

# Synthesis of and Statistics for Recent GPS-enhanced Travel Surveys

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Submitted to the  
INTERNATIONAL CONFERENCE ON SURVEY METHODS IN TRANSPORT:  
HARMONISATION AND DATA COMPARABILITY  
France 2008

## **ABSTRACT**

Within the past few years, GeoStats has been involved in six large-scale GPS-enhanced travel surveys. Three of these are large metropolitan household travel surveys that had an in-vehicle GPS augment for auditing trip reporting as well as for evaluating other travel behavior details; these regions include Washington DC, Baltimore, and Chicago. The other three studies are sizable studies using wearable GPS devices and activity monitors to monitor and measure physical activity and travel behavior in three very diverse populations (visually impaired veterans, asthmatic children, and adult users of trails in Massachusetts). This paper will present a detailed overview of each study's recruiting methods as well as an analysis of participation (ie, response) opportunities available in each study.

## **Introduction**

Within the past few years, GeoStats has been involved in six large-scale GPS-enhanced travel surveys. Three of these are large, metropolitan household travel surveys that have an in-vehicle GPS augment for auditing trip reporting as well as for evaluating other travel behavior details; these regions include Washington DC, Baltimore, and Chicago. The other three studies are sizable studies using wearable GPS devices and activity monitors to monitor and measure physical activity and travel behavior in three very diverse populations (visually impaired veterans, asthmatic children, and adult users of trails in Massachusetts). In each study, participants are recruited to install or carry GPS data logging devices to assist in the collection of travel details. This paper will present a detailed overview of the purposes of and methods used in these GPS-enhanced studies. In addition, stages of participation will be discussed along with preliminary recruitment statistics for each study (if available).

## **Overview of Recent GPS-enhanced Household Travel Surveys**

Year-long household travel surveys were conducted by NuStats in the Washington DC, Baltimore, and Chicago metropolitan regions from early 2007 through early 2008. Each study included a GPS subsample to help assess the level of trip underreporting present in the full sample. (This method has been used for almost a decade as a cost-effective and passive measurement (ie, objective) approach for identifying the types of trips underreported and the characteristics of households or individuals associated with missed trips.) The GPS component for each study was conducted by GeoStats. A summary of the basic parameters of these large-scale GPS augments is shown in Table 1.

The first study listed is the recent Metropolitan Washington (DC) Council of Governments (MWCOG) Regional Household Travel Survey, which included the largest GPS augment ever conducted in the United States (US). In the GPS component, a total of 1050 households were provided with up to three in-vehicle GPS loggers for a two-weekday deployment period – the first 24 hours of which they were also asked to complete travel diaries for each household member and to report these recorded trips via a computer-assisted telephone interview (CATI). Households that had Friday diary dates were asked to keep the GPS loggers installed for four days to collect GPS data for Friday through Monday travel.

After a pre-test was conducted in the fall of 2007 (which included 174 GPS-deployed households), the original GPS sample size for the full study was set at 416 households out of the 10,000 planned for the main household travel survey that began in early 2007. Within a few months of the start, the Maryland Department of Transportation sponsored the deployment of an additional 400 households located in Maryland counties within the MWCOG planning region. Then, in early 2008, MWCOG decided to add another 234 households to the study from all jurisdictions; these households were from the portion of the main sample where phone numbers were not available. Consequently, these households were recruited into the study by a mailed letter asking for their participation and providing a phone number for them to call if they were interested.

The goals of this large-scale GPS travel survey effort were to audit vehicle trip rate reporting and to calculate independent vehicle trip rates and vehicle miles traveled (VMT) by trip purpose based on traditional four-step travel demand modeling categories (home-based work, home-based school, home-based other, and non-home based). The methodology used for trip rate auditing consists of collecting diary data independently of GPS data, converting the diary data into unique vehicle trips, processing the GPS vehicle data into trips, and then comparing the two sets of trips on a vehicle by vehicle basis. The calculation of trip rates and VMT by trip purpose is an automated process that tags the GPS trip ends based on the household's geocoded home, work, and school addresses that were collected during the recruit call.

