Review of the Potential Role of 'New Technologies' in the National Travel Survey

Report of work conducted in Work package 1

by

Jean Wolf[1], Peter Bonsall[2], Marcelo Oliveira[1], Lauren Leary[1] and Michelle Lee[1]

[1]GeoStats LP

[2]The Institute for Transport Studies, University of Leeds

Executive Summary

The objective of the first work package for the DfT research project 'National Travel Survey: Review of the potential role of new technologies' involved compiling an inventory of applicable new technologies and corresponding facts about such technologies. Consequently, work package 1 reviewed worldwide experience with, and prospects for, "new technologies" which might contribute to the maintenance and enhancement of the National Travel Survey. To achieve the objectives of work package 1, the research team conducted five subtasks:

a. Inventory of advanced technologies associated with or applicable to the collection of travel data
b. Survey of practitioners and researchers located around the world and known to have conducted a technology-enhanced travel survey or to have expressed interest in conducting such a survey.
c. Literature review for studies involving technologies used in travel / activity surveys since 2002.
d. Assessment of NTS current methodologies knowledge base gained through NTS reports and discussions with NatCen staff.
e. Consideration of NTS sample augmentation using commercially available datasets.

After a thorough technology review was conducted spanning three months, a draft report for work package 1 was distributed and reviewed with the DfT. The main conclusions of work package 1 were as follows:

- GPS-enhanced travel surveys are becoming more and more common; to date, the primary use has been for auditing purposes, but GPS is increasingly being used, in conjunction with prompted recall techniques, to replace more conventional travel diary methods.

- Off-the-shelf passive GPS devices have fallen in price (to around £50 to £500 per unit) and are simple for respondents to use. However, the problem of providing a reliable and convenient power supply for such devices is still not solved, and many of the lower cost devices also have memory / storage limitations.

- Although mobile phones offer a cheap and unobtrusive method of monitoring peoples' trips, they do not offer sufficient precision to establish trip end locations.

- Although mobile phone tracking may have a role in auditing the travel record, we are not yet convinced that the tracking services are suitable for large scale monitoring of the National Travel Survey.

- New hybrid / merging technology devices such as smart phones show considerable promise, but are still in their infancy.

- Handheld data collection devices such as PDAs and mobile phones require additional IT resources to handle device technology (hardware and software) as well as data transmissions and storage.

- Pedometers are a very inexpensive technology that can be used to estimate walk trip distances by capturing step counts. It is also possible that the use of a pedometer may cause respondents to remember and record walk trips which might otherwise remain unreported.

- Activity monitors, which use accelerometers to measure levels of activity, would undoubtedly assist in improving the estimates of walk trip lengths and durations but their cost is too high to justify their use in the context of the National Travel Survey.

- Self completion of electronic forms could offer a reasonably low cost option for data entry and may provide an attractive option for some respondents. Problems have been experienced, however, in designing software which will operate effectively on the full range of computers.

- Internet-based surveys offer a reasonably low cost option for data entry. Control is centralized, allowing for easy maintenance, updates, and data consolidation. They may provide an attractive option for some respondents – particularly those who have Broadband access

- A number of organisations are building up datasets containing logs of the movement of GPS-equipped vehicles. It is possible to buy access to these anonymised data and/or to more disaggregate data derived from vehicles whose addition to the datatset has been specifically requested. Access to this data would make it possible to explore the representativeness of NTS's single week records. It might also provide the basis for a longitudinal dimension to the NTS data and might be an administratively simple way of obtaining detailed locational data for car trips made by a subsample of NTS respondents.

Table of Contents

1. Introduction

This report is the product of Work package 1 of the Department for Transport's Research Project UG599 ('National Travel Survey: Review of the potential role of new technologies'). The final report for the project can be found in Bonsall et al (2006). http://www.dft.gov.uk/stellent/groups/dft_transstats/documents/page/dft_transstats_613849.pdf. The objective of Work Package 1 of the project was to establish an 'inventory of facts' regarding new technologies that could be implemented as a supplement to the current paper-based diary method used in the National Travel Survey (NTS). The purpose of this technology supplement to the NTS would be to improve the quality of NTS data without placing undue burden on respondents and / or to improve the processing of diary data from raw to usable form in terms of speed, efficiency, and accuracy. To achieve this objective, we conducted the following activities:

a. An inventory of advanced technologies associated with the collection of travel data was conducted using the Internet as the primary tool, with vendor phone calls and emails used when necessary to obtain details of products available. Technologies (both hardware and software) were divided into groups based on the primary technology product category (e.g., web-based survey software or passive GPS data loggers). This inventory was then used as the foundation of the technology review. Appendix A contains tables that list specific products by product category; the contents of these tables are not intended to be comprehensive, but rather to be representative of products in the category.

b. A questionnaire was created and distributed to 56 practitioners and researchers from around the world who were known to have conducted travel / activity surveys with a technology component or to have interest in conducting such a survey. For the purpose of this particular inventory, only studies conducted since 2002 and having at least 20 participants were applicable. Responses obtained on 29 studies were used to augment the inventory of facts collected in this report. Appendix B contains the questionnaire and Appendix C contains a report on the questionnaire and responses received.

c. A literature review was conducted for studies that involved technologies used in travel / activity surveys since 2002. In addition, specific references were sought for any questionnaire recipient who did not return the questionnaire or references, but who was known to have definitely conducted a recent technology-enhanced travel survey. Two of the studies found were deemed important enough to justify the ‘self-completion of a questionnaire and addition to the questionnaire response database. All references found are listed in either the Reference section if cited directly or in the Expanded Bibliography section if not cited.

d. Recent NTS reports were reviewed and discussions were held with NatCen staff. The resulting understanding of the current NTS methodologies for data collection and processing was necessary to guide the inventory of facts, especially in evaluating the ability of various technologies to collect NTS travel diary elements. Appendix D contains a summary of the current NTS travel data collection and processing methodology.

e. Consideration was given to the possibility of augmenting the NTS sample with one or more of the increasing number of commercially available datasets containing information on personal trip movements.

In our inventory of facts, we provided cost estimates whenever it was feasible to provide costs that were not dependent upon prevailing labour rates or the scope of work for a particular study. In cases where we could not provide costs, we have explained the cost drivers.

2. Technology Group 1: GPS / Mobile Phone Systems for Passive Data Collection

This group of technologies includes passive data collection devices that are based on either Global Positioning System (GPS) or mobile phone technologies. For the purpose of this report, both technologies in this category will be evaluated only for their location tracking capabilities in this section. Devices that combine either of these technologies with electronic user interfaces will be discussed in Section 4, Combined Technologies. We also recognize that there are other location-based technologies such as RFID tags and readers, and Bluetooth / WiFi based devices that require a localized infrastructure for tracking movement through an area; however, we deemed these as impractical for implementation across a study area as large as Great Britain.

The DfT is interested in the application of GPS / Mobile Phone Systems to either validate data reported through conventional means or to improve the quality of diary data collected. Given that this category of technologies is used primarily for obtaining location information that typically includes a timestamp; these technologies can be used to collect details of trips and activities (origin and destination locations, arrival and departure times, total time at location, total time between locations). En route location points allow other trip details such as travel route and speeds to be obtained.

2.1 GPS Technology

Since the Global Positioning System (GPS) became fully operational in 1995, much has been written by travel behaviour researchers about its applicability for augmenting or replacing travel diary data collection. Wolf and her colleagues have written extensively about their studies ((Wolf 2000, Wolf et al 2001, Wolf et al, 2003a, Wolf et al, 2003b, Zmud and Wolf 2003, Wolf 2004a, Wolf et al. 2004b). Stopher has also conducted a range of GPS-enhanced travel surveys and explains the role of GPS in travel surveys in Stopher 2004. Given that these references are readily available, this report will assume that readers have basic knowledge of how GPS works (details of GPS can be found in Wolf (2004c)). This system of 24 satellites sending signals to receivers located on land, sea, and air provides second-by-second location information at three to five meter accuracy levels. Other data elements provided by GPS include date, time, speed, heading, and altitude.

Global navigation satellite system (or GNSS) is a generic term referring to a system containing at least one or more satellite navigation systems. Beyond GPS, which certainly qualifies as a GNSS, is GLONASS, Russia's Global Navigation Satellite System. GLONASS is similar to GPS in that it is based on a 24-satellite constellation and was designed by the Russian Ministry of Defence for military purposes in the 1970s. The biggest difference between the two systems, however, has been the lack of operating satellites (and budget) for GLONASS.

The European Commission (EC) and European Space Agency (ESA) have been planning for Europe's own GNSS – Galileo. When Galileo is implemented, it will be the first GNSS designed primarily for civilian use. One primary motivation for the development of a GNSS independent of GPS is that Europeans and civilians worldwide would be equally independent of the United States (US) government's (more specifically, the Department of Defence) control of GPS. In December 2005 a test satellite for Galileo was launched. Projected dates for a fully operational system range from 2008 to 2012.

Prior to May 2000, the US government, which owns and operates the GPS, intentionally diminished the accuracy levels of the signals to 30 to 100 meters. Differential corrections provided by more expensive equipment were required to overcome these errors. However, in May 2000, 'Selective Availability' was removed and accuracy levels for relatively inexpensive consumer GPS products immediately dropped from approximately 100 meters into the five to ten meter range.

Consequently, a multitude of consumer applications has arisen, driving the development of small, low power demand, and inexpensive GPS components for a wide range of consumer products. Navigation systems, vehicle recovery systems, and emergency location services were some of the first application areas. More recently, the introduction of GPS chips into consumer devices such as PDAs, mobile phones, and vehicle navigation systems has enabled location-based services such as targeted marketing based on location and individual preferences / profiles.

Simple, passive GPS data logging devices that are practical for travel surveys (which require sufficient power and data storage capacity for at least one full day of travel) have been slow to arrive on the market as other higher demand consumer devices have been produced (e.g., GPS-enhanced watches for runners). Consequently, custom solutions such as the GeoStats wearable GeoLogger were created to meet the need for person-based GPS logging in travel surveys. However, within the past two years a range of portable GPS data logging devices has hit the market (a representative sample of these can be seen in Appendix A, Table A-1.).

2.1.1 Inventory of Relevant Facts

- Until recently, GPS has been used mostly as an augment to audit traditional travel surveys.

- Recent trends are to use the GPS log to assist the respondent to recall their trips (this method is sometimes referred to a GPS-based prompted recall) GPS cannot capture all attributes in a travel survey; it can, however, collect very detailed mobility and travel time data and, particularly if used in conjunction with Geographic Information Systems (GIS) databases, allows mode and purpose to be deduced for some trips

- Combined GPS and mobile phone approaches, which are implemented on a mobile phone using either GPS only positioning (where a GPS chip on the phone provide location information) or assisted GPS (A-GPS) positioning (which is a combination of GPS and mobile phone positioning), are an attractive option but they face high data transmission costs

Extent, scope, and purpose of use in travel / activity surveys worldwide

GPS technology has become a very popular data collection tool in travel surveys worldwide, especially in the US and Australia. The literature review has identified more than fifteen statewide or regional travel surveys that featured a GPS component. Most surveys have focused on combining GPS with CATI surveys for auditing diary / CATI reporting accuracies, although prompted-recall surveys have recently become popular as well. In a research study funded by the Transport for London, Steer Davies Gleave and GeoStats (SDG and GeoStats, 2003) conducted a pilot study testing wearable GPS devices for augmenting the London Area Travel Survey (LATS). This study was conducted in 2002 and 2003, and found that although the London urban form and transit system resulted in significant sky obstructions, GPS devices were able to collect enough information to prove feasible for use in future London travel surveys.

To date, there have been no GPS augments to a national travel survey. In the US, plans for the next National Personal Travel Survey (NPTS 2007) initially included a 10% in-vehicle sample (for 2500 households) for up to one week of data collection, although funding challenges now make the likelihood of this doubtful. It is more likely that one or more of the state or regional add-ons to the NPTS will sponsor a GPS augment to their study. In France, a 10% GPS person-based augment (or approximately 1500 individuals) for a one-week period is planned for the upcoming national travel survey; the GPS component is dependent upon authorisation by the Commission on Privacy and Informatics (Marchal et al 2006). In preparation for this, a study of national travel surveys in other countries was conducted and data collection methodologies was one of the items inventoried (Bonnel and Armoogum (2005).

Evidence of achievable accuracy and reliability

Most of the GPS-enhanced travel studies found in this inventory reported achieving reasonably good accuracy and reliability. Accuracy levels within 5 to 10 meters have been typical, with outliers caused by urban canyons (i.e. tall buildings) or data collected inside buildings (note that GPS requires a clear sky view to receive signals from at least four satellites in order to calculate position and time). Coverage of total travel was a more common problem, with lack of data occurring as the result of sky obstructions due to travel in urban canyons or tunnels, improper use/wear, or because of cold start signal acquisition delays[1]. Battery reliability (and dependency on study participants to recharge these batteries) was also reported as a challenge, if not a problem. Studies using in-vehicle GPS loggers did not experience this particular problem because power was provided by the vehicle itself.

Evidence of ease of use or respondent burden relative to conventional methods

Since the applications in this category are passive, they do not generate significant respondent burden. Most reported burden issues involved person-based studies where the participants were required to carry the instrumentation around, which was a problem with the earlier, bulkier setups required to provide uninterrupted battery power to the GPS receiver and logger (Doherty, Papinski and Lee-Gosselin, 2006). Recent portable GPS loggers such as the StepLogger (Appendix A, Table A-1) are available in small form factors, although some issues remain with power supply and with respondents remembering to carry the device for all trips.

[1] Cold starts are typical in GPS devices; they can range from 30 seconds to two minutes or more and they occur after the GPS receiver/antenna has been out of sky view for at least one hour, on average.

Evidence of public response to this technology

When GPS augments to travel surveys began in the mid to late 1990s, few citizens were aware of the technology or its potential for location / tracking services. Today, this is no longer the case. However, the message given to recruit GPS study participants has been consistently worded within the context of the study itself. For example, in the US, recruits into the general purpose household travel survey have been asked if they would also like to participate in the GPS component in which they would receive GPS logging devices for each household vehicle to help collect additional information about regional travel patterns. There is no evidence available that would indicate that the number of households deciding not to participate in the GPS sub-sample is growing, even given the increased awareness of GPS technology and capabilities.

However, recent analyses of several GPS-enhanced travel surveys in the US indicates that respondents who self-select in GPS travel studies are different than those who do not participate (Bradley et al 2005, Bricka and Bhat 2006a and 2006b). For example, the Kansas City Regional Household Travel Survey GPS Final Report documented that GPS participants tended to report higher incomes and own their own homes as compared to those who elected not to participate. In the upcoming Washington DC regional household travel survey pilot study with 800 households, a 200 household sample will be instrumented with in-vehicle GPS devices for auditing the number of vehicle-miles travelled (VMT) – these households will not be given a choice to 'opt in' to the GPS component; instead, they will be automatically assigned to the GPS component in an effort to better identify characteristics of households that refuse participation once selected to the GPS portion of the study. This pilot study will occur in September and October of 2006, with the main study to start a month later and to last for one year.

2.1.2 Costs Associated with the Technology

The main factors driving the costs of GPS technology for travel surveys are:

Equipment costs

The typical cost of a state-of-the-practice portable GPS unit is currently in the range of £50 to £500. The number of devices needed for a particular study is the number of units needed for a given deployment wave, which in turn is dependent on the overall sample size, the study duration, the sample period per respondent, the number of persons / vehicles to be instrumented per household and per deployment wave, and the amount of time it will take to deliver the devices, pick them up, download the data, and reset the equipment for deployment.

Data transfer costs

Most of the GPS studies inventoried in this research effort did not use wireless data transmission to retrieve GPS data – instead, devices were retrieved and downloaded at a central location before deployment. For more details on wireless transmission costs, see section 2.2.3 on mobile phone data transmission costs.

Deployment costs

These costs include shipping, equipment tracking, data downloading, and respondent training and are dependent on shipping / delivery costs, as well as labour costs for handling the equipment and the data. In addition, basic training on equipment use must also be provided to the interviewers who will be in turn training the participants. A helpline and/or website should also be made available for participants who may have questions or problems.

Data processing costs

These costs are dependent on the quality of the GPS device used, the amount / quality of supporting data (including GIS databases) available, the labour costs associated with data processing, hardware costs associated with storing and processing large quantities of high resolution data, and the purpose / methods of the GPS component.

2.1.3 Ability to Collect NTS Diary Elements

The key data elements contained in the travel diary (obtained from the NTS 2003-2004 Technical Report) can be seen in the first column of Table 1. In the second column, an explanation is provided of the capabilities of GPS technology to capture each element. It is clear that some elements could be captured exactly and perhaps more accurately (e.g., location and time elements), others could be imputed or derived using other information including GIS datasets (e.g., trip purpose and mode) with varying levels of accuracy, and a few cannot be obtained from GPS or GIS data (e.g., transit ticket type and cost and driver or passenger designation).

The mode of deployment (wearable or in-vehicle) of the GPS device clearly impacts the ability to capture all trips or trip elements – elements – note that although a few studies have used both modes of deployment in the same study, each household received only one or other depending on whether they reported transit/walk trips or vehicle trips as their primary travel mode.

