. Ashby and C. Gorugantua (2004) “Advances in the Application of GPS to Household Travel Surveys”, National Household Travel Survey Conference, Washington D.C.

Wolf, J., R. Guensler, S. Washington, and L. Frank (2001) “Use of Electronic Travel Diaries and Vehicle Instrumentation packages in the Year 2000 Atlanta Regional Household Travel Survey”, *Transportation Research Circular E-C026*, Transportation Research Board, National Research Council, Washington D.C.

Wolf, J., S. Hallmark, M. Oliveira, R. Guensler, and W. Sarasua (1999) “Accuracy issues with route choice data collection by using Global Positioning System”, *Transportation Research Record 1660*, TRB, National Research Council, Washington, D.C., pp. 66-74

Wolf, J., M. Loechl, J. Myers and C. Arce (2002) “Trip Rate Analysis in GPS Enhanced Personal Travel Surveys”, the International Conference on Transportation Survey Quality and Innovation, Kruger Park, South Africa, August 2001

Murakami, Elaine. Personal email to Jorge Argote, (October 24, 2007).