The Baltimore Metropolitan Council (BMC), which consists of six counties / jurisdictions, three of which are shared with the MWCOG planning region, joined the massive MWCOG GPS data collection effort in May 2007, with another 400 households targeted for deployment with in-vehicle GPS devices for a 48-hour period. The study methodology and goals defined for MWCOG study were shared by the Baltimore planning agency.

The Chicago Metropolitan Agency for Planning (CMAP) also launched its regional household travel survey in early 2007, with an initial GPS study plan to deploy 500 households with in-

vehicle GPS devices for one day. The criteria for inclusion in the GPS component was based on a high frequency of trips or long distance trips reported during the recruitment call. The deployment plan was modified in May 2007 to a 7-day deployment period for 300 households to capture multi-day trip data.

It is important to note that when the MWCOG and CMAP studies began in 2006, there was no reliable, cost-effective GPS device commercially available that could be used for large-scale household travel surveys that also met the memory and battery capacity requirements of these types of studies. Consequently, the decision was made to use the GeoStats in-vehicle GeoLogger, a fairly rugged GPS data logger that had been successfully used in many previous household travel surveys. However, during the course of the data collection efforts of the MWCOG and CMAP studies, small GPS data loggers came to market that could meet study needs.

Since CMAP was also interested in person-based GPS logging and GeoStats had identified and tested one commercial GPS device that could meet CMAP's study needs, a wearable GPS augment was added to the CMAP study in September 2007. In this augment, wearable GPS logging devices were deployed to 160 households that reported transit, walk, or bicycle travel modes for their work trips during the recruitment call. Up to five household members of age 16 and older received a logger. The goals of both GPS components were to audit trip reporting accuracy for the full sample (which was 5800 households in the 1-day diary study – there was also a two-day diary study with an additional 5800 households, but this sample was not part of the GPS augment) as well as to provide additional travel behavior details.

**Table 1. Study Parameters Summary of Recent GPS-enhanced Household Travel Surveys Conducted by GeoStats**

	<b>MWCOG</b>	<b>BMC</b>	<b>CMAP</b>	<b>CMAP</b>
<b>Area</b>	Washington DC Region	Baltimore Region	Chicago Region	Chicago Region
<b>Duration</b>	14 months	9 months	8 months	4 months
<b>Timeline</b>	02/07 through 03/08	05/07 through 02/08	03/07 through 10/07	09/07 through 12/07
<b>Deployment Period</b>	2 week days, with diary on day 1	2 week days, with diary on day 1	7 days, with diary on day 1	7 days, with diary on day 1
<b>Number of Vehicles or Persons</b>	Up to 3 vehicles per household	Up to 3 vehicles per household	Up to 3 vehicles per household	Up to 5 persons per household of age 16 and older
<b>Method of Recruitment</b>	Randomly pre-assigned, could opt out	Randomly pre-assigned, could opt out	Screened for qualification, then could opt in	Screened for qualification, then could opt in
<b>GPS Sample Size</b>	1050 households (includes 29 for BMC counties)	400 households	300 households	160 households
<b>Total Sample Size</b>	10,200 households (includes 700 for BMC counties)	3800 households	5800 1-day diary households, 5800 2-day diary households	5800 1-day diary households, 5800 2-day diary households
<b>Percent of Total Sample</b>	10.3 %	10.5%	5.2 % of 1-day diary households (0% off 2-day diary households)	2.8 % of 1-day diary households (0% of 2-day diary households)

### **GPS Component Qualification**

To date, the primary criteria used for GPS household qualification in household travel surveys conducted by NuStats and GeoStats has been based on goals by study area (such as by county or jurisdiction). These targets have been roughly proportional to the sampling distribution established for the full study for these same geographies. For the MWCOG and BMC studies, deployment and completion targets were established at the county / jurisdiction level for both planning regions. Households were qualified if they reported at least one vehicle for the household and if the households were still needed for the county / jurisdiction of their home location.

The Chicago GPS study did not use geographic targets; instead, certain types of households were recruited such as those that had at least one vehicle and reported high levels of travel or long distance work commutes during their recruit call for the in-vehicle GPS study and those that reported walk, bike, or transit work trips during the recruit call for the person-based GPS study. In all studies, the qualification of households was implemented automatically within the CATI recruitment software.