The question is not just if GPS can collect the same data elements as the diary, it is also important to examine the collection of travel diary data within the full range of NTS diary data collection and processing in the current methodology and to ask what could be achieved using GPS with supporting processes to audit and correct the derived data. One such supporting process could be a prompted recall interview conducted with the respondent implemented by a range of survey methods (including face-to-face, Internet-based self-administered, and Internet-based telephone interviews). A full description of the current NTS diary data collection and editing process can be found in Appendix D.

2.1.4 Practical implementation issues

Power Demand

This can be a serious issue because GPS power losses will result in data loss. The power demands of GPS receivers result in the need for additional batteries which can make the equipment package uncomfortably heavy or bulky (particularly if the equipment is to be carried or worn); the batteries used often require frequent recharges and can prove to be a burden to respondents. Lightweight equipment might need to be recharged after 10 hours of continuous use and the recharging itself can take several hours.

Legal issues (privacy, liability, road safety)

Surprisingly, privacy concerns in GPS-based travel surveys have not been an issue to date. Respondents have typically been agreeable to participation and the datasets generated have been transferred directly to the study client, who is typically a planning agency or department. Liability associated with the release of the data is transferred to the client with the delivery of the dataset. We have no knowledge of GPS datasets released in a manner that would have violated participant privacy concerns. Passive GPS devices by design require no user interaction and therefore introduce little to no issues with road safety (other than the participant not placing it securely in the vehicle prior to driving). Procedures that request the participant to place the logger on the dashboard of the vehicle should also provide some mechanism to keep the logger from sliding around or off the dashboard.

Table 1: Ability of GPS to Collect Traditional Travel Diary Elements

Travel Data Elements (Day 1-6)	Ability of GPS to Collect
Purpose of Journey	Indirectly, it can be derived based on habitual destination information and other behavioural characteristics; GIS information enhances ability to deduce purpose. (Wolf et al, 2001).
Time Left	Yes, based on change in location / movement
Time Arrived	Yes, based on stoppage in movement and other characteristics
Origin – Where the journey started (From Village/ Town/ Local Area)	Yes, based on coordinates at journey start time (or coordinates of last journey's destination)
Destination – Where the journey ended (To Village/ Town/ Local Area)	Yes, based on coordinates at journey end time
Method of Travel (Car, bus, walking etc.) (Only walks that were more than one mile, or took more than 20 minutes are included)	Indirectly; Some modes can be differentiated using speed profiles and routing information. Further differentiation is possible if the GPS is used in conjunction with a physical activity monitor. (Oliveira et al, 2006).
Distance (yards or metres/ miles)	Yes, this can be calculated accurately based on distance along network links or GPS points
Number in party (split into adults and children)	No, if vehicle based instrumentation (although some possibility of imputing based on household travel patterns) Yes, for household members if all household members have personal instrumentation
Time travelling (in minutes)	Yes, this is collected automatically and accurately
Ticket Type (Single/ return/ travel card etc.)	No
Cost	No
Number of boardings (the number of trains/ buses etc. used to reach journey destination)	Indirectly, this could be calculated based on detected modes and mode changes
Which car / motorcycle etc. used (only if journey was made not by public transport, but by car / motorcycle etc.)	Yes, if vehicle instrumentation used, No, if person-based instrumentation used
Driver or Passenger? (and whether they were a front or rear passenger) (only if journey was made not by public transport, but by car/ motorcycle etc.)	No
Drivers only: where they parked and the cost	Parking location possible where could be determined if accurate GIS parcel-level database is available. Cost not possible
Drivers only: Road/ Congestion charges paid (introduced in 2003)	If vehicle instrumentation is used and if GIS data regarding tolled roadways is available then the toll payable may be deduced.
Day 7 additional information requested	
Postal address details for both the origin and destination of journeys	Yes, locations are accurate to postal code level (even better)
All walks over 50 yards (including those less than one mile, or twenty minutes in length)	Yes, although cold start signal acquisition may cause loss of some short journeys
Young Person Only (<16): Any time spent in the street not classified as a journey (e.g. playing with friends, skateboarding, riding bikes etc.)	Yes, if person-based instrumentation is used and worn while playing

Risk factors

- respondents may forget to wear GPS loggers in person-based studies
- respondents may forget to recharge wearable equipment
- equipment must at all times have reasonable view of the sky
- cost implications if uninsured equipment is lost or damaged
- potential safety (and legal) issues if the equipment distracts drivers (e.g. by falling off the dashboard).

2.2 Mobile Phones

Mobile phones are an attractive mode of data collection because of their market penetration (estimated at 84% of the United Kingdom population[2]) and because they can operate in more adverse conditions than GPS receivers (i.e. underground and indoors, assuming that a signal is available). Also, the power demands of mobile phone based tracking are much lower than those of GPS, enabling instrumentation packages to be lighter and to have greater autonomy. The main disadvantage of this approach for travel survey data collection is that the positional data has lower accuracy and resolution.

The technology currently used, unlike that used in the late 1990's, does not require users to be on a phone call to be tracked. It is based on the Global System for Mobile (GSM) protocol, which only requires the user to have a "signal", i.e. the phone must be powered on. This technology will not work underground unless cell antennas are installed in the tunnels.

There are several possible approaches for computing positioning information from GSM mobile phones. The first utilizes data captured at the mobile phone masts without the need to have modifications (such as configuration and / or software installation) in the handsets. This approach keeps the technology costs largely independent of the number of handsets (or mobile devices) in the field. The second approach uses signal strength information gathered in the mobile phones together with "triangulation" algorithms to compute location (Wermuth et al, 2001).

---

[2] According to the Wireless World Forum at www.w2forum.com/UK_Mobile_Market_Statistics_2006

The first approach works with data that is generated when a mobile phone connection is "handed-off" from one mobile phone mast to another as the user moves across the service coverage area. These data points are combined with a network model to generate approximate routes and traffic statistics. In the US, for example, mobile phone masts (known there as "cell phone towers") are located, on average, every quarter of a mile in a metropolitan area or every half mile or further in a rural area. The main factors affecting the accuracy of the data are the density of the mobile phone masts and the quality of the model used to match the hand-off locations to the road infrastructure. Typical positional accuracies of this type of technology with mast densities of ¼ to ½ mile are approximately 100m (Smith et al. 2003). A child location service in the UK (ChildLocate) states that the accuracy of GSM position is dependent upon the distance between the mobile phone being located and the base station that the mobile phone is connected with at the time. This service has published the following expected accuracy levels: 1) Urban areas: 150 – 400 meters; 2) Suburban Areas: 450m to 2km; and 3) Rural areas: 1.5km to 9.0km. In the last few years, a few companies (e.g Itis Holdings, Cell-Int, AirSage and Intellione) have started selling traffic information derived from mobile phone based positioning systems built around this approach. Most of the research and technology applications in this arena have focused on generating network performance information for traffic monitoring systems (NCHRP 70-01, 2005).

The second approach involves installing custom software on the mobile phones themselves. This software uses signal strength from several mobile phone masts to compute a position. Information is stored locally and needs to be transmitted to a central storage / processing location. Disadvantages of this approach include the fact that it requires "modified" phones to compute and collect the positional data and the fact that it incurs data transmission costs, usually proportional to the duration of the data collection period.

There is a third mobile phone approach to determining location; this technique combines GPS and GSM, allowing for improved accuracy and more frequent position fixes, which is more suitable for travel studies that require more accurate trip start and end information. However, this approach also requires that the handsets actively log and transmit GPS positions. This approach is currently being evaluated by the UK Department for Transport in a study being conducted by Itis Holdings (NCHRP70-01, 2005). The goal of this study is to measure congestion across the road network, thus enabling DfT to produce detailed reports on the patterns and locations of congestion.

Finally, there is a technology that employs a synergistic approach to position computation by combining information from a GPS receiver to signal strength triangulation from mobile phone masts, this combination allows the phone to compute positions when GPS data is limited (sky view is obstructed) or unavailable. This approach is often called assisted-GPS (or A-GPS) and is marketed by Qualcomm[3], a technology provider firm for mobile phones, as "gpsOne". Ohmori et al. (2006) reported using phones equipped with this technology. These two later technologies are also referred to in this report as GPS-augmented. Appendix A Table A-2 lists representative mobile phone products –with and without GPS functionality.

2.2.1 Inventory of Facts

Extent, scope, and purpose of use in travel / activity surveys worldwide

There is very limited experience with the use of mobile phone technology in travel surveys, and we found no examples where the locational capability of mobile phones was relied on as the sole source of positional data. Most of the recently reported studies (Ohmori et al 2006, Aona et al 2006) using mobile phones in travel surveys have been conducted in Japan and used mobile phones with either GPS-only positioning or assisted-GPS positioning. Wermuth et al (2003) reported on a study conducted in Germany in the late 1990's using a GSM-only positioning approach. This study required custom software to be installed on the mobile phones and used information from up to five mobile phone masts to compute participant positions; no information on logging frequency was provided. In the questionnaire distributed to researchers and practitioners, Doherty reported using a Bluetooth-enabled mobile phone to both log and transmit GPS data collected using a teletype Bluetooth GPS receiver in a series of pilot size (~20 participants) studies in Canada conducted between 2002 and 2005, but major issues reported included data loss due to transmission problems.

Evidence of ease of use or respondent burden relative to conventional methods and of public response to this technology

If mobile phone tracking is used without a GPS component the respondent burden is low – all they have to do is to keep their phone with them and keep it turned on (which is what

---

[3] Information on the "gpsOne" was obtained at: http://www.cdmatech.com/products/gpsone.jsp.

most mobile phone users do anyway as a matter of course). However if, in order to improve locational precision, a GPS component is included the resulting power requirement do bring an additional burden. Itsubo and Hto (2006) report that their smart phone and GPS integrated system (MoALS) required that the user would recharge the unit at all available times, meaning that the participants were required to carry chargers with them and always be on the lookout for power outlets. Ohmuri et al. (2006) identified issues related to the battery demands of GPS receivers on mobile phones and mentions that some participants would not engage in longer activities because they were aware that the cell-phones' battery would not last over their duration.

2.2.2 Ability to Collect NTS Diary Elements

Table 2 lists the key data elements contained in the NTS diary along with qualitative assessments on the ability of mobile phones to capture them. The key difference between the mobile phone technology and GPS technology to collect NTS diary elements is the level of position resolution, which in turn impacts the ability to derive other elements such as mode and trip purpose.

Table 2: Ability of Mobile Phones to Collect Traditional Travel Diary Elements

Travel Data Elements (Day 1-6)	Ability of Mobile Phones to Collect
Purpose of Journey	The low positional accuracy (60-100 meters) may prove challenging to determine this indirectly
Time Left	Yes, but at a coarse level, based on change in location / movement
Time Arrived	Yes, but at a coarse level, based on stoppage in movement and other characteristics
Origin - Where the journey started (From Village/ Town/ Local Area)	Yes, based on coordinates at journey start time (or coordinates of last journey's destination) – but low precision
Destination - Where the journey ended (To Village/ Town/ Local Area)	Yes, based on coordinates at journey end time – but low precision
Method of Travel (Car, bus, walking etc.) (Only walks that were more than one mile, or took more than 20 minutes are included)	Indirectly; it can be derived based on speed profiles and other characteristics if GPS augmentation is used
Distance (yards or metres/ miles)	Yes, this can be calculated approximately if points are matched to the street network and distance is computed along links, however short journeys may not be captured unless GPS augmentation is used
Number in party (split into adults and children)	No
Time travelling (in minutes)	Yes, but only approximately since it may be difficult to determine start and end times accurately if GSM only positioning is used.
Ticket Type (Single/ return/ travel card etc.)	No
Cost	No
Number of boardings (the number of trains/buses etc. used to reach journey destination)	Indirectly, this could be calculated based on detected modes and mode changes (only possible if GPS augmentation is used)
Which car / motorcycle etc. used (only if journey was made not by public transport, but by car / motorcycle etc.)	No
Driver or Passenger? (and whether they were a front or rear passenger) (only if journey was made not by public transport, but by car/ motorcycle etc.)	No
Drivers only: where they parked and the cost	No
Drivers only: Road/ Congestion charges paid (introduced in 2003)	No
Day 7 additional information requested	
Postal address details for both the origin and destination of journeys	Yes
All walks over 50 yards (including those less than one mile, or twenty minutes in length)	Maybe, the low positioning accuracy of GSM only mode may not allow this determination, however GPS augmentation should enable it
Young Person Only (<16): Any time spent in the street not classified as a journey (e.g. playing with friends, skateboarding, riding bikes etc.)	Yes if young persons are be instrumented

2.2.3 Costs Associated with the Technology

The main factors driving the costs of mobile phone technology for travel surveys are:

- The cost of **the mobile devices** – ranging from £50 up to £400, depending on the features desired (see Appendix A Table A-2). Note however that it is quite possible, if the respondent gives their permission and they already own a mobile phone of the appropriate type, to conduct the logging via their existing phone – the logging process need not interfere with their normal use of the phone.

- The cost of any **custom programming for the mobile phone** required. These costs are dependent upon current labour rates for programming services.

- If information is to be collected in the phones, **data transmission costs** can be a significant item. Ohmuri et al. (2006) report that keeping transmission costs down was a constant requirement in the design and operation of the system. Appendix A Table A-3 shows some current data rates. Where data is collected and stored remotely this cost does not apply, but there will be a cost for the location check itself. We are aware of a company offering an every-five-minutes location check at a cost of £1 per day.

- **Algorithm development**, to overcome the shortcomings of the data collected. These costs are dependent upon current labour rates for programming and engineering services.

- **Data storage and processing**, which is dependent upon the size of the study and the complexity of the algorithms and system needed to manage and process the data.

Appendix A Table A-2 identifies prices of different handsets and Table A-3 shows data transmission costs obtained recently from several UK-based providers. However, some of the implementations of these technologies require custom software and / or hardware to be installed in different segments of the mobile phone network (handsets and mobile phone masts) and thus are very difficult to cost.

2.2.4 Practical Implementation Issues

The main issues related to mobile phones in travel surveys identified in the literature review and surveys are:

- Insufficient positional accuracy, unless augmented by GPS, to determine precise trip origins, destinations, or route details;
- Power requirements – (if GPS-augmented);
- Data loss due to power or transmission failures;
- Access to the most advanced technology mobile phones (if the application requires a sophisticated mobile devices that can support custom logging and data transmission);

- Potential conflict with the DfT policy regarding use of mobile phones in personal vehicles (if the applications requires active input from the respondent).

3. Technology Group 2: Computer-Based Self-Completion Diaries

This group of technologies includes online and offline self-completion diaries running on desktop, laptop, or handheld / mobile PCs, and portable data collection devices (such as PDAs or Tablet PCs) incorporating electronic travel diaries. Input for data collection can range from the full set of travel diary data elements to just the basic elements.

3.1 Web-Based Self-Completion Diaries

This group of technologies includes survey applications that are serviced over the Internet. These types of survey present an electronic interface for respondents to complete on their own. The main advantages of using an electronic interface to collect diary data include:

- that the respondent cannot skip or omit fields (i.e., the application can require an entry before allowing the respondent to continue);
- that the respondent cannot enter invalid or illogical responses (the application can limit the options available for an answer and can include real-time error checks for valid field entry, valid travel information across journeys reported for that person or even across the entire household); and
- that details of travel previously entered can pre-loaded into the boxes - allowing respondents simply to modify only the portion that has changed (note that there is some concern as to whether this might result in a new manifestation of respondent fatigue – an undue preponderance of similar trips rather than the more usual problem of missing trips).

If the application is not mobile (i.e. the participant does not receive or have a wireless communication enabled device such as a wireless enabled Personal Digital Assistant – PDA or smart phone, but does have access to a desktop or laptop PC at home or at the office), then the respondent will need to wait until the application is accessible. However, this may not be much different than current diary practice, and a memory jogger could be provided for these respondents or applications. Finally, this technology assumes that the participant will have access to the Internet, and while this might not seem to be a problem at first, (the UK's estimated Internet market penetration is 62.9%[4]), it has the potential to introduce bias into the sample. In the recent National Statistics Omnibus Survey, 63 per cent of adults in Great Britain (29 million) had accessed the Internet in February 2006.[5] The most common place reported to access the Internet was at home (86 per cent), with 46 per cent accessed at work, 28 per cent accessed at another person's home, 16 per cent at a place of education and 10 per cent at a public library. To counter-act this potential technology access bias, it is important to use this technology in combination with other technologies, such as offline electronic surveys, paper diaries, and CATI interviews to reach those potential participants that do not have access to the Internet.

3.1.1 Inventory of Facts

According to Alsnih (2004) and Adler (2006), there are many benefits to using web-based surveys. One major advantage is that they might capture an audience that is traditionally hard to reach and are usually part of the non-respondents in traditional household travel surveys: the larger households and high income households. Additionally, the cost to deploy an Internet based survey is often lower than employing a telephone call centre or producing a mass mailing, especially in the face of declining response rates. Other benefits include automated data entry, the ability to add visual aids and other animation to assist respondents in remembering their travel (especially quick trips), and hidden skip patterns and branching of questions that can be confusing on a paper diary. Adler (2006) states that computer assisted telephone interview (CATI) approaches have provided a cost-effective alternative both for recruiting participants and for retrieving survey responses for the past two decades. But this method is quickly being replaced with Internet solutions.