### **Stages of Recruitment**

In each GPS augment presented in this paper, there were several stages at which a travel survey recruit decided to participate or continue to participate in the GPS component of the study. Statistics for these stages from the studies presented in this paper appear in Table 2. The percentages shown in the last four categories are based on the number of households not deployed. Final study statistics will be available once the respective clients approve the final study reports, which should occur by the summer of 2008.

**Table 2. Preliminary Recruitment Statistics**

	<b>MWCOG</b>	<b>BMC</b>	<b>CMAP</b>	<b>CMAP</b>
<b>Area</b>	Washington DC	Baltimore	Chicago	Chicago
<b>GPS Basis</b>	Vehicle	Vehicle	Vehicle	Person
<b>Recruit Method</b>	Opt Out	Opt Out	Opt In	Opt In
<b>Total GPS Recruited Households</b>	1989	791	1397	1025
<b>Total GPS Deployed Households</b>	1049 (52.5%)	404 (51%)	300 (21.5%)	160 (15.5)
<b>Refused When Called</b>	160 (17.0%)	65 (17.0%)	159 (15%)	126 (14.5%)
<b>Missed Appt or Refused on Delivery</b>	23 (2.5%)	15 (4.0%)	26 (2%)	6 (0.5%)
<b>Could Never Reach</b>	339 (36.0%)	76 (19.5)	273 (25%)	223 (26%)
<b>Did Not Try to Reach / Overrecruit</b>	418 (44.5%)	231 (59.5%)	639 (58%)	510 (59%)

The following section explains these stages of recruitment (or opportunities for consent).

1. The Initial Recruit Call.

During the recruitment call, if a household meets the GPS study qualification criteria (as explained in the previous section), the standard method for GPS recruitment has been to ask the household if they would like to participate in the GPS component of the study as well – this is the Opt In approach. These households are told that if they are selected for this component, they will receive a call from the GPS deployment team to schedule the delivery of the equipment. This method generates a large pool of GPS study candidates from which the deployment team schedules equipment delivery based on an optimal distribution of equipment across travel days. This method was used in both of the Chicago GPS components.

In the Washington DC and Baltimore GPS studies, NuStats implemented an ‘Opt Out’ approach whereby a percentage of each counties’ main study sample was pre-assigned to the GPS study prior to the recruit call. (Percentages were defined based on the study targets established for each county.) Then, once it was established that these households were qualified for the study during the recruit call, the households were informed that they were also selected to be in the GPS component of the study. At this point, if a household refused to participate in the GPS component, they were allowed to remain in the diary portion of the study. This latter method proved to be an effective method for getting a better representation of households in the study while simultaneously minimizing the level of over-recruitment in the GPS component experienced in typical Opt In methods.

## 2. GPS Deployment Scheduling

Once a household is successfully recruited into the study using either the Opt In or Opt Out Method, the household information is made available to the deployment team via a GPS Study Project Management password-protected website. The deployment team uses the recruit information on the website to call the household and schedule delivery. The website is also used to track deployment status. This method of deployment was used for the DC, Baltimore, and Chicago in-vehicle GPS studies.

During the initial recruitment call, respondents are asked which household vehicle is driven most frequently, with that vehicle assigned as vehicle number one. Other household vehicles are assigned subsequent vehicle numbers, also in order of frequency of use. During the delivery scheduling call, the field deployment team confirms the vehicles in the household and assigns equipment to the first three working vehicles in the list.

The Chicago wearable study also used the project website to manage field deployments, but given the small size of the wearable loggers, it was decided to use mailout methods instead of personal delivery. The deployment person still called each recruited household to confirm the shipping address and names of all adult household members – this was

done due to concerns about shipping devices directly to recruited households based only on the recruit call itself. It was suspected that some households may agree to be in the GPS component during the recruit call without understanding fully what was involved.

This deployment scheduling / confirmation stage is indeed a second level of GPS study consent. Some households are never reached again, so no equipment is delivered or sent. Others will refuse to participate in either the GPS component of the study or in both the diary and GPS parts of the study at this stage – often because they are too busy to participate or they did not realize initially what was required of them. The decision to contact these households a second time (once after the initial recruit call) prior to equipment delivery has been a conscious decision given the costs (of equipment, delivery, pickup, and data processing) associated with providing GPS equipment to these households.

### 3. GPS Equipment Delivery

Once a household is scheduled for equipment delivery, the deployment person delivers up to three in-vehicle GPS devices to the home location on the agreed upon date and time. The deployment person offers to install one or more of the devices, but most households do not require this given that the equipment is very easy to install (the GeoStats in-vehicle GeoLogger was used for all vehicle studies; it requires power to be provided via the cigarette lighter / power socket). For the Chicago wearable study, the wearable GPS devices (the GlobalSat GPS Data Logger) were mailed to each household. The decision to use a mailout method was used for two reasons: 1) the equipment is significantly smaller than the in-vehicle devices and therefore could more easily fit into a mailbox; and 2) the equipment is relatively inexpensive and the potential equipment losses that could result from using a mailout approach were expected to be acceptable.

In the case of in-person deliveries, the household could again refuse to participate or could simply miss the scheduled delivery time. If no one was home to accept the equipment and the home location did not have a safe location for the deployment person

to leave the equipment, then the equipment was not left there and another attempt at scheduling delivery was made if there was time before the assigned travel date.

In the Chicago wearable GPS study, there were several cases where the postal service could not deliver the equipment to the participant address. Most of these packages were eventually returned through the postal system. There were a few other cases where the postal service stated that they did deliver the package but the household insisted that no equipment arrived – in these cases, the equipment was considered to be lost.

#### 4. GPS Equipment Usage

Once the GPS equipment is successfully delivered to the household, there is still a possibility that one or more members of a household will change their mind and decide not to install or to carry the equipment. When this occurs for one day deployments, it is not possible to determine if this situation is the result of non-participation or no travel unless diary information is also collected by CATI methods. For multi-day GPS deployment periods, non-usage of equipment is easier to identify since it is much more unlikely that a respondent would not travel for multiple days

#### 5. GPS Equipment Return

When the in-vehicle GPS devices were delivered to each household, the pickup date and time was finalized. Deployment staff would call prior to arriving at the household to confirm that someone was home to return the equipment. As mentioned above, in-person deliveries have been the norm in these studies to minimize equipment losses as well as to encourage participation. The use of retired police officers as our deployment workforce has made equipment losses in these studies very rare.

In the Chicago wearable study, the equipment package included a return FedEx envelope with instructions for the participant to call the toll-free FedEx number after the seven-day study period to arrange for equipment pickup. This method was chosen to simplify the return process for the participants, but even so quite a few households did not return the GPS devices, even after repeated phone calls, letters, and visits to the home location.

## 6. Travel Diary Usage / CATI Trip Reporting

In order for the GPS data to be useful in this type of household travel survey, it is essential for the household to also report their travel via CATI. Once CATI trip data are retrieved, these can be compared with the GPS trip data (or no travel status) to identify levels of under-reporting. Consequently, this is considered the final stage for successful GPS study participation.

### Physical Activity Studies

Beyond traditional household travel surveys, GeoStats has been involved in three physical activity studies that have deployed both wearable GPS devices and activity monitors (i.e., accelerometers) to collect travel and physical activity data simultaneously from study participants. These studies are the Active Living Research (ALR) Trail Usage Study, the Fresno Asthmatic Children’s Environment Study (FACES), and the Veterans Affairs Study for Mobility Outcomes (VA Mobility Study). These three studies focused on three very diverse and distinct population groups – adult users of trail systems in the state of Massachusetts, children with asthma located in or near Fresno, California, and visually impaired veterans (typically elderly, retired military personnel). Table 3 lists the basic attributes of each of these three physical activity studies. It should be noted that data collection for the VA Mobility Study is still underway and reported statistics are current as of April 3, 2008.

**Table 3. Study Parameters Summary of Three Recent Physical Activity Studies**

	<b>ALR Trail Usage Study</b>	<b>FACES</b>	<b>VA Mobility Study</b>
<b>Duration</b>	2 years	2 years	3 years
<b>Timeline</b>	2004-2006	07/06 through 06/08	09/05 through 08/08
<b>Type</b>	Single Deployment	School/Summer	Before/After
<b>Deployment Period</b>	4 days - 2 weekdays and 2 weekend days	5 days per phase	14 days per phase
<b>Participant Age</b>	Adults aged 18 and older	Ages 7-18	Average Age 72; range from 47-90
<b>Sample Size</b>	178 participants	150 participants 87 deployed twice 7 deployed thrice	201 participants 303 deployments (to date)

Table 4 provides an overview of the recruitment stages (as defined for the household travel survey section) in each study. An overview of each study then follows these tables.