In spite of the clear advantages to this technology, disadvantages exist that, depending on the nature of the survey, can be challenging to work around. One major disadvantage is that certain populations, such as older adults or individuals of a lower socio-economic status, may not have access to the Internet. This would create a sample bias towards the younger, better educated, or more affluent segments of the population. Such a bias might not matter

[4] Internet market penetration rate obtained at http://www.internetworldstats.com/stats9.htm; estimate was based on total population estimates from data contained in world-gazetteer.com. and usage numbers from various sources, primarily from data published by Nielsen//NetRatings , ITU , C-I-A, local NICs and private sources.

[5] Source: Individuals accessing the Internet – National Statistics Omnibus Survey

much if other respondents still had the option of using alternative, low technology, procedures but any improvement associated with using the web-based diary would then not apply to all classes of respondent.

A potential problem with on-line diaries is that, even if respondents are willing and able to complete the survey, equipment or software problems such as incompatible browsers or slow communications links, may result in an incomplete survey. Furthermore, web based access and security issues (such as the potential for hackers) exist that are not considerations with off-line or hardcopy questionnaires.

Although an advantage of electronic data entry is that it can allow immediate validation checks (to ensure internal consistency among all questionnaire elements, including individual legs of a travel tour and shared intra-household trips), the implementation of these checks can be burdensome to respondents.

There is a wealth of options available for conducting web-based travel surveys using self-completion diaries. We have identified over a dozen companies that either sell the software (software as a product) necessary for conducting these surveys or provide the online tools to build and deploy questionnaires on their servers (software as a service approach). Table 3 shows a few examples of companies in these two categories.

Table 3: Companies that Provide Web-Based Surveys

Type of Web-Based Survey Firm	Company Examples
Develop web-based survey specific to a customer's needs	Resource Systems Group (Adler, 2002)
	PTV (Fell, 2006)
	GeoStats
Develop web-based survey templates that customer modify for their needs	Voxco
	Survey Monkey
	Zoomerang
	Super Survey
	Poll Cat

The first type of web-based survey company tailors its product to the customer's needs. These surveys are often complex, include numerous types of questions, and are targeted at a specific population. Additionally, the survey company extensively tests the survey before it is released and may even perform a pilot study with a small sample population. Flexible options usually exist in this scenario such as adding a geographic component to the survey, testing the survey, involvement in the recruitment process, reviewing and post-processing the data before it is released, and revising the survey at a later date for a different use. Some of these companies, including GeoStats, do not provide customers with the software code, but rather provide an executable program that runs on a PDA or online.

One of the more recent innovative web-based applications has been developed by PTV, a German transportation consulting and software firm that has implemented a web-based CATI system with real-time geocoding for virtual call centres. This system was used successfully for the recent Italian National Travel Survey (Fell 2006). It is currently being enhanced to support self-completion travel surveys in a study due to be conducted in Zurich in autumn 2006.

The second category of web survey companies or products allows users to customize their surveys with different types of questions (single response, multiple-choice, and branching), specialized instructions, and company logos. Typically, there is no limit to the number of questions that can be included in the survey; however, an additional cost may be charged per response if the number of responses exceeds a quota. Surveys are hosted online for a set amount of time such as one week, one month, or one year – after which time, the survey is removed from the on-line server. Technical support, via phone or email, is often offered as part of the fee to host the survey. In most cases, data can be viewed on the survey website (with a password) and downloaded into a spreadsheet or database application for further processing.

Extent, scope, and purpose of use in travel / activity surveys worldwide

As mentioned earlier, the latest Italian NTS used a web-based CATI system for travel survey data collection. In Denmark, an experiment in their NTS was conducted in 2005 using a sample of 30,000 households from Copenhagen and Frederiksberg (Christensen 2005). This sample was invited to answer by Internet and was also told that they would be called by telephone if they did not answer by Internet. They reported a 12% response rate on the Internet. Other studies have also experimented with Internet reporting options (see references by Adler, Bonnel, de Blaeij, for example).

3.1.2 Ability to Collect NTS Diary Elements

This type of technology is capable of replicating the paper diary and there is thus no reason to suppose that it is not capable of collecting all the data elements present in the existing

NTS diary. Indeed, it could be argued that the possibility of real-time error prevention and logic-testing, and of using automation to speed the entry of repetitive trip details, results in a more effective instrument for collecting complete and accurate records.

3.1.3 Costs Associated with the Technology

The main factors driving the costs of web-based self-completion diaries are:

- Custom survey programming (dependent upon prevailing labour rates for programming services)

- Survey web-site hosting and response data storage (dependent upon size of survey and number of responses collected)

In terms of cost, the web-based survey companies that tailor their products to customer needs typically have higher costs based on the specific requirements of the survey. Most “software as service” companies have a base ‘subscription or member’ cost of a few hundred pounds per year which includes an unlimited number of surveys and questions, with a fixed number of complete responses obtained. After this number of responses is passed, an additional cost per response (ranging from £0.03 to £0.14) may be added to the bill. Some companies require a contract for an agreed upon amount of time, and others, such as Survey Monkey, allow the user to cancel the account and online survey at any time. Firms that provide custom surveys may also charge for storage of survey responses, whereas those that offer commercial web-survey products typically include data storage in their subscription fee.

If the web-based survey is not accessible from the respondent’s home or office-based desktop or laptop PC, then additional costs may include:

- The access device itself (see Appendix A, Tables A-2 and A-4 for representative costs)
- Deployment costs, shipping and receiving devices through the mail or personally delivering them
- Data transmission costs, if data is to be sent remotely from participants (as seen in Appendix A, Table A-3); although many participants may have (and already are paying for) unlimited Internet access.

3.1.4 Practical Implementation Issues

The main implementation issues associated with this technology are:

- Internet accessibility of the desired sample participants (can be addressed by using a multi-modal approach to survey methods)
- The willingness and ability of the target group to enter their own data
- Consistency checks that become burdensome to respondents, encouraging underreporting
- The possibility of data loss or incomplete recording in the event of system malfunction.
- Distribution / deployment of web-enabled devices for participants who do not have Internet access.

3.2 Self-Completion Diaries Hosted on Personal Computers or PDAs

Personal Computers (PCs) in the form of desktops, laptops, or tablets are ubiquitous, with a majority of people using one either in their home or at work. Personal Digital Assistants (PDAs) originated as personal organizers, but have become much more versatile over the years. These devices often require both hands to operate (hold with one while providing input with the other), feature a touch-screen, and employ solid-state based storage technology.

The advantages of using PCs or PDAs to collect travel data are similar to the advantages of web-based surveys. One advantage is that the data are collected in digital form and directly transferred to the study's database, thus eliminating key-entry errors. Another advantage is that the PC or PDA can be programmed to ensure that only logical and consistent values are reported. However, there is always the risk of unnecessarily increasing respondent burden, which might encourage the participant to shorten the survey, omitting certain trips that they consider too complicated to report. An advantage of a PDA, laptop PC, or tablet PC-based survey compared to a desktop PC-based survey is that these devices are portable and can therefore be carried on trips, allowing the participant to capture travel details electronically in ‘near to real’ time. Of course, web-based surveys that can be administered via PDA or laptop PC would also share this advantage.

The current generation of PCs have sufficient memory capacity and processing speed to meet the requirements of any of the contemplated off-line travel surveys. The memory capacities of current PDA models range from a few Megabytes to as much as a Gigabyte through the use of expansion memory cards. Processor architecture advances over the last few years have resulted in PDAs that have processing power equivalent to that of desktop PCs from the late 1990's. Appendix A Table A-4 contains a range of PDAs on the market today. It should be noted that the Palm operating system, which had as much as 80% of the PDA market in the late 1990s, has lost considerable market share to the Windows handheld platform over the past decade and its continued existence may be in doubt.

PDAs have recently converged with mobile phones[6], giving rise to "smart-phones" such as the Blackberry. These integration and convergence trends have created a natural aggregation of the PDA market into the four categories shown in Table 4. The main differences between the four categories are the amounts of memory (32MB, 64MB, expansion slot), the ability to access the web through a wireless connection, and the presence of advanced technology features such digital cameras, streaming video, and mp3 players. The basic models act as organizers and do not have wireless technology. The mid-level models have more memory, better operating systems, wireless networking, and, possibly, a few other key features like integrated GPS (e.g. Garmin iQue M4 and Navman PIN). The HP iPAQ hw6515 unit has all three of these tech components: PDA with a GPS and mobile phone. These units are discussed in more detail in Section 4.

Survey software for off-line PCs/PDAs falls into similar categories as those listed for web-based surveys. Companies may choose either to develop their own PC/PDA survey software, to contract another firm to provide custom survey software, or to purchase commercial PC/ PDA survey software. In the past decade a range of companies have offered commercial PC/PDA software; Appendix A Table A-5 lists a few of the relevant software products currently available. The companies that offer web-based survey products (presented previously) often have off-line versions as well.

---

[6] Many of these PDA-phone devices now feature GPS receivers; this later integration was in part motivated by the E911 (for emergency call location) passed in the late 1990's by the US Congress, it specifies that calls to phone number 911 (the US's standard number for emergency event reporting) originating from cell-phones have to be pinpointed with an accuracy of 100 meters at least 67% of the time.

Table 4: Main Categories of PDA Devices in the Market

Model Category	Example Models	Capabilities	Price Range
Basic model	Palm Z22 PalmOne Zire 31	Organizer, store photos, ebooks	£109
Mid-level model	HP iPAQ Pocket PC Palm Tungsten E2 Dell Axim X51V	Organizer, audio capabilities, wireless networking (802.11b)	£100 – £210
Mid level with GPS	Garmin iQue M4 Navman PiN 570 Toshiba E740	Integrated GPS, mapping, wireless networking, mp3 player, organizer, etc.	£ 210 - £370
Higher end models "Smart-phone" models	Palm Treo 700p Smartphone Blackberry HP iPAQ hw6515	Mobile phone, email, organizer, messaging, web access, digital camera, video capture, mp3 player, optional GPS	£ 370+

3.2.1 Inventory of Facts

Extent of use in travel / activity surveys worldwide and scope and purpose of these uses

Ohmuri et al (2006) examined the reliability of travel survey data collected using PDA-type devices using two pilot studies conducted in Japan in 2004 and 2005. The first one used only PDA devices and was mainly used as a trial of the application's interface (i.e., they collected comments and recommendations from the participants which were in turn used to develop the next version of the application) while the second one collected data using both PDAs and paper diaries. The comparison of the two resulting datasets revealed that participants tended to report longer duration for mandatory activities in the PDAs, especially the out-of-home ones. Conversely, discretionary activities featured longer durations in the paper surveys, when compared with the PDA data.

Evidence of achievable accuracy, reliability, response burden and public response

We were not able to find direct evidence on these issues but surmise that the accuracy will be similar to that found for wearable GPS but that reliability may be reduced because of the greater complexity of the device and the greater likelihood of it being left behind. We also surmise that some respondents would not be comfortable with the implied respondent burden.

3.*2.2* Ability to Collect NTS Diary Elements

Given that an electronic travel diary on a PC or PDA will essentially mimic a paper diary, there is no reason to doubt that all of the elements contained in the paper diary can be collected in an electronic diary.

3.2.3 Costs Associated with the Technology

The main factors driving the costs of PC or PDA technology for travel surveys are:

- ***The cost of the devices*** can range from £200 to £1250 for PCs and from £50 to somewhat over £1000 for PDAs, depending on the sophistication of the technology desired.
- ***Survey software or programming costs*** are dependent upon commercial software rates and/or current labour rates for programming services.
- ***Data transmission costs*** are incurred if the survey software is to be downloaded or respondents' data is to be received electronically. The cost of transmission to /from PCs (desktop, laptop or tablet) will depend on the owner's contract with their network service provider – the marginal cost will be zero where people have an unlimited-use contract. Even where this is not the case the transmission costs would be negligible. Even though many of the higher- level PDA devices have the capability to connect to the Internet via mobile phone networks, the associated costs are significant; a recent survey of five major wireless service providers in the UK (see Appendix Table A-3) revealed the average monthly cost of wireless communication to be between £35 and £75 per device. Deployment of 250 devices over a 12-month period, would thus result in a total communication costs in the range of £105,000 to £225,000.
- ***Deployment costs,*** which can include shipping, equipment tracking, data downloading, and training, are dependent on shipping / delivery costs, as well as labour costs for handling the equipment and the data.
- ***Data storage and processing costs*** are dependent upon the size of the study and the complexity of the algorithms and system needed to manage and process the data.

3.2.4 Practical Implementation Issues

The main implementation issues are:

- ***Power supply -*** A common issue with all PC and PDA applications is the need for a reliable and light-weight power supply. Power issues are especially important for devices that store information in volatile random access memory (RAM) because this will be erased completely during power failure events (ie, when the voltage drops below the minimum required level).

- ***Security -*** Another issue related to the use of this technology is the problem of lost or stolen devices. Since portable PCs and PDAs have an obvious use outside of diary data collection, respondents may want to keep the device for other purposes.
- ***Logistics and Deployment -*** PDA synchronization to a single PC was fairly straightforward with Palm-based handheld devices. This is not the case for Windows handheld applications – increasing the need for IT expertise in managing even simple field deployments.
- ***Respondent ability to deal with digital data entry -*** This is, potentially, a very significant issue. Significant proportions of the population have limited abilities to deal with “computers” and are unlikely to feel comfortable entering their own data. Even if they can be persuaded to do so, there is a risk of data entry error or (perhaps more insidious) of deliberate under-reporting of trips.

4. Combined Technologies: Electronic Travel Diaries with GPS / Mobile Phones

Although we have dealt separately with technologies for logging movements and for data entry, in practice it is quite common for both technologies to be applied together (8 out of the 29 respondents in our survey who used electronic data collection were also using GPS in the same survey). These hybrid applications generally use high-end PDAs (or mobile phones) equipped with GPS. Appendix A Tables A-6 and A-7 list examples of integrated PDA/GPS and GPS devices for PDAs, respectively. The main advantage of this category of technology is that it combines the "'best of both worlds" – a self-completion survey with an automatic location log, through the leveraging of merging technologies.

The technologies in this group include PDAs with GPS, PDA/Mobile Phones, Broader Systems with Passive GPS and feedback loop to participants for confirmation and completion. According to market analyst Gartner Inc. (Kort et al, 2005), the coming to market of the functionality integrations displayed in the mid and higher levels have also coincided with a shift of PDAs from personal organizers into personal communicators, allowing users to send and receive email as well as browse the web while on the go. These higher-level devices are often called "smart Phones".

The issues raised by this kind of hybrid application are essentially a composite of those raised by each technology in isolation (and have thus been dealt with in previous sections of this report). There are, however, some issues which are unique to the hybrid applications and it is to these that we now turn. Two key disadvantages are that they often require the respondent to enter detailed data for logging to occur, and they face increased power demand, especially when configured to constantly collect location data (which may result in the loss of both diary and location data).

Kochan et al (2006) presented an application that runs on a GPS-enabled personal digital assistant (PDA). According to the authors, the key development issues were: (i) desire to capture the dynamic activity-travel scheduling processes, (ii) desire to reduce respondent burden and (iii) to improve activity-travel data quality.

Itsubo and Hato (2006) used a GPS-integrated smart-phone with a Web travel diary (MoALS) to collect travel data from a sample of 31 respondents in Matsuyama, Japan. The use of these integrated devices combined the benefits of a PDA travel survey with the passive logging of GPS data. This system makes use of its interface to confirm stops and routes captured by the GPS. Before using the smart-phones this same group of participants used a paper diary to collect travel information. Comparing these two data sets, the researchers concluded that the mobile phone / internet approach improved the precision of trip reporting while possibly reducing the problem of underreporting.

The incorporation of GPS into a PDA increases the power requirements and this can be a serious issue because of the vulnerability of RAM data in the PDA to power loss. In the MoALS system (Itsubo and Hato, 2006), the battery of the devices had to be constantly recharged throughout the day, so the participants had to carry the chargers with them and have the units plugged into a wall outlet at every available opportunity.

5. Pedometers and Accelerometers

There has been much interest recently in combining passive location loggers with physical activity monitors (such as accelerometers) to measure the levels of physical activity study participants experience as they move throughout their day and environment[7]. Pedometers and accelerometers, the latter also referred to as piezoelectric pedometers or activity monitors, are the two most common technologies used to measure physical body motion in humans. While the mechanics and accuracy between the two vary, the basic functionality is the same. Each time the foot strikes the ground, the change in motion triggers the mechanism inside the unit to count that step, and, if properly setup, to record the distance travelled. Pedometers use either a hairspring or coil spring attached to a lever arm to close the circuit inside the unit, thus recording each step made. Accelerometers have a strain gauge mechanism whose deformation is proportional to the intensity of each step; the unit can thus record the intensity of each step made.

There are advantages and disadvantages to both technologies. Accelerometers are much more costly but are more accurate, more durable and can provide a time-stamped electronic record of a series of activity events (i.e., intensity counts are recorded in one-minute epochs across the data collection period). The biggest advantage pedometers have over accelerometers is cost; typically ranging from 1 to 25 pounds in small quantities, and significantly less in large quantities, pedometers are very economical. Accelerometers have generally cost between 150 and 450 pounds (though a model costing less than 40 pounds is now being marketed) with additional software and hardware costs sometimes required to reap the full benefits of the technology. Appendix A Tables A-8 and A-9 list examples of accelerometers and pedometers, respectively.

---

[7] This interest is associated with the increasing recognition of the prevalence of obesity problems and is particularly evident in the US where physical activity research has been sponsored by private foundations (such as the Robert Wood Johnson Foundation) and the National Institutes for Health and where many health promotion programs have been giving away free pedometers to persuade people to 'count their steps' – with personal goals ranging from 5000 to 10,000 steps per day.

The primary reasons for the cost disparity between these two technologies are accuracy, reliability and functionality. The hairspring, and to a lesser extent the coil spring technology is less accurate and less reliable than the strain gauge technology. The spring technologies also tend to deteriorate more quickly, resulting in data quality below research standards. While accelerometers are more expensive, they have proven to be the most reliable and accurate technology for recording movement over time, and are the choice of researchers – not least because they provide an electronic record of the intensity of activity which can be downloaded and analysed.

For the purpose of use in a travel survey, pedometers may prove more than sufficient to provide estimates of travel distance for walk trips. They may also serve as a memory trigger for respondents to remember to report these typically underreported trips – although this advantage might be outweighed if the novelty of using a pedometer were to cause respondents to make extra trips. Evidence on either of these possibilities is weak. However, a recent study presented by Oliveira reported that the use of GPS and accelerometer data provided better estimates of activities and modes than GPS data alone (Oliveira et al 2006). Another study, currently underway in London, is using wearable GPS watches and accelerometers to collect travel and activity data from children – this study is called the Children's Activities, Perceptions, and Behaviour in the Local Environment (CAPABLE) project and is a joint research initiative between four University College of London departments and four non-academic partners (Kitazawa 2006).

6. Use of Commercial Databases on Person Movements

This section reports on a supplementary investigation that we regard as relevant to the current study.

Applications of GPS technologies in markets such as in-vehicle navigation, stolen-vehicle-alert services, vehicle fleet monitoring and mileage-based insurance products have, in recent years, been yielding large datasets containing second-by-second GPS data on vehicle movements. Also, in addition to these datasets where the data is a by-product of the main application, a small but increasing number of datasets of GPS-based vehicle movements are being produced because of the inherent commercial value of the data (one example being the collection of vehicle movement data to assess the potential value of roadside advertisement sites). The owners of these datasets may be keen to find new markets for their data.

The existence of nationwide networks of ANPR cameras obviously offers the possibility of a massive database on vehicle movements (although not offering much precision). The possibility of widespread use of GPS as a component of road pricing schemes clearly raises the prospect of a massive and detailed database on vehicle movements.

One travel behaviour study that has evaluated GPS data collected for a road pricing project is the AKTA road pricing experiment conducted several years ago in Copenhagen, where 200 vehicles were instrumented with GPS devices for two 8 to 10 week periods (Nielsen and Jovicic, 2003). Wolf et al (2004b) also conducted travel behaviour studies on a large GPS dataset collected for a speed / safetey study conducted in Borlange, Sweden. More recently, Schonfelder et al (2005) evaluated GPS data collected in a GPS-based value pricing study conducted in Atlanta for destination choice behaviours and activity spaces.

The GPS and ANPR databases discussed above can, of course, only yield data on vehicle movements. Equivalent data on the movement of individuals can only come from wearable GPS or mobile phone records. Although mobile phone companies create (and, we understand, temporarily retain) information on the location of their customers' phones (provided they are turned on), they have not wanted to raise the issue of the potential uses of this data because of the obvious sensitivities about personal privacy and the legal issues surrounding this.

Key issues when considering the secondary use of data from such sources include the sampling framework, the availability of socio-demographic information on the participants, the possibility of contacting the individuals to obtain additional data which is not available via the GPS record, and, of course, the question of privacy and data protection. The owners of the GPS databases apparently have permission from the individuals or companies whose vehicles are being monitored to use their data provided that the individuals cannot be identified. In practice this means that the raw data cannot be released and so processing has to be done in-house. However, we are aware that the possibility exists for a third party, such as NTS, to "sponsor" a number of GPS units in return for access to the detailed data acquired by these units (the arrangement with the monitored individual would expressly allow this).

A number of possibilities therefore exist which may be of relevance to NTS.

1. NTS might use one of this new breed of data companies to equip the vehicles of a subset of the individuals sampled for the NTS survey (the cost of so doing being about £400 per unit). Data from these units could then be compared with the journey records collected, using normal NTS procedures, for that individual.

2. As (1) above but, since the equipment would be yielding data for an indefinite period (until the vehicle is sold), longitudinal data could be obtained and analysed to determine the representativeness of the survey week.

3. As (2) above, but instead of sponsoring new installations, a check might be made among vehicles already equipped to see if any happen to be among the designated NTS sample (the alternative approach of drawing part of the NTS sample from people who are already equipped with GPS would raise complicated sampling issues).

4. DfT might seek, either from among people who are already equipped with GPS or from among people who are prepared to be equipped, a sample of individuals to contribute to a new, longitudinal, survey based on ongoing monitoring of their GPS record and periodic questionnaires (perhaps web-based!).

5. DfT might commission the dataset owners to provide an ongoing stream of summary data (e.g. on trip lengths and durations, departure times, repeat trip making etc) based on individuals within their sample. This might be a very cost effective option but might

suffer from unwanted effects due to changes in the composition of the sample and would raise issues about the representativeness of that sample.

7. Summary and Conclusions

7.1 Summary of Findings

Table 6 provides a summary of technology categories and evaluation criteria responses discussed in detail in the previous sections.

Table 6: Comparisons of Technology Options for NTS Evaluation Criteria

Evaluation Category	GPS / Mobile Phones	PDA / Web-based electronic diaries	Hybrid Technologies
Extent of use in travel / activity surveys worldwide	GPS becoming more common, especially in US and Australia. Use of mobile phones is only just beginning	Web-based has been used in limited applications. PDA applications are still research oriented	Mobile Phones with GPS/PDA apps are primarily being used for research in Japan and Canada
Scope and purpose of these uses	1. to audit reported travel, and 2. to replace diary by prompted recall	Replace paper-based diaries	Combine strength of electronic travel diary with automatic location logging
Capital and maintenance costs	GPS costs continue to decrease; Mobile phone data transmission costs remain high	Web-based solutions easiest to implement PDA costs (equipment and data transmission) are significant but continue to decrease	Higher equipment costs Data transmission costs remain high
Ability to collect NTS diary elements	Partial	Complete	Complete
Evidence of achievable accuracy and reliability	Location accuracy within 10m (GPS) or within 60 to 100m (mobile phone).	As reliable as paper surveys with added benefit of built-in checks	As reliable as GPS
Evidence of ease of use or respondent burden relative to conventional methods	Passive devices not very burdensome but wearables require the participant to remember to carry them, and battery pack may be a burden	Has the potential to be less burdensome for respondents than traditional methods	Has the potential to be less burdensome than traditional methods but wearables require the participant to remember to carry them, and battery pack may be a burden
Evidence of public response to this technology	Positive to neutral response	Positive response	Positive response
Practical implementation issues	Battery power if person-based	Equipment deployment for PDAs Market penetration for Internet OS compatibility	Battery power if using GPS-based position logging Data transmission costs
Legal issues (privacy, liability, road safety)	Apparently solvable	Apparently solvable	Apparently solvable
Risk factors	Data loss if power failure	Minimal	Interactive nature of technology could introduce safety risks to participants (if operate while on the go). Data loss if power failure

7.2 Conclusions

Our main conclusions are as follows:

- GPS-enhanced travel surveys are becoming more and more common; to date, the primary use has been for auditing purposes, but GPS is increasingly being used, in conjunction with prompted recall techniques, to replace more conventional travel diary methods.
- Off-the-shelf passive GPS devices have fallen in price (to around £50 to £500 per unit) and are simple for respondents to use. However, the problem of providing a reliable and convenient power supply for such devices is still not solved, and many of the lower cost devices also have memory / storage limitations.
- Although mobile phones offer a cheap and unobtrusive method of monitoring peoples' trips, they do not yield sufficient precision for detailed monitoring of trips, or even to establish trip ends, outside urban areas
- Although mobile phone tracking may have a role in auditing the completeness of the travel record, we are not convinced that the currently available tracking services are suitable for large scale monitoring of the National Travel Survey.
- New hybrid / merging technology devices such as smart phones show considerable promise, but are still in their infancy.
- Handheld data collection devices such as PDAs and mobile phones require additional IT resources to handle device technology (hardware and software) as well as data transmissions and storage.
- Pedometers are a very inexpensive technology that can be used to estimate walk trip distances by capturing step counts. It is also possible that the use of a pedometer may cause respondents to remember and record walk trips which might otherwise remain unreported.
- Activity monitors, which use accelerometers to measure levels of activity, would undoubtedly assist in improving the estimates of walk trip lengths and durations but their cost is too high to justify their use in the context of the National Travel Survey.
- Self completion of electronic forms could offer a reasonably low cost option for data entry and may provide an attractive option for some respondents. Problems have

been experienced, however, in designing software which will operate effectively on the full range of computers.

- Internet-based surveys offer a reasonably low cost option for data entry. Control is centralized, allowing for easy maintenance, updates, and data consolidation. They may provide an attractive option for some respondents – particularly those who have Broadband access
- A number of organisations are building up datasets containing logs of the movement of GPS-equipped vehicles. It is possible to buy access to these anonymised data and/or to more disaggregate data derived from vehicles whose addition to the datatset has been specifically requested. Access to this data would make it possible to explore the representativeness of NTS's single week records. It might also provide the basis for a longitudinal dimension to the NTS data and might be an administratively simple way of obtaining detailed locational data for car trips made by a subsample of NTS respondents.

References

Adler, T., L. Rimmer, and D. Carpenter (2002), "Use of Internet-Based Household Travel Diary Survey Instrument," Transportation Research Record 1804, pp. 134-142.

Alsnih, R., 2004, "Characteristics of Web Based Surveys and Applications in Travel Research". Presented at the International Conference on Transport Survey Quality and Innovation, Costa Rica, August (in press).

Aono, S., N. Ohmori, and N. Harata (2006). "Development of a Web-GIS Based Scheduling Simulator on Holiday Non-Work Activities," Proceedings of ICTTS 2006. (in press)

Bonnel, P. (2004). "Web-based surveys: potential for travel survey?" Presented at the International Conference on Transport Survey Quality and Innovation, Costa Rica, August (in press).

Bonnel, P. and J. Armoogum (2005). "National transport surveys – What can we learn from international comparisons?" Presented at the European Transport Conference, Strasbourg, October, 2005.

Bonsall, P., Wolf, J. and Holroyd, s. (2006) "Review of the potential role of 'new technologies' in the National Travel Survey"; Final report on DfT research project no UG599, DfT. [Taj - can we make this a link through to the main report]

Bradley, M., J. Wolf, and S. Bricka (2005). "Using GPS Data to Investigate and Adjust for Household Diary Data Non-Response." Presented at the Transportation Planning Applications Conference, Portland, Oregon, April.

Bricka, S. and C. Bhat (2006). "A Comparative Analysis of GPS-Based and Travel Survey-Based Data." Presented at the 85th Annual Meeting of the Transportation Research Board, Washington, D.C., January (in press).

Bricka, S. and C. Bhat (2006). Using GPS to Inform Travel Survey Methods. Presented at the TRB Conference on Innovations in Travel Demand Modeling, Austin, Texas, May.

Christensen, L. (2005). "Internet-Interview in a National Travel Survey." Danish Transport Research Institute. Presentation. (WG3 Meeting in Berlin, November?)

de Blaeij, A., M. Dijst, and S. Farag (2006). Effects of data collection methods in travel behaviour surveys; comparing an Internet and a mail sample; Presented at the 85th Annual Transportation Research Board, Washington DC, January.

Doherty, S., D. Papinski, and M. Lee-Gosselin, (2005). "An Internet-based Prompted Recall Diary with Automated GPS Activity-trip Detection: System Design," Presented at the 85th Annual Meeting of the Transportation Research Board, Washington, D.C., January.

Fell, B., T. Haupt, and U. Reiter (2006). “New Methods and Technologies for complex activity dairy surveys – the SIMPT experience,” Presentation at the WG3 Meeting, Budapest, April.

Itsubo, S. and E. Hato (2005). A study of the effectiveness of a household travel diary using GPS-equipped cell phones and a WEB diary through a comparative study with a paper-based travel survey, Presented at the 85th Annual Meeting of the Transportation Research Board, Washington, D.C., January.

Kitazawa, K. (2006). CAPABLE GPS Report Draft 2. Study report for the Children’s Activities, Perceptions, and Behaviour in the Local Environment project. July.

Kort, T., R. Cozza,, K. Maitam, and T. Lillian (2005). PDA Market Has Record First Quarter, Growing 25 Percent, The Gartner Group Inc.

Kochan, B. T. Bellemans, D. Janssens, and G. Wets (2006). Dynamic activity-travel diary data collection using a GPS-enabled personal digital assistant. Presented at the TRB Conference on Innovations in Travel Demand Modeling, Austin, Texas, May.

NCHRP 70-01, 2005, Private-Sector Provision of Congestion Data Probe-based Traffic Monitoring, State-of-the-Practice Report, University of Virginia Center for Transportation Studies - Virginia Transportation Research Council, November.

Marchal, P., S. Yuan, and P.O. Flavigny (2006). “Person-based GPS component: preparation of the next French NTS,” Presented at the WG3 Meeting, Budapest, April.

Nielsen, O.A. and G Jovicic (2003). The AKTA road pricing experiment in Copenhagen. Presented at the International Conference on Travel Behaviour Research, Lucerne, Switzerland, August.

Ohmori, N., N. Nakazato, K. Sasaki, and K. Nishii (2006). “Activity diary surveys using GPS mobile phones and PDA,” Presented at the 85th Annual Meeting of the Transportation Research Board, Washington, D.C., January.

Oliveira, M., P. Troped, J. Wolf, C. Matthews, E. Cromley, and S. Melly (2006). “Mode and Activity Identification Using GPS and Accelerometer Data.” Presented at the 85th Annual Transportation Research Board, Washington DC, January.

Rindsfuser, G., H. Muhlhans, S. Doherty, and K. Beckmann (2003). Tracing the planning and execution of activities and their attributes – Design and application of a hand-held scheduling process survey. Presented at the International Conference on Travel Behaviour Research, Lucerne, Switzerland, August.

Schonfelder, S., H. Li, R. Guensler, J. Ogle, K. Axhausen, (2005). “Analysis of Commute Atlanta Instrumented Vehicle GPS Data: Destination Choice Behavior and Activity Spaces,” *Arbeitsberichte Verkehrs- und Raumplanung,* 303, IVT, ETH, Zurich.

Smith, B., H. Zhang, M. Fontaine, and M. Green, (2003). Cell Phone Probes as an ATMS Tool, Research Report No. UVACTS-15-5-79, University of Virginia Center for Transportation Studies - Virginia Transportation Research Council.

Steer Davies Gleave and GeoStats (2003). The Use of GPS to Improve Travel Data, Study Report. Prepared for the DTLR New Horizons Programme, London Department for Transport.

Stopher, P. (2004). GPS, Location, and Household Travel in D. Hensher, K. Button, K. Haynes, and P. Stopher (editors), Handbook on Transport Geography and Spatial Systems, Elsevier (Handbook Vol. 5, Chapter 24).

Wermuth, M., C. Sommer, and M. Kreitz. 2003. "Chapter 27: Impact of New Technologies In Travel Surveys." Transport Survey Quality and Innovation. Elservier Science Ltd.

Wolf, J. (2000), "Using GPS Data Loggers to Replace Travel Diaries in the Collection of Travel Data," Dissertation, Georgia Institute of Technology, School of Civil and Environmental Engineering, Atlanta, Georgia.

Wolf, J., R. Guensler, and W. Bachman. (2001). Elimination of the Travel Diary: An Experiment to Derive Trip Purpose from GPS Travel Data. TRR 1768, Transportation Research Board, pp.125-134.

Wolf, J., M. Oliveira, and M. Thompson (2003a). The Impact of Trip Underreporting on VMT and Travel Time Estimates: Preliminary Findings from the California Statewide Household Travel Survey GPS Study. Transportation Research Record No. 1854, pp. 189-198.

Wolf, J., M. Loechl, M. Thompson, and C. Arce (2003b). Trip Rate Analysis in GPS-Enhanced Personal Travel Surveys. Transport Survey Quality and Innovation, Chapter 28, pp. 483-498. Elsevier, England.

Wolf, J. (2004a) "Applications of New Technologies in Travel Surveys," Presented at the International Conference on Transport Survey Quality and Innovation, Costa Rica, August 2004 (in press).