**Table 4. Recruitment Stages of Recent Physical Activity Studies**

	<b>ALR Trail Usage Study</b>	<b>FACES</b>	<b>VA Mobility Study</b>
<b>Recruitment Approach</b>	Opt-In	Opt-In	Opt-In
<b>Recruit Source</b>	General public using selected trails	Children enrolled in FACES study	Blind veterans enrolled in VA sponsored blind rehabilitation programs
<b>Initial Contact Method</b>	Intercept Survey	Telephone	Telephone
<b>Delivery Scheduling</b>	Telephone	Telephone	Telephone
<b>Equipment Delivery &amp; Return</b>	In-person at public place	In-person at participant home	Mail (Shipping)
<b>Travel Diary Data Retrieval</b>	Log returned with equipment	Log returned with equipment	Log returned with equipment / travel also retrieved by telephone 3-4 times during deployment period

The goal of the two-year ALR Trail Usage Study, a study sponsored by the Robert Wood Johnson Foundation, was to objectively evaluate the contribution of trails to adults’ physical activity patterns, specifically the amount and proportion of moderate and vigorous physical activity obtained on the trails themselves. Participants of age 18 and older were recruited into the study after completing an intercept survey at one of five trail facilities in eastern Massachusetts. These participants were walking, jogging/running, bicycling or in-line skating when recruited into the survey and had to report using the trail at least four times during the previous four weeks in order to qualify for the instrumentation portion of the study. Once qualified, each participant was asked if they would agree to wear an accelerometer and personal GPS device for four consecutive days (covering two weekdays and two weekend days). If a

participant agreed to be instrumented, they were met at a convenient public location (city hall, library, coffee shop) where the participant received the equipment.

Of the 1194 trail users surveyed, 294 persons were qualified and initially agreed to participate in the accelerometer and GPS portion of the study. Equipment was deployed to 178 individuals (60.5%), the remaining 116 individuals did not participate in the study due to scheduling conflicts, loss of interest or the inability of the research staff to contact those individuals.

FACES, which first began in 2000, is a large epidemiological study of the effects of air pollution on children with asthma. A total of 300 children aged 7-18 who reside in the Fresno California area have been enrolled in the study. The overall goal of this study is to determine the effects of different components of particulate matter (PM), in combination with other ambient air pollutants, on the natural history of asthma in young children.

In 2006, FACES added a GPS and accelerometer component to the study and recruited 214 of the children in the study for this component. The children were asked to wear an accelerometer and GPS device, and to fill out a travel diary for five consecutive days (on a Wednesday-Sunday schedule). Equipment was delivered to and retrieved from the participants' home by a FACES research team member. At the time of equipment delivery, the participant (and a parent) was given instructions about how and when the equipment was to be worn and shown how to fill out the travel diary.

Of the 214 children recruited for the study, 150 agreed to participate and were deployed at least once during the school year. There were a total of 251 deployments, 187 deployments during the school year and 64 deployments during summer break. Eighty-four percent of deployments returned both GPS and Activity data. Based on initial analysis of the data, it appears that participants tended to be more compliant earlier in the five-day deployment period. It is not known whether this is due to participation fatigue over time (tired / forgot to wear the equipment), or simply choosing not to wear the equipment on the weekend. The GPS and physical activity data will be evaluated by the University of California, Berkeley led research team in conjunction with pollution sensor data that were collected at the children's home and school locations.

The goal of the three-year VA Mobility Study is to objectively assess change in the amount, frequency and patterns of mobility associated with orientation and mobility (O&M) training provided in the course of blind rehabilitation sponsored by the Department of Veterans Affairs (VA) by using a combination of GPS, GIS, and accelerometer technologies. A secondary goal of this study is to demonstrate the capability and efficacy of these technologies as an effective, low-cost and highly objective mechanism to collect mobility outcomes of veterans who receive blind rehabilitation training.