Wolf, J., S. Schönfelder , U. Samaga, M. Oliveira and K.W. Axhausen (2004b). 80 weeks of GPS-traces: Approaches to Enriching Trip Information, Transportation Research Record 1970, pp. 46-54.

Wolf, J. (2004c). "Defining GPS and GPS Capabilities," in D. Hensher, K. Button, K. Haynes, and P. Stopher (editors), Handbook on Transport Geography and Spatial Systems, Elsevier (Handbook Vol. 5, Chapter 23).

Zmud, J. and J. Wolf (2003). Identifying the Correlates of Trip Misreporting: Results from the California Statewide Household Travel Survey GPS Study. Presented at the International Conference on Travel Behaviour Research, Lucerne, Switzerland, August.

Expanded Bibliography (not cited in report)

American College of Sports Medicine. Objective Monitoring of Physical Activity: Closing the Gaps in the Science of Accelerometry. Supplement to Medicine & Science in Sports & Exercise, Volume 37, No. 11, November 2005.

Aono, S., N. Ohmori, and N. Harata, (2004). "Development of an Internet-Based Travel Survey System for Multi-Modal Transportation Planning with Relocation of Large Scale Facilities," Proceedings of the International Symposium on City Planning 2004, pp.41-50.

Arentze, T., I. Bos, E. Molin, and H. Timmermans (2005). "Internet-Based Travel Surveys: Selected Evidence on Response Rates, Sampling Bias, and Reliability." Transportmetrica (Special Issue: Some Recent Advances in Transportation Studies), 1, pp. 193-208.

Axhausen, K. (2003). "Methodological Research for a European Survey of Long-Distance Travel," ETH IVT, Zurich.

Beighle A. and R. Pangrazi (2006). Measuring Children's Activity Levels: The Association between Step-Counts and Activity Time. Journal of Physical Activity and Health. Volume 3, Number 2, April 2006.

de Jong, R. and Mensonides, W. (2003), 'Wearable GPS device as a data collection method for travel research', ITS Working Paper 03-02, Institute of Transport Studies, Sydney.

Doherty, S., N. Noel, M. Lee-Gosselin, C. Sirois, and M. Ueno (2003). "Moving Beyond Observed Outcomes: *Integrating Global Positioning Systems and Interactive Computer-Based Travel Behavior Surveys."*

Forrest T. and D. Pearson (2005). "Comparison of Trip Determination Methods in Household Travel Surveys Enhanced by a Global Positioning System," Transportation Research Record: No. 1917, pp. 63-71.

Guensler, R. (2004). "Using Global Positioning Systems Data to Understand Day-To-Day Dynamics of Morning Commute Behavior." Transportation Research Record No. 1895.

Hato, E., S. Itsubo, and T. Mitani (2006). Development of MoALs (Mobile Activity Loggers supported by gps-phones) for travel behaviour analysis. Presented at the 85th Annual Transportation Research Board, Washington DC, January.

Lee-Gosselin, M., S. Doherty, and D. Papinski (2006). "Internet-Based Prompted Recall Diary with Automated GPS Activity-Trip Detection: System Design," Transportation Research Board Annual Meeting 2006 Paper #06-1934.

Matthews, C.E., Freedson, P.S., Herbert, J.R., Stanek III, E.J., Merriam, P.A., & Ockene, I.S. (2000). Comparing physical activity assessment methods in the Seasonal Variation of Blood Cholesterol Study. *Medicine & Science in Sports & Exercise,* 976-984.

Mathews, C.E., Ainsworth, B.E., Thompson, R.W., & Bassett Jr., D.R. (2002). Sources of variance in daily physical activity levels as measured by an accelerometer. *Medicine & Science in Sports & Exercise,* 1376-1381.

Morimichi, N., N. Ohmori, S. Aono, T. Maruyama, and N. Harata (2006). “Development of a Web GIS-Based Activity-Travel Simulator for Travel Feedback Program,” Proceedings of ICTTS 2006. (in press)

Montoye, H.J., Kemper, H.C.J., Saris, W.H.M, Washburn, R.A. Measuring Physical Activity and Energy Expenditure. United States: Human Kinetics, 1996.

Nijland, L., T. Arentze, A. Borgers, and H. Timmermans (xxxx). “Modeling Complex Activity-Travel Scheduling Decisions: Procedure for the Simultaneous Estimation of Activity Generation and Duration Functions.”

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

Richardson, A.J., and H. Battellino(1997). “Similar, Yet Different: Some Emerging Trends in Travel Surveys in Australia,” TRB Transportation Research Circular E-C008: Transport Surveys: Raising the Standard.”

Roorda, M., M. Lee-Gosselin, S. Doherty, E. Miller, and P. Rondier (2005). “Travel/Activity Panel Surveys in the Toronto and Quebec City Regions: Comparison of Methods and Preliminary Results,” Presented at the PROCESSUS Second International Colloquium on the Behavioural Foundations of Integrated Land-use and Transportation Models: Frameworks, Models and Applications, Toronto, June, 2005.

Tan, A., B. de Vries, and H. Timmermans (2005). “Using a Stereo Panorama Interactive Navigation System to Measure Pedestrian Activity Scheduling Behaviour: A Test of Validity.” Environment and Planning B: Planning and Design, 32, pp. 567-580.

Verhoeven, M., T. Arentze, H. Timmermans, and P. van der Waerden, (2005), “Modeling the Impact of Key Events on Long-Term Transport Mode Choice Decisions: Decision network Approach Using Event History Data.” Transportation Research Record, 1926, pp. 106-114.

Welk, G. J., ed. Physical Activity Assessments for Health-Related Research. United States: Human Kinetics, 2002.

APPENDIX A: Hardware / Software Inventory by Technology Type

Table A-1: Integrated GPS Loggers (with minimum of 24,000 point capacity)

Product Name	Compatibility	Battery / Power Drain	Battery Life	Connection Type	Accuracy/ WAAS	Capacity in Points	Weight	Size	Price
Neve StepLogger	laptop	Lithium Ion, rechargeable	10 hours continuous	USB	2.5m	393,168	84 g	75 mm L x 45 mm W x 25 mm H	£489
Neve StepLogger	laptop	Lithium Ion, rechargeable	10 hours continuous	USB GPRS/GSM	2.5m	393,168	84 g	75 mm L x 45 mm W x 25 mm H	£543
GeoStats GeoLogger – V4 * no longer available	Laptop / desktop	Lithium Ion, rechargeable	72 hours	USB or DB9	WAAS 3m	466,000	794 g, w/cables and etc.	66 mm L x 66 mm W x 27 mm H	£475
Laipac G30L -Integrated logger, antenna and receiver	PDA or pc/laptop	.3 Watts (avg.)		DB 9 or USB	WAAS 3m	54,000	85 g	66 mm L x 51 mm W x 25.4 mm H	£71
San Jose Nav. GL-50B - Integrated logger, antenna and receiver	PDA or pc/laptop	AAA rechargeable	8 hours continuous	USB	15m	50,000	79.95 g	63 mm L x 42 mm W x 27.4 H	NA
RoyalTek BlueGPS RBT-3000	PDA or pc/laptop	Lithium Ion	10 hours continuous	Bluetooth	WAAS 10m	30,000	60 g	108 mm L x 53 mm W x 23.6 mm H	£ 55
PreTec Bluetooth GPS	PDA or pc/laptop	Lithium Ion	Minimum 12 hours	Bluetooth	25m	30,000	64.92 g	108 mm L x 52 mm W x 19 mm H	£ 149
EverMore DL-200	pc/laptop	Lithium Ion	more than 7 hours	USB	WAAS 5m	25,000	94.7 g	93 mm L x 84 mm W x 31 mm H	£ 49
EMTAC BTGPS II Trine	PDA, pc/laptop	Lithium Ion	10 hours	Bluetooth	WAAS 10m	24,000	77.96 g	48.3 mm L x 89 mm W x 20.3 mm H	£138
San Jose Nav. GL-50	All PDAs	105 mA @ 5V		DB 9	Not WAAS 15m	25,000	85 g –w/o cable	56 mm (Diam) x 28 mm H	NA
Delorme Bluelogger GPS Receiver	All BT Compatible PDAs – tested with Axim X50v	118mA at 3.7V	8 hours	Bluetooth	WAAS	50,000	48.2 g w/o battery; 28.35 g battery	82.5 mm L x 44.5 mm W x 19 mm H	£ 82

Table A-2: Mobile Phones (with and without GPS)

Manufacturer	Product	Internal Capacity (MB)	Connection Type	Operating System	GPS	Price*
O2	O2 X4	10 MB internal, plus 64 MB card	Infrared, 3G (384 kbps), GPRS, USB	Microsoft Windows Mobile 5.0	No	£50
LG	LG G1800	64 MB, shared	GPRS, USB	NA	No	£79
Siemens	Siemens CL75	11 MB, shared	GPRS, IR, USB	NA	No	£80 Pay as you go
Samsung	Samsung X700	35 MB, shared	GPRS, EDGE, Bluetooth, USB	Symbian OS	No	£140, free for pay monthly plans
Palm	Palm Treo 700p Smartphone	128 MB	MultiMediaCard, SD, and SDIO	Windows Mobile 5.2.2, Pocket PC Phone Edition	No, but Bluetooth Parrot 3400LS GPS available	£217
BenQ-Siemens	BenQ-Siemens M81	27 MB	GPRS, EDGE, Bluetooth, USB		No	Not released yet
Motorola	Motorola i415	NA	Java-enabled	NA	Yes	£44
Blackberry	Blackberry 8700g	64 MB	USB, IR, EDGE	BlackBerry Handheld Software	Yes	£119 or less, free with higher minute monthly plans
Nextel	Nextel i710	2 MB	USB	NA	Yes	£131
Hewlitt Packard	HP iPAQ hw6510	55 MB	Bluetooth, IR, ActiveSync, SDIO, USB	MS Windows Mobile 2	Yes	£299
LG	LG U8380	23 MB, shared	GPRS, 3G, Bluetooth, USB	LG proprietary	Yes	£323
Mio	Mio A701	192 MB	GSM, GPRS	Windows Mobile 5 – “Magneto”	Yes	£379

*Prices posted are lowest available, unless noted. Some phones are free with a 12-month contract, in other cases the price varies based on monthly plan chosen.

Table A-3 : Data Plan Prices by Main UK Mobile Phone Carrier

UK Mobile Phone Service Providers	Service Name	Price Per Month
O2	Data Plan	£ 75
Orange	Mobile Data	£ 35
T-Mobile	“Web n Walk”	£ 40
Virgin	NA	£ 15 base + £ 0.05 per kilobyte
Vodaphone	“Vodafone live!”	£ 45

* Prices quoted are for unlimited data plans, unless noted, and with a 12 month contract.

Table A-4: PDAs

Product	Internal Capacity (MB)	OS	Expansion card type (CF, SD, other)	Battery style	Re-charge info	Price
HP iPAQ hw6515	128 MB total, 55 MB available to user	Windows Mobile 2003, 2nd Edition	SDIO, SD	1200 Lithium Ion	Rechargeable battery, user swappable	£299
Toshiba e805	128 MB, 32 MB Flash ROM	Windows Pocket PC 2003	SD, CF	1320 Lithium Ion	Rechargeable battery, user swappable	£325
Palm Z22	32MB hard drive	Palm 5.4	USB cable	Lithium Ion	Rechargeable battery	£54
PalmOne Zire 31 PDA	16 MB, 14 of those available to user	Palm Garnet 5.2.8	SD/SDIO	900 Lithium Ion	Rechargeable battery, not user replaceable	£70
Palm Tungsten E2	32 MB (26 MB actual storage	Palm 5.4	SD, SDIO, MMC	Lithium Ion	Rechargeable batteries	£108
Sony Clie PEG-SJ30*	16 MB	Palm 4.1	Memory Stick Slot	Lithium Ion	Rechargeable batteries	£119
Dell Axim X51v PDA	256 MB	Windows Mobile 5	CF, SD	1100 Lithium Ion	Rechargeable battery, user swappable	£168
Palm LifeDrive Mobile Manager	4 GB, 64 MB available for Palm OS Apps and Data	Palm 5.4	MMC, SD, and SDIO	Lithium Ion	Rechargeable batteries	£217
Symbol MC50	64 MB	Microsoft Windows Mobile 2003, 2nd Edition	USB	1560 Lithium Ion	Rechargeable	£544
OQO	20 GB	Windows XP	USB, Bluetooth, FireWire	Lithium Polymer 4000 mAh	Rechargeable, user changeable	£1034
Nokia 770 Handheld	128 MB	Linux	RS-MMC	1500 Lithium Ion	Rechargeable	£191
DualCore PC	30 GB	Windows XP 2005 and Windows Mobile 5.0	Bluetooth, 3G, USB, mini-VGA	Unavailable	Rechargeable	£817

* Recently discontinued

Table A-5 : Commercial PDA Survey Software

Product	Capabilities	Limits on # Questions	Base Cost	Additional Costs
Snap Surveys Snap 8	multiple choice, single- and multiple-response, and interview logic	65,000/survey	Professional Edition £705 ProNet Edition £1249	PDA module £542 first 5 users, £324 subsequent 5-pack user modules; Results edition £270
Survey System	Multiple choice, text answers, fill-in-the-blank, logic	32,000 single answer questions, or fewer multi-answer questions (i.e. 3200 questions with 10 answer choices). Evaluation edition works with smaller surveys.	Evaluation Edition £27 Basic Edition £273 Professional Edition £544 Enterprise Edition £1088	Internet Module £273 / £545 Indexer £273 / £545 Statistics Module £109 / £218 Voice Capture Module £273/ £545
SyncSurvey	multiple choice, multiple questions per form, list boxes, barcode, magnetic stripe reader, free form (numeric and alpha)	999, however, one type of question supported can have up to 5 sub-questions, so technically up to 5000 questions per survey	Research Pro £55, Survey Pro £28, Data Pro £0	Recurring fee for Research Pro is £16/month or £163/year; Survey Pro is £28/month, Data Pro is £0/month. Pricing is based on how many respondents go through survey.
Techneos Entryware	multiple choice, text answers, fill-in-the-blank, logic.	Small business - 100; Professional - 500, Enterprise - Unlimited	Small Business starter - £542 Professional - £1,359	Professional edition - £136 additional Mobile licenses, £436 additional designer licenses, £273 entryware Data manager licenses

Table A-6: Integrated PDA and GPS

Product	Compatibility	Power Source	Battery Life	Connection type	GPS Accuracy	Price
Garmin iQue M5 Bluetooth Enabled Wireless GPS/Pocket PC*	Garmin integrated GPS/Pocket PC	Lithium Ion	5 to 7 hours in continuous operation	Bluetooth or USB	WAAS enabled 3m	£ 253 £223 (lowest)
Garmin iQue 3600 - slightly larger than 3200 model, additional features such as MP3*	Garmin integrated GPS/PDA. Palm OS	Lithium Ion	3 to 4 hours in continuous operation	USB	WAAS enabled 3m	£ 298 (MSRP) £114 (lowest)
Garmin iQue 3200*	Garmin integrated GPS/PDA. Palm OS	Lithium Ion	3 to 4 hours in continuous operation	USB	WAAS enabled 3m	£ 119 (lowest)
Navman PiN	integrated GPS/"low-tech" PDA	Lithium Ion	5-8 hours in continuous operation	USB	NA	£ 217
Mitac Mio 168	integrated GPS/PDA	Lithium Ion	4 hours	USB	NA	£ 271
On Course Navigator All-In-One 818	integrated GPS/PDA	Lithium Ion	8 hours with backlight off	NA	NA	NA
Garmin iQue M4	Windows Mobile 2003/integrated GPS	Lithium Polymer	5 to 7 hours in continuous operation	USB	WAAS enabled <5m	£379 (MSRP) £284 (lowest)

*Recently discontinued

Table A-7: GPS Receivers for PDAs

GPS Product	Compatibility	Battery style	GPS Accuracy	Price
Delorme Earthmate GPS and powerpack	Dell Axim, IPAQ 3800 and 3900 via USB or serial cable	4-AAA	WAAS enabled 2-5m	£ 49
Deluo / Holux compact flash gps receiver	All PDA w/ compact flash socket	3.3 volt draw from PDA	WAAS enabled - 5m	£ 380
Garmin cf Que 1620 - CompactFlash GPS module	All PDA w/ compact flash socket	no spec info on Garmin website	WAAS enabled	£ 136
Globalsat SDIO GPS Receiver	Dell Axim X3, HP iPAQ h1930, 1940, 2210, 3970, 4150, 5550, 6xxx, iMATE	NA	WAAS enabled 1-5m	£ 71
Holux GM - 270 Ultra	CF card type 1	3.3V	WAAS enabled 3m	£ 49
Navman GPS 3450 for IPAQ PCs - GPS sleeve	iPAQ H5400, H3700, and H3800	3.3 V DC from the HP iPAQ via Navman vehicle power cable	WAAS enabled 5m	£ 122
Pharos Pocket GPS Navigator	Dell Axiom X5 / maybe others with a compact flash adaptor	NA	WAAS enabled <10m	£ 136
Pretec's CompactGPS Card	All PDA w/ compact flash socket	NA	Not WAAS enabled 10m	£ 182
Rayming Trip Nav TN202 Compact Flash GPS Receiver	Windows CE and Pocket PCs with a type 1 or 2 compact flash port	NA	WAAS enabled - 3m	£ 81
TeleType GPS cf v3.0 Receiver	All PDA w/ compact flash socket	3.3V DC	WAAS enabled - 3m	£135
Transplant Computing GPS Jacket	HP IPAQ 3600 and 5400 series	NA	WAAS enabled - 3m	

Table A-8: Accelerometers

Product	Size(cm)/ Weight(g)	Capacity	Frequency/ Sensitivity	Transfer	Price
ActiGraph GT1M	3.8 x 3.8 /31	22 days	1 minute epoch/.6g	USB	£ 214 unit
AMI Micro-mini Motionlogger	3.8 diameter/28	32K – 22 days	10 Hz	Reader Interface to PC	£ 479 unit £ 265-Interface/Software
Dynastream AMP 331	7.1 x 2.4 x 3.7/50	10-12 days	1 minute epoch	USB	£ 241 unit/sleeve £ 642 - Starter Pack w/ unit, software, download link and sleeve.
IM Systems – ActiTrac	unknown	128K; 88 days	40 per second/.012g	Connects directly to PC	£ 107 unit £ 268- Starter Pack w/ unit, cable and software
New Lifestyles NL2000	5.7 x 4.4 X 1.9/23.3	7 days	Unknown	No PC Connection	£ 35 unit
MiniMitter Actical	2.8 x 2.5 x 1 /19	64K – 45 Days @ 1 minute epoch	15 second epoch/.5-2	Reader Interface to PC	£ 428 unit £ 266-cable and software
Stay Healthy RT3	7.1 x 5.6 x 2.8/71.5	3 hours@1 second, 21 days@1 minute	1 second to 1 minute epoch	Docking station to PC	£ 161 unit £ 268- Starter Pack w/ unit, docking station, cable and software

Table A-9: Pedometers

Product	Size(cm)/ Weight(g)	Capacity	Resolution/ Range	Transfer	Price
High Gear Fitware	5.7 x 5.4 x 2.9cm/28.4	99,999 Steps	0.16/0.16km to 9994km	No PC Connection	£ 11 unit
Lifestyles Digi-Walker 700	5.1 x 3.8 x 1.9/23.3			No PC Connection	£ 16 unit
Sportbrain I-Step X1	5.7 x 5.4 x 2.54	99,999 Steps	0.16/0.16km to 9994km	USB Download	£ 21 unit
Sportline Fitness Pedometer 360		7 Day Memory	Distance measured to .01km	No PC Connection	£ 21 unit
Walk 4 Life W4L Pro		1 Million Steps		No PC Connection	£ 15 unit

APPENDIX B : Technology Assessment Questionnaire

National Travel Survey:

Review of the potential role of 'new technologies'

Request for Information

Dear Colleague,

The UK Department for Transport has contracted Leeds University (in association with GeoStats and the National Centre for Social Research) to conduct a review of new technologies* for potential applications in the Great Britain National Travel Survey.

As an element of this study, GeoStats is contacting all practitioners and researchers active in the field of travel surveys and asking that they provide some basic information about their experiences with these technologies.

If you have employed these technologies in a travel survey with 20 or more participants since 2002, we would be grateful if you would complete the attached questionnaire. (Please extend the size of any text space if you need additional room.) Also, we would appreciate any supporting reference materials that may further explain your questionnaire responses.

To meet the project schedule, we will need to receive the questionnaires by May 15, 2006. Please email your responses to Jean Wolf (jwolf@geostats.com) and Lauren Leary (lleary@geostats.com) or fax your answers to GeoStats at (US) 404.588.1227.

If you know of anyone else who is not on the attached list but who has conducted work of this kind since 2002, please let us know or forward this email directly to them.

Thanks,

Jean Wolf

GeoStats LP

Atlanta, Georgia

USA

---

*For the purpose of this study, “new technologies” are defined as:

- Electonic user interfaces for travel diary entry (CASI) such as the Internet, downloaded software, PDAs, or cell phones
- GPS data logging or cell-phones / mobile phones for location information (logging either passively or with a user interface to collect other travel details)

Questionnaire

Please copy this form and complete for each technology-assisted travel survey you have conducted since 2002. For this purpose, to qualify as a separate “survey,” a study should have involved at least 20 respondents and have been analyzed separately.

A. Study Background:

1. Your Name *(or leave blank if you wish to remain anonymous)*: ________________________

2. Your Organization’s Name: ____

3. Study Name: ____

4. Client/Sponsor’s Name: ____

5. Study Date: Start Month ______ Start Year ______ End Month ______ End Year ______

6. Total Technology Budget Amount: ____________ Currency _________

What did this amount cover? (e.g. equipment, software, training, data processing, etc…)

B. Recruitment Information:

1. How were participants recruited? (*please provide details of the recruitment process*).

2. Were participants required to use technology in order to participate in the study or was another option provided (e.g. paper diary)? *Please check one of the answers below.*

- ❑ Technology component was required
- ❑ Technology component was optional

3. Were participants provided with an incentive to finish the study? *Please check one of the answers below*.
   - ❑ Yes, the incentive was: (*please describe, if money please state amount and currency)*__________________
   - ❑ No
4. What was the total sample size? # of households: ________ or # of persons: ________
5. What was the total sample size that used technology? # of households: ________ or # of persons: ________
6. If the survey was conducted at the household level, how many persons per household were instrumented with technology? ________
7. How many days were data recorded for each household or person: ________

C. Types of Technology Employed:

1. What types of technology were used in the study? Please check one or more answers and provide details including product name and manufacturer in the space provided below.

- ❑ Electronic user interface (Internet, PDA, or cell/mobile phone)
- ❑ GPS data logging
- ❑ Cell/mobile phone location

2. If more than one type of technology was used, were the systems integrated into one unit (e.g. a PDA with GPS data logging capability)? *Please check one of the answers below*.

- ❑ Yes
- ❑ No

3. Approximately how much did the technology cost? Cost per household: ________ or cost per person: ________

4. How was the technology distributed to study participants? *Please check one or more answers below.*

- ❑ Mailed out
- ❑ Delivered to home by member of the survey team
- ❑ Picked up by participant
- ❑ Other: ____

5. How were participants trained to use the technology? *Please check one or more answers below.*

- ❑ Instructed in person
- ❑ Instructed over the phone
- ❑ Provided with hard-copy directions

- ❑ Provided with on-line directions
- ❑ Other: ____

6. How was the technology recovered from participants at the end of the study? *Please check one or more answers below.*

- ❑ Mailed in
- ❑ Delivered to a central study location by participant
- ❑ Picked up by study team member
- ❑ Other: ____

7. If electronic user interfaces were used, what is the total number of units that were

deployed? ________ How many of these units were returned? ________

8. If GPS data logging equipment was used, what is the total number of units that were deployed? ________ How many of these units were returned? ________

9. If cell or mobile phones were used to gather location information, what is the total number of units that were deployed? ________ How many of these units were returned? ________

10. What was the overall participant response to the technology? *Please check one or more answers below.*

- ❑ Easy to use
- ❑ Difficult to use
- ❑ Easy to carry throughout the day

- ❑ Difficult to carry throughout the day
- ❑ Other: ____

D. Technology Trade-Offs

1. For what reason(s) was the technology or combination of technologies chosen to aid the collection of travel data? *Please check one or more answers below*.

- ❑ To improve the process of converting raw data to digital form
- ❑ To improve data reporting on all trips
- ❑ To improve data reporting on short trips, especially those under 1 mile
- ❑ To gain better trip origin and destination data
- ❑ To gain better accuracy of distance data
- ❑ To gain better accuracy of travel time data
- ❑ Unit size
- ❑ Unit cost
- ❑ Ease of use for participants
- ❑ Appeal to certain population subgroups, such as teenagers and older adults

- ❑ Other: ____

2. *If a combination of an electronic user interface* <u>*and*</u> *location logging technology was used, please answer the following two questions (a. and b.).*

   a. Which technology component was most important to the success of the study? *Please check one answer below.*

      - ❑ Electronic user interface (Internet, PDA, cell/mobile phone)
      - ❑ GPS data logging or cell/mobile phone
      - ❑ Both equally important
      - ❑ Neither more important than the other

   b. If only one type of technology could have been used, would you have chosen to have participants: *Please check one answer below.*

      - ❑ Use a paper diary and locational logging technology?
      - ❑ Use an electronic interface with no locational logging technology to capture all travel information

3. What reliability and accuracy problems occurred? *Please check one or more answers below*.

   - ❑ Missing data caused by malfunction
   - ❑ Dropped signal in certain areas
   - ❑ Participant did not carry unit throughout the day
   - ❑ Participant found unit difficult to use

- ❑ Other: ____

E. Data Processing

1. How was the electronic and / or GPS data downloaded *(please describe the process)*:

2. What tools and / or software programs, including GIS information, were required to convert the downloaded data to a usable form?

3. What problems were encountered linking the travel data to particular locations and roads? How were these problems handled?

4. Were missing data points imputed, where possible, or removed from the trip segment? *Please check one answer below.*

   - ❑ Imputed
   - ❑ Removed
   - ❑ Other: ____

5. If GPS or cell/mobile phone data was used to verify self-reported locations, what problems arose? How were these problems handled?

6. If GPS or cell/mobile phone locational data was used, did you perform an accuracy evaluation on one or more of the following? *Please check one answer below*.

- ❑ Trip Times (Start, End, and Duration)
- ❑ Trip Origin and Destination Locations
- ❑ Trip Distance

F. Additional Comments or Information

Thank You for Your Time!

APPENDIX C: Technology Assessment Survey

In order to complete this effort, practitioners and researchers active in the travel survey arena and were contacted and invited to share their experiences with technology-assisted travel surveys conducted since 2002. In this initial query, particular attention was placed on gaining an understanding of the types of new technologies that are being used in the field, their advantages and disadvantages, survey sample sizes, participant response to the technologies, technology budgets, reliability and accuracy issues, and the data download process.

1 The Questionnaire

In early May 2006, GeoStats emailed a six-page technology assessment questionnaire to 56 travel survey professionals. This questionnaire asked practitioners and researchers to document their experiences with "new" technologies that have been used in recent travel surveys with at least 20 participants. For the purpose of this study, "new" technologies have been defined as the following:

- Electronic user interfaces for travel diary entry (CASI) such as the Internet, downloaded software, PDAs, or cell phones
- GPS data logging or cell-phones / mobile phones for collecting location information (logging either passively or with a user interface to collect other travel details)

The questionnaire, appearing in Appendix B, is comprised of the following sections:

- Study background including the study timeframe and technology budget
- Recruitment information such as the manner in which participants were recruited, whether the use of technology was optional or required for participation, and the sample size
- Types of technologies employed, and technology distribution and collection methods
- Technology tradeoffs, participants' response to the technology, and reliability and accuracy problems

- The process to download and convert data to a useable form
- Other additional information

The list of travel survey professionals who received the questionnaire is comprised of members of the TRB Survey Methods Committee, participants of recent Survey Methods in Transport conferences, and individuals suggested by DfT. Others receiving the questionnaire were recommended by the first round of recipients.

The first page of the questionnaire provided background information on the technology assessment study and asked individuals to respond within a two-week time period, by May 15th. Follow up correspondence was emailed to individuals who did not respond within 10 days of the original mailing. The original due date was extended until the end of May, and on May 25th, another email was sent to a handful of professionals who had not responded with a completed questionnaire, reference materials, or a note indicating that they did not have sufficient information to share. Additionally, GeoStats contacted a few of the key professionals via phone to ensure that their work was included in this assessment.

As a result of these efforts, a total of 29 questionnaires were received along with a number of journal articles and conference presentations. A few professionals responded that they did not have time to complete the questionnaire within the desired timeframe but sent project reference materials. Only a handful of individuals did not respond at all, and it is believed that the primary reasons for non-response were: 1) they have not conducted technology-assisted travel surveys in the past four years; 2) their technology-assisted travel surveys did not meet the 20-participant threshold; 3) they were not interested in sharing what could be considered proprietary information; and 4) they were simply too busy to respond. A few of the individuals contacted worked together and jointly responded to the call for information.

Published articles describing the work of several key professionals who did not complete questionnaires or send reference information were obtained and read by GeoStats staff, and questionnaires were filled out with the information available on studies conducted by two of these professionals – bringing the total number of studies evaluated in this assessment to 31. It should be noted that a wealth of supporting information, such as Microsoft PowerPoint presentations, that did not translate well to the technology assessment questions and therefore were also collected but have not been included in this survey of the state of the practice.

Following the collection of completed questionnaires, All the information was coded into a project database. Table C-1 includes a list of the study and article names for which questionnaires were completed.

Table C-1
Technology Assisted Travel Studies and Journal Articles

Study or Article Name
South Australia TravelSmart Evaluation Pilot Project
NTCBP Sponsored Add-On GPS Panel Survey
TravelSmart Households on the Move, Travel Behaviour Change Pilot Project, Canberra
RTA Using GPS To Validate Sydney Household Travel Survey
An Integrated GPS-GIS System for Collecting Spatio-Temporal Microdata on Personal Travel in Urban Areas
Travel Activity Panel Survey
AKTA (Alternative Driving and Congestion Charging)
Congestion Index
Web survey for individuals who refuse to respond or who are not reachable for the traditional face to face travel survey.
3 pilots of the French NTS 2007, person-based GPS components
Household Travel Survey for the National Italian Transportation Model SIMPT
Young and Mobile Cohort - Specific time use of young adult people in Berlin and Brandenburg
Perception of border regions within the European Union by adolescent on the example of Slubice – Frankfurt (Oder)
Mobility of adolescents over time (panel)
Development of a Web-Based Scheduling Simulator on Holiday Non-Work Activities
Activity Diary Surveys Using GPS Mobile Phones
Web-GIS based Activity Travel Simulators with GPS Mobile Phones
Swiss Poster Research Plus
Cosim (Within the "Combined Route and Mode Choice Model" Project)
EX-ACT (EXamine the ACTivity Planning Process) within the project ILUMASS (Integrated Land Use Modeling and Transportation System Simulation)
Using a Stereo Panorama Interactive Navigation System to Measure Pedestrian Activity Scheduling

Behavior: A Test of Validity

CAPABLE (Children's Activities, Perceptions, and Behavior in the Local Environment)

Lexington Travel Habit Study

Household Travel Diary for Las Cruces, New Mexico

Real-time Tracking of Activity Scheduling and Execution under a Unified Data Collection Framework

Putting Behavior in Household Travel Behavior Data: An Interactive GIS-based Survey Via the Internet

Rio Grande Valley Texas 2004-05 Household Activity Travel Survey

COSMO (Continuous Survey for Monitoring Household and Travel Decisions in Oregon GPS Pilot Study)

Washoe County (Reno, Nevada) Travel Characteristics Study Household Travel Survey

Harvard School of Public Health Trail Usage Study

The Use of GPS to Improve Travel Data

---

2. Inventory of "New" Travel Survey Technologies

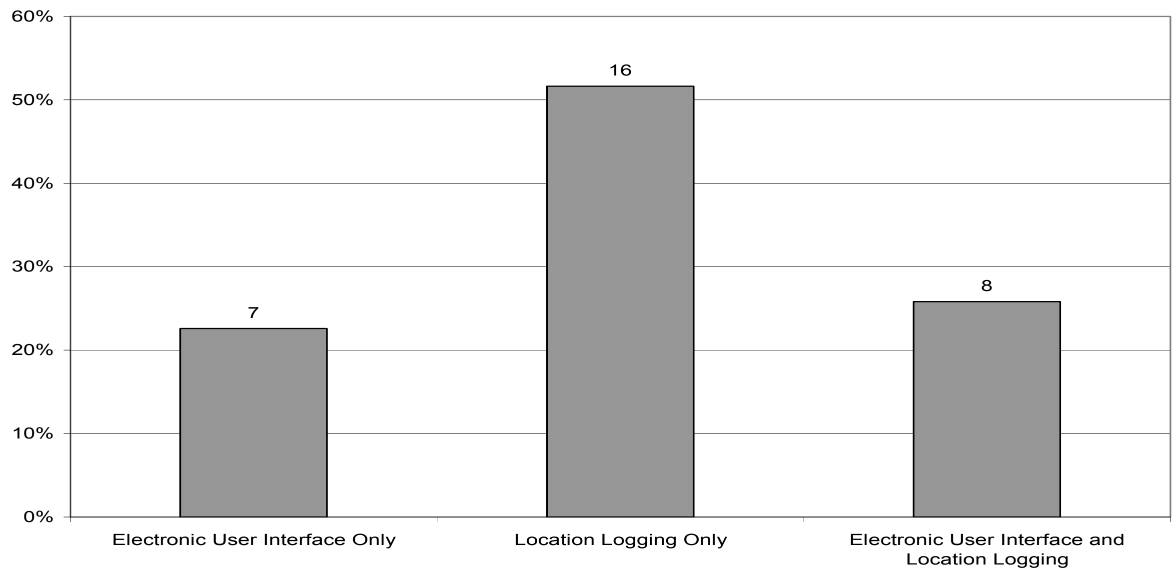
The following sections include summaries of responses received to the "new" technologies questionnaire. Responses are reported in categories and discussed based on the technology type (electronic data entry, location logging, or a combination of the two technologies). This inventory complements the technology inventory by providing experiences as reported by travel survey practitioners and researchers.