Participants are visually impaired veterans 55 years of age or older who are scheduled to receive VA-sponsored blind rehabilitation services, specifically residential inpatient cane training within the following 2-3 months. Potential participants are identified through application wait list files maintained by VA Blind Rehabilitation Centers throughout the US and are then recruited via telephone interviews conducted by the Atlanta Rehabilitation Research and Development (R&D) Center. Participants are asked to wear an accelerometer and a GPS device, and to report travel for 14 consecutive days before they attend cane training and then again after they have completed the training.

A control group of normally sighted, aged matched persons are also recruited into the study and follow the same study methodology. Equipment is delivered to and returned by participants using a two-day shipping service. Detailed equipment instructions are included with the equipment delivery (an oversized font and additional line spacing are used so those participants with low-vision can read the instructions) and the recruitment person from the Atlanta Rehabilitation R & D center contacts the participant by telephone on the day before the first day of travel, at which time the instructions are discussed and any questions are answered. The participant is again contacted via telephone up to three times throughout the deployment. During these calls, daily instructions are reviewed and any travel to date is recorded on the project website. Most participants also have sighted peer available to assist with equipment and travel reporting, although this is not a requirement for inclusion in this study.

Of the 201 participants who have been recruited into the study, 101 are rehabilitation participants. To date, there have been 303 deployments (total of before and after deployments). Twenty participants who collected data during the before deployment phase refused to participate in the after phase of the study.

### **Conclusions and Recommendations**

Trends in recent household travel surveys conducted around the world suggest that multi-day GPS augments and, quite possibly, replacements to traditional survey methods will become more commonplace. The commercial availability of small GPS data loggers and ongoing GPS device technology improvements have removed the limitation of vehicle-only studies and have enabled large-scale person-based studies that can collect all modes of travel. Physical activity studies, by definition, dictate the need for wearable devices that can measure travel and activity levels. These trends were certainly observed within the studies covered by this paper.

There has been much research conducted on the potential (and actual) benefits of GPS technology for the collection of travel data. This paper did not attempt to cover these benefits, but rather provided an overview of the many stages of participation in a GPS-enhanced travel survey. Of the studies presented in this paper, one significant finding is that mail out, mail back procedures for GPS equipment deployment in household travel surveys may present a challenge with respect to equipment retrieval. The CMAP wearable GPS study offered a \$10 gift to households that returned the equipment and successfully completed the study. However, there were a significant number of GPS devices that were never returned, even after repeated phone calls, mailed letters, and even personal visits were made.

The VA Mobility Study also used a similar deployment method, the VA study population has a vested interest in the study and each participant receives \$50 at the end of each two-week deployment wave. To date, there have been no equipment losses in this study. As study managers attempt to control costs and reduce participant contact (as this could be perceived as additional burden), trade offs between deployment methods, delivery and retrieval costs, and equipment losses will continue to be a challenge.

Although there is a clear goal overall to reduce respondent burden in household travel surveys, not enough is known about participation rates and data quality at the various stages of travel surveys conducted using different methods. It is evident that additional research is needed to better understand the respondent's perspective in these studies, with the ultimate goal of improved participation rates, higher quality travel data, and more comprehensive travel behavior data to be used for travel demand modelers, transportation planners and engineers, and health researchers.

### **Acknowledgements**

The authors would like to recognize and thank Kermit Wies of CMAP, Robert Griffiths of MWCOCG, and Victor Henry of BMC for support and direction in the GPS components of the Chicago, Washington DC, and Baltimore regional household travel surveys (respectively). GeoStats would also like to recognize the Robert Wood Johnson Foundation's Active Living Research program, which provided funding for the Massachusetts Trail Usage Study, and Principal Investigator Dr. Phillip Troped (formerly of Harvard University and now at Purdue University). This was the first study in which GeoStats merged GPS and Actigraph data to develop joint measures of travel and physical activity. GeoStats also gratefully acknowledges the University of California, Berkeley's School of Public Health and the Atlanta Department of Veterans Affairs Blind Rehabilitation Research Center for their interest and collaboration in the research endeavors reported in this paper.