It is important to note that the technology assessment questionnaire is subjective in nature. Not only may respondents have had different interpretations of the assessment questions, but the travel surveys reported on vary in scope, size, and budget. Some respondents filled out the questionnaire in its entirety and provided reference materials to back up their responses. Others answered the majority, but not all, of the questions – in some cases, due to the ongoing status of their project. Major outliers are present, and a few responses have been re-coded based on additional information provided by the respondent. These cases are documented in the analysis. In spite of the subjective nature of this work, the questionnaire responses are assumed to be comparable for the purpose and objective of Work Package 1.

2.1 Types of Technologies Used and Reasons for Selection

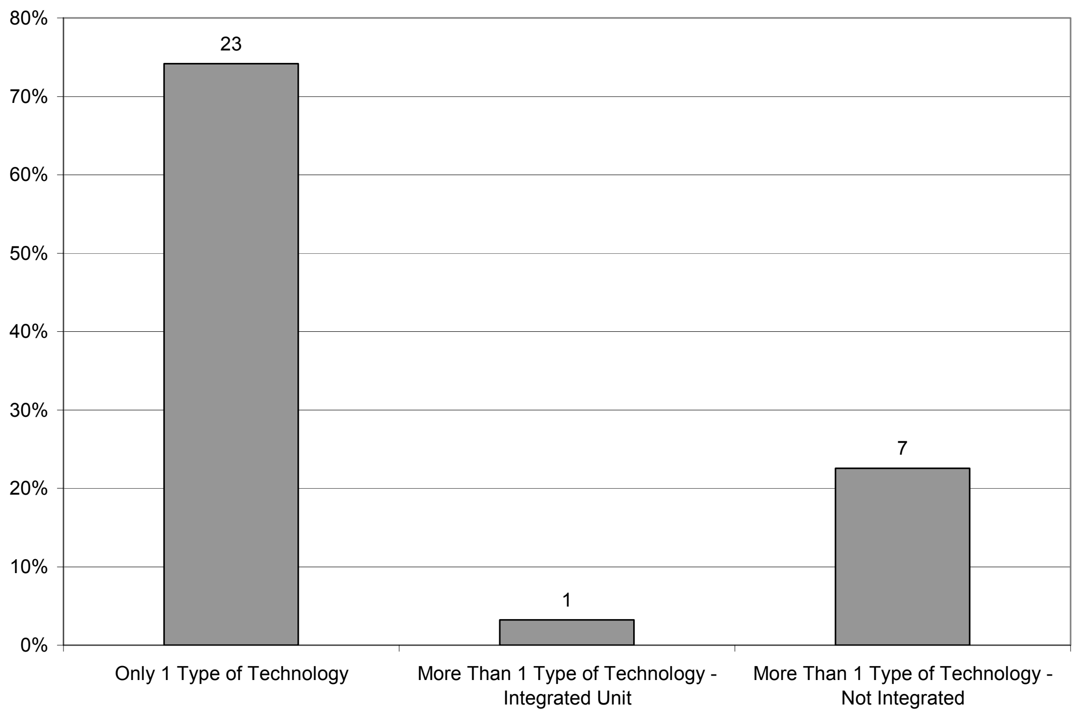
One of the main purposes of the technology assessment questionnaire was to gain a better understanding of the types of technologies researchers have chosen for their studies. Since a number of technology options exist for collecting travel survey responses and information on location, and these technologies continue to evolve over time, there is no one right technology solution. Different options and combinations of technologies suit various studies depending on the study size, positional accuracy requirements, project funding amounts, and respondents' ability to access, use, and carry devices. Figure C-1 shows the reported technology solutions broken down into three general categories: electronic user interface, location logging, and a combination of the two. Respondents reported 7 studies that used an electronic user interface, 16 studies that used a passive location logging technology, and 8 studies that collected data with a combination of these two technologies.

Figure C-1: Technology Categories



As illustrated in Figure C-2, 23 of the 31 studies inventoried employed one type of technology (PDA, GPS device, web based survey, etc.). For the eight studies that had respondents using multiple types of technology, two studies used integrated mobile phone / GPS units which allowed survey participants to answer questions on the interface while their locations were passively recorded.

Figure C-2: Stand-Alone or Integrated Unit



Not all of the technology assessment questionnaire responders provided detailed information, such as manufacturer specifications, about the electronic user interface or location logging device that was employed. Reasons for leaving this question blank possibly include not wanting to share sensitive, proprietary information with competitors or not knowing the exact device specifications due to contracting the technology portion of the study out to another firm. Table C-2 provides a list of equipment that was reported as used in the technology-assisted surveys.

Table C-2: List of Electronic User Interface and Location Logging Equipment Used in Technology-Assisted Travel Surveys

Technology Category	Category Detail	Type of Equipment
Electronic User Interface	Web	Internet survey and web-GIS software
	Web	eMapCATI technology (CATI with data entry and realtime geocoding over the Internet)
	PDA	Compaq PDA – IPAQ3950
	Virtual Reality System	Virtual Tour
Location Logging	GPS	GeoStats in-vehicle logger
	GPS	GeoStats GeoLogger
	GPS	GeoStats GeoLogger
	GPS	Neve Steplogger
	GPS	Garmin Foretrex 201
	GPS	Swiss "MobilityMeter"
Electronic User Interface and Location Logging	Mobile Phone and GPS (Not Integrated)	Sony-Ericson p900 cell phone / PDA combined with Teletype Bluetooth GPS unit
	Mobile Phone with Integrated GPS	GPS equipped mobile phones by KDDI Corporation
	Pocket PC and GPS	HP Pocket PC 3876 with a wireless card, Teletype GPS receiver, and Elan Speech recognition system
	PDA / GPS	XDA2 PDA by telecom provider 02 and Royaltek BTT 3000 GPS

Laptop Computer and GPS	CHASE survey on IBM Thinkpad notebooks and Personal GPS loggers

One of the most important questions in the technology assessment questionnaire was the one that asked respondents for the reason or reasons why the technology or combination of technologies was chosen. Ten answer choices were provided with an “other” response and section to add further information. The answer options to this multiple-choice question, along with the corresponding number of responses, are shown in Table C-3.

Table C-3: Technology Trade-Offs -- Answer Choices, Description, and Number of Responses Based on Technology Type

Technology Trade-Offs	Description	# of Responses for Studies Using:		
		Electronic User Interfaces	Location Logging Technology	Both Types of Equipment
1	Improve the process of converting raw data to digital form	4	4	8
2	Improve data reporting on all trips	4	11	6
3	Improve data reporting on short trips, especially those under 1 mile	2	7	6
4	Gain better trip origin and destination data	3	11	5
5	Gain better accuracy of distance data	4	10	6
6	Gain better accuracy of travel time data	3	11	6
7	Unit size	0	3	4
8	Unit cost	1	1	2
9	Ease of use for participants	3	7	5
10	Appeal to certain population subgroups such as teenagers and older adults	0	2	4
11	Other	3	7	3

Improving the process of converting raw data to digital form was one of the most important reasons why electronic user interfaces were used. Other top reasons why this type of equipment was selected include improving data reporting on all trips, gaining better accuracy of distance data, and respondent ease of use. As noted in the technology inventory, Kochan et all (2006) found that eliminating key-stroke errors and ensuring that only logical values were reported were important advantages of electronic data entry systems. Alsnih (2006) and Adler (2006) reported that web based surveys could be coded to provide validation checks to ensure internal consistency – again improving the quality of the collected data. Furthermore, questionnaire respondents added that electronic user interfaces were used in order to customize hypothetical settings relevant to each respondent (web-based survey) and so that respondents could record activity diaries at any time and at any location.

GPS and cell phones equipped with location logging technology were chosen when the survey required improved data reporting on all trips, including short trips, better trip origin and destination data, and more accurate travel time data. As noted in the technology inventory, Itsubo and Hto (2006) employed GPS integrated smart-phone technology (MOes) in order to confirm traveler stop locations and travel paths. Questionnaire respondents added comments to the “other” answer choice indicating that they chose location logging technology to improve data reporting for all modes of trips, to gain better route data for travel modeling purposes, to test the accuracy of travel diaries, and to measure the effect of “TravelSmart” survey software.

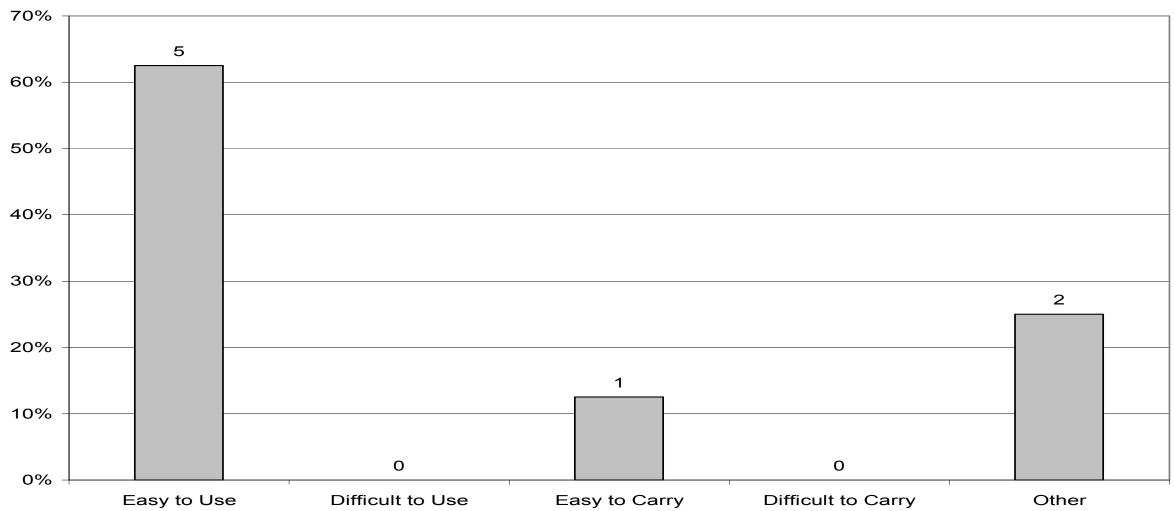
The top reason selected for using both technologies was to improve the data conversion process. Other important reasons for selecting a combination of equipment types include improving data reporting and quality on all types of trips. It is important to note that unit cost (response # 8) was not a top priority when both types of technologies were used. As confirmed in the technology inventory, the higher end units that act as personal communicators with organizer, mobile phone, GPS, digital camera, and other features cost around 200 to 325 GBP per unit.

If respondents used both an electronic user interface and a location logging technology, they were asked to select the more important technology. Of the eight studies that used both technologies, three respondents reported that the electronic user interfaces were more important, four respondents indicated that the study could not have happened without both types of equipment, and one respondent did not answer the question.

2.2 Participant Response to the Technology

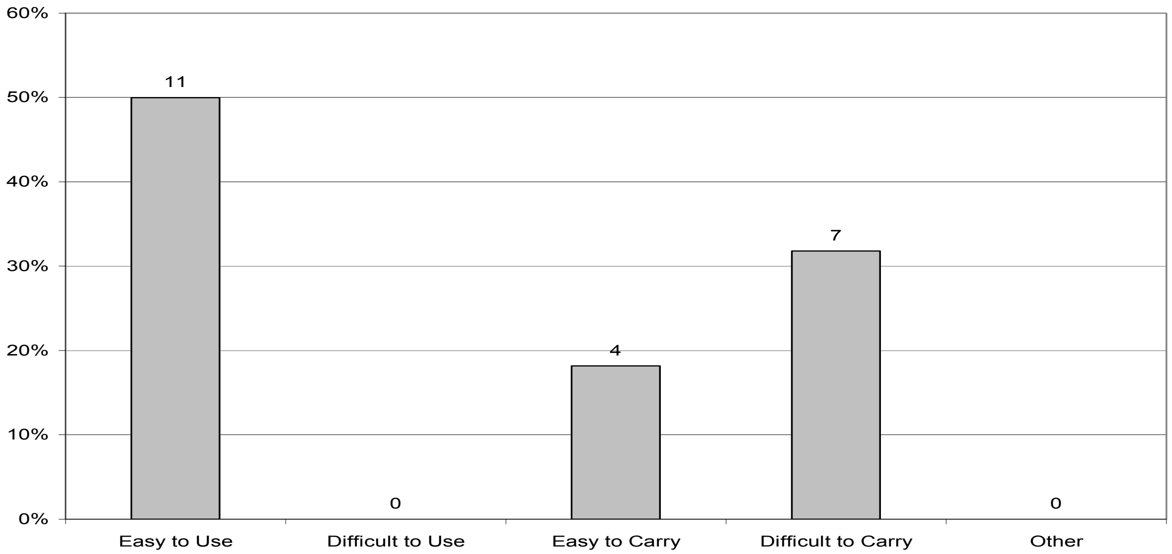
An important factor in selecting the most appropriate technology package was ensuring that the survey participants would have a positive response using the devices. Figures C-3 to C-5 illustrate how the survey professionals rated their participants' responses for each of the technology categories.

Figure C-3: Summary of Participant Response to Electronic User Interface Technology



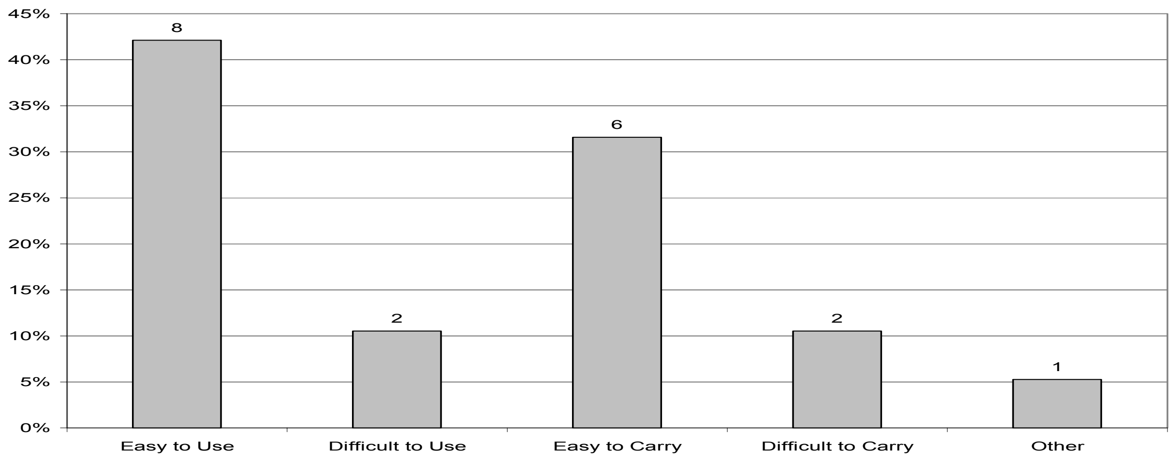
Respondents reported that a majority of study participants found the PDAs and web based surveys easy to use. One major reason for this is that these surveys can be tailored to be simple and straight- forward. As discussed in the technology inventory, complex skip patterns that can be confusing on a paper diary format, are hidden in the software code. An "other" response was that the PDA was not only easy to carry, it was convenient to use at various times of the day.

Figure C-4: Summary of Participant Response to Location Logging Equipment



Eleven responses indicate that the location logging equipment was easy to use and carry. This is not surprising given the passive nature of these instruments. However, a couple respondents indicated that the equipment was difficult to carry. (It should be noted that one respondent, reporting on four studies, noted that the passive GPS equipment was difficult to carry for participants in each study.) This may be due to the fact that participants are required to carry the unit for the duration of the study period -- 1 day to over a week in some cases. One respondent noted that the GPS had a low battery capacity and needed to be recharged often.

Figure C-5: Summary of Participant Response to Using Both Electronic User Interface and Location Logging Technology



The majority of respondents noted that using a combination of technologies was not a problem for participants. Given that the majority of these studies did not use integrated equipment, it is surprising to find that respondents did not feel that study participants had difficulty carrying multiple pieces of equipment. However, the studies using multiple pieces of equipment were, on average, shorter in duration than those that used location logging equipment.

With technology trends moving towards integrated and smaller systems, it will only become easier (although still costly) to deploy participants with passive tracking and active data entry systems that will not be a burden.

2.3 Technology Budgets, Sample Sizes, Costs per Survey Unit, and Days of Data Collection

In order to gain an understanding of the amount of money needed to fund a technology-assisted travel survey, respondents were asked to provide an estimate of the budget allocated for the technical components including items such as equipment, software, training, and data processing. Since this information was provided in various currencies, it has been converted into pounds (GBP) with the assistance of the currency converter located on the www.oanda.com website. The input information for the currency converter included the date that the study commenced, rounded to the first day of the month.

It is important to note that seven respondents left the technology budget question blank. Additionally, one study reported a substantial technology budget with a total amount of 1,524,770 GBP over a six-year period. It is unclear if this amount is actually the technology budget or the total study budget. Figure C-6, shows a graphical, cumulative distribution of the technology budget amounts for the studies in which this information was reported and under 200,000 GBP.

Figure C-6: Cumulative Distribution of Technology Budgets (number of studies with budget not exceeding 200,000 GBP) -

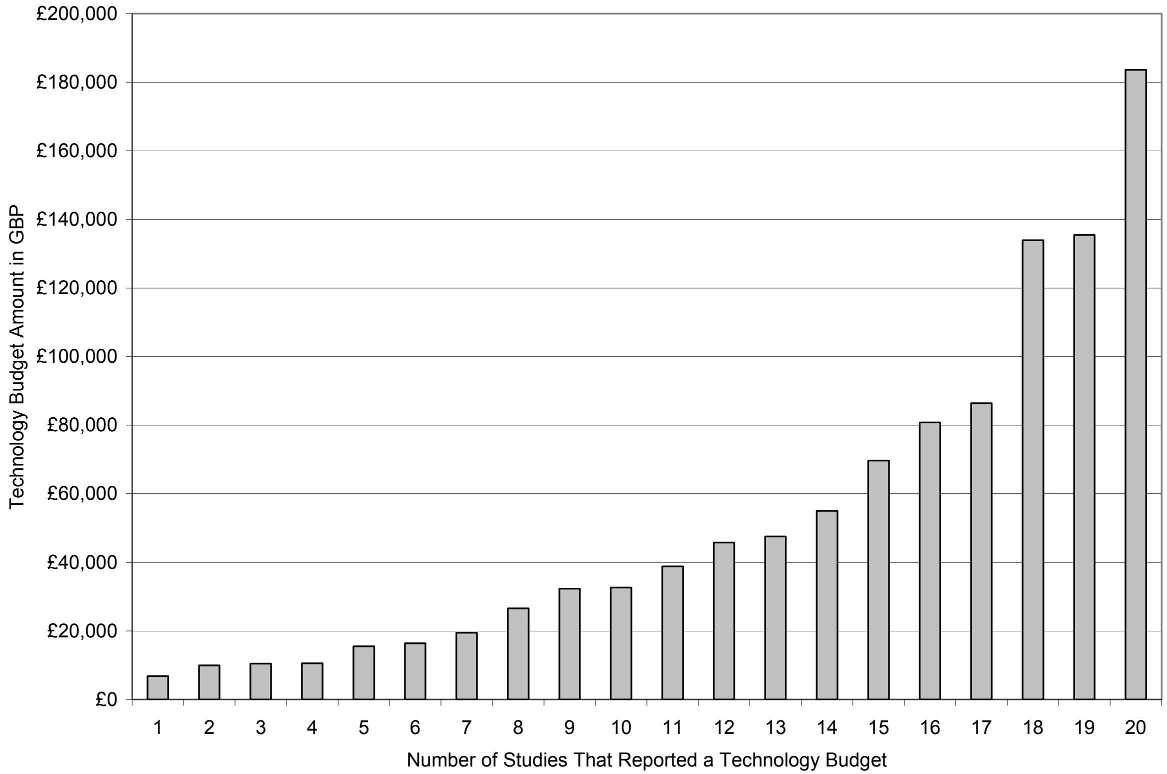


Table C-4 provides descriptive statistical data for the study budgets for each technology category.

Table C-4: Descriptive Statistics of the Technology Budgets by Technology Category for studies with budgets not exceeding 200,000 GBP

Technology Type	Min Budget	Max Budget	Mean Budget	Median Budget
Electronic User Interface	£2,962	£135,510	£56,942	£32,354
Location Logging	£1,350	£183,617	£47,006	£29,608
Electronic User Interface and Location Logging	£987	£86,385	£33,641	£15,503

For the majority of the projects, the technology budget covered items such as software, hardware, survey design, participant recruitment, and data processing.

As shown in Table C-5, the majority of the surveys were conducted at the person level, but a couple of surveys were performed at the household or vehicle level. Table C-6 provides an estimate of the cost per survey unit.

Table C-5: Descriptive Statistics of the Study Sample Sizes

	Sample Size (Person Level Studies)	Sample Size (Household Level Studies)	Sample Size (Vehicle Level Studies)
Min	20	47	50
Max	10,000	21,799	500
Mean	707	3,346	275
Median	120	256	275
number of responses	21	7	2

Table C-6: Descriptive Statistics of the Study Costs for Each Survey Unit (Person or Household)

	Estimated Cost per Survey Unit in GBP (Person Level Studies)	Estimated Cost per Survey Unit in GBP (Household Level Studies)
Min	49	55
Max	1,581	283
Mean	369	169
Median	140	169
number of responses	15	2

No survey costs were reported for vehicle level studies.

Table C-7 provides the number of days for which survey data was collected. Similar to the UK National Transport Survey, a number of these studies reported a week-long data collection period.

Table C-7: Days of Data Collection by Technology Category

Technology Categories	Days of Data Collection	Number of Studies
Electronic User Interface	1 day	2
	7 days	2
	> 7 days	1
Location Logging	1 day	3
	> 1 day, < 7 days	6
	7 days	2
	> 7 days	5
Electronic User Interface and Location Logging	> 1 day, < 7 days	4
	7 days	4

2.4 Recruitment Process

Many of the studies in the assessment used traditional recruiting methods in which home addresses and telephone numbers of prospective participants were obtained from a market research firm or other, ongoing travel studies such as regional household surveys. In some cases, these lists were purchased, and in smaller studies, respondents were recruited by word of mouth and through school or department email lists. One respondent noted that the trouble with email lists is the lack of geographic information associated with the address.

Most respondents noted that a follow up telephone call or interview was scheduled to determine that prospective participants met the demographic, socio-economic, and technology qualifications (i.e. general comfort level with technology, access to the Internet, willingness to carry a device, etc.) for the study.

2.5 Technology Distribution and Collection Methods

Four options were provided for technology distribution methods: mailed out, delivered to home by member of the survey team, picked up by participant, and other. Only one response, “delivered,” was given for a study that used electronic user interfaces. For studies that employed location logging as well as a combination of electronic user interfaces and location logging technologies, over 60% delivered the equipment utilizing staff or courier services to make the delivery. A smaller percentage of studies had participants pick up the equipment. A pick up was required in cases in which in-vehicle GPS technology needed to be installed at a central location, such as an auto garage. In most cases the technology was recovered in the same manner it was distributed.

2.6 Training Method

For the majority of the studies, training was done in a two-stage process. First, a member of the survey team discussed the study details and how to use the technology with each survey participant either in person or over the phone. After this briefing, hard copy or online instructions were given to the participant or mailed to the home address. None of the studies used only the phone or internet to provide training. All studies had some person-to-person training either in person or over the phone.

2.7 Reliability and Accuracy Issues

Numerous respondents selected more than one reliability and accuracy problem that the participants experienced with the technology devices. One responder noted that it was difficult to differentiate between a unit that malfunctioned and a participant who did not carry the unit during the day.

Technology Reliability and Accuracy Issues for Electronic and User Interfaces

Only one respondent reported having difficulty with an electronic user interface. Again this speaks to the fact that a large segment of the international population is computer literate and familiar with PDA and web technology.

Technology Reliability and Accuracy Issues for Location Logging Equipment

Eleven respondents noted that the GPS signal drop was problematic. Eight responses were checked for both missing data caused by malfunction and a participant not carrying the unit throughout the day. An additional three respondents noted that the participant found the unit difficult to use, and one respondent mentioned that respondents did not always wait a sufficient amount of time for the GPS to establish a position fix after a long stay indoors. Furthermore, a respondent commented that it was difficult to differentiate missing data caused by a malfunctioning unit and one that was not carried properly or throughout the entire day.

Technology Reliability and Accuracy Issues for Both Electronic User Interface <u>and</u> Location Logging Technologies

Three responses indicate that GPS signal drop was an issue for participants. It is unclear if the participants were underground or in a dense, urban area (canyon) where it can be difficult for a GPS to hold a positional lock. Two respondents reported that the location logging equipment had missing data due to a malfunction, and two more indicated that the participant did not carry the unit throughout the day.

2.8 Data Processing

Numerous methods of downloading data and converting it from a raw to a usable form were reported; Tables C-8 and C-9 show the responses to the data processing and software / tools portion of the questionnaire.

Table C-8: Download Processes by Technology Category

Technology Category	Download Process
Electronic User Interface	Via cable to a PC (docking station)
	Data stored in an Oracle database server which was connected to the internet via a front-end server
	Answered data was sent to our server PC by the Internet and recorded in a Microsoft Access database
	Automatically from client side program to server side at end of each session
Location Logging	Data was downloaded to a central server via WWAN wireless link
	Serial interface to PC
	By flashcard
	Via cable and specific software including WinStep
	The data was downloaded onto PCs. Checks were made and then the data were put into an Access database with other data, such as that from activity monitors and the diaries
	Downloaded by on-site research assistant
	Deployment team members downloaded data at home to local PC and then posted to the project website
	Downloaded to a laptop and transmitted via the internet to a market research firm after one week
	Data was downloaded to PCs and transmitted over FTP for processing
Electronic User Interface and Location Logging	GPS data was downloaded via bluetooth interface to a stationary PC. Electronic diary data was downloaded via SD-card or cradle/cable to a stationary PC
	GPS data by HTTP and activity diaries by email in 1st survey; GPS data and activity diaries by HTTP in 2nd survey
	Travel diaries and GPS tracking data were transmitted to the server computer by HTTP

Geologger data downloaded by hand. p900/teletype/geostat-battery backpack data was sent via GPRS to project server were it was logged to a database which could be accessed via a web interface

Table C-9: Tools and Software Programs Used in the Data Download Process by Technology Category

Technology Category	Tools and Software Programs Used in the Data Download Process
Electronic User Interface	Microsoft ACCESS database. Software on PDA directly writes data into the database
	Oracle
	ASP (Active Server Page) technology
	Maptitude for the web plus enhanced GIS data created by Geographic Data Technologies. RSG's IVISxi survey generation software - HTML and server-side database queries
	Microsoft ACCESS and various GIS (ARC)programs, but no particular analysis/processing software was requried
Location Logging	TransCad and in-house data conversion programs. Once the GPS devices are retrieved and the data are downloaded, a GIS software package is used to modify and illustrate the trip data. First, a program is run removing all bad data points and creating trip ends where the device is stationary for 120 seconds or more or if the Heading changes direction by 180 degrees within 30 seconds. For the wearable data, additional manual interpretation is needed to identify trip ends. A second program is run that creates route information. This includes origins, destinations, distance travelled, start time, end time, and travel time for each trip for each day of data recorded. Maps are produced that illustrate the routes taken and the trip ends.
	Software that came with GPS units
	Special made software (processing of raw data, map matching, activity detection methods, purpose detection methods) + ArcGIS + SAS + BioGeme
	Standalone programs for download and data processing. Standalone program integrating Mappoint for data validation and visualization
	Custom programs “SPR + Raw Point Filter” used to eliminate clusters of points. “SPR + Mobility Office” used to covert raw points to tracks containing travel info.
	Raw data was downloaded via WinStep and converted from binary format to a *.csv file

	Proprietary Trip Identification and Analysis Software was used to identify trip ends and to match to CATI reported trips for one group of participants and a custom web-based prompted recall system to display processed GPS trips to CATI operators for prompted recall retrieval calls to participants for the second group of participants.
	Custom programs in VB.NET and C were used to import the data into a relational database, to process it into trips and summarize it into "minutes of activity." GPS points were also mapped to a GIS database of trails.
Electronic User Interface and Location Logging	GIS: ARC-Info, Map-Info; Diary Data: Access; SPSS
	PHP (Hypertext Preprocessor), ASP (Active Server Pages)
	ArcGIS, ArcPad
	Software provided by GPS manufacturer plus in-house developed programs. TransCad Interface
	Custom program
	CHASE survey package

APPENDIX D: NTS Travel Data Collection and Processing Overview

Travel Diaries

In the current NTS travel data collection process, diaries are provided to participating households during the initial CAPI (computer-assisted personal interview) session. Interviewers spend a significant amount of time showing participants how to complete the diary, often using journeys made on the previous day by the respondent as an example.

Travel diaries are provided in booklet form and come in two versions – one for adults (aged 16 and older) and one for children (where adults may complete the diary for children who are too young to complete it themselves). The questions in the adult and child versions are nearly identical, with the primary differences centering around age-specific differences such as whether the participant is driving the vehicle (adult only) and time spent playing in the street with friends (child only). Memory joggers are also provided to help participants remember basic details when traveling without their diaries.

Each household participant is asked to complete a one-week travel diary, with journey locations provided based on the name of the village, town, or local area. On the seventh day of the travel diary, respondents are asked to provide full address and postcode details of the origin and destination for each journey.

Checking Travel Record data with households

After the travel week is complete, an NTS interviewer will return to the home to collect and check the diaries, and to administer a short ‘pick-up’ interview. According to Simon Holroyd of NatCen, interviewers will try to review each household’s Travel Records during the Pick-Up Interview and before leaving the household. Whether or not this is possible, the interviewers work through each household’s Travel Records at home before sending them to NatCen's Brentwood office. They look for omissions and discrepancies in the Travel Records. There are some occasions when they can resolve problems using their own local knowledge (such as the charge in the carpark of a particular supermarket) or by using telephone directories to look up missing Day 7 postcodes for commercial properties. If they cannot, they will contact the household. After this review is complete, the Travel Records are forwarded to NatCen.

All Travel Records are then inspected at the NatCen Brentwood office and the staff there will contact interviewers if they identify any further problems. If necessary, the original interviewer will then contact the household concerned. The Brentwood team will give feedback to any interviewers whose Travel Records frequently contain problems and may also pass on this feedback to their supervisor.

Coding CAPI Data and Travel Records

NatCen has a separate, small team of coders who are dedicated to processing the Travel Records. Although interviewers will have checked the Travel Records before returning them to the office, a coding team member will take the hard-copy Travel Records for each household, open them all at the same day's page, and then inspect them for errors, omissions and inconsistencies, not just within Travel Records but also across those of members of the same household. This coder will scrutinise modes, mileages and travel costs against an extensive catalogue of gazetteers, maps, timetables and price information that has been compiled, as well as a series of useful websites. For example, the coding team knows the distances between London tube stations, the parameters for taxi fares across Great Britain, and which roads and bridges do or do not currently attract tolls or other charges.

If the coding team finds any errors or has any queries, they will contact the interviewer who sent the Travel Records and may require them to go back to the household in question to seek clarification. This takes place before the Travel Record data have been entered which makes it easier to go back to respondents quickly. In terms of quality control, it also means that interviewers can be given rapid feedback on the quality of the checks they themselves are carrying out. As a result, most interviewers quickly reach the point where they require very little follow-up.

Diary entry

After these initial checks, diary data are entered into the Diary Entry System (DES) by the coding team. The coding of data items such as journey purpose, origin and destination, method of travel, ticket type, etc. take place as the data are entered into the system. The DES also has a number of subsidiary screens for displaying relevant information to assist data entry, and to enter further data specific to day 7 only. A screen to create journey details as a repeat or a duplicate of another journey is also provided.

An export facility then transforms all the travel record data entered for a wave into text files. This is called the "Quantum Export" as the data is fed into software developed using Quantum. Following the export of the data, the text files are processed outside the NTS Diary system. An edit-checking program is run on the files to conduct a comprehensive set of consistency checks, with a report being produced. The NTS diary system is used to rectify any validation errors reported, and the data are re-exported. When the data are clean, they are delivered to the survey's sponsors, the DfT.

Editing the travel record data

Two extensive sets of checks are run on the travel record data. First, certain checks are applied in the DES as the travel record data were entered. These checks are put in place in order to catch keying errors and implausible or impossible data combinations. The editor either deals with these errors immediately, or if they cannot resolve them, they refer them to an experienced supervisor.

Once the data are entered and coded, a second set of checks is run on the data. These checks look for inconsistencies with the CAPI data (for example a household with no car saying they used their own car for a journey). The CAPI data are checked and, if appropriate, either these or the travel record data are altered.

Geocoding of address data

Up to 2001, the only information recorded on travel diaries about the origin and destination of journeys was the name of the town or village. However, in 2002 and for subsequent survey years, respondents were required to provide more details. For day 7 only, respondents were asked the full address (including the postcode if they knew it) for the origin and destination of their journeys.

This assignment of a postcode to the origin and destination of journeys enables further analysis of the NTS data, as it allows other coding to be applied including ward, urban/rural classification and National Transport Model (NTM) code. An external company - Gatepost Systems – is used to supply and validate postcodes from the locations recorded, using approximations as needed. Where the respondent has not provided full address details, databases using the Postcode Address File (a "complete" listing of all addresses in the UK) are used, supplemented by whatever other data sources are available to resolve ambiguous addresses.

The following table shows the match rates for postcode to exact locations achieved for the 2003 and 2004 NTS geocoding of destination and origin details provided in the day 7 travel diaries.

Address	2003	2004
Origin	88.6%	88.1%
Destination	88.5%	88.3%