Review of the potential role of 'new technologies' in the National Travel Survey:

by

Peter Bonsall[1], Jean Wolf[2] and Simon Holroyd[3]

[1]The Institute for Transport Studies, University of Leeds
[2]GeoStats
[3]National Centre for Social Research

Research project no: UG599

Executive Summary

Introduction

This report summarises a five-month study conducted in response to an invitation to tender for a project to review the potential role of 'new technologies' in the National Travel Survey. It summarises the findings from the project and indicates the Department for Transport's (DfT) immediate plans to act on these conclusions. A separate report (Wolf et al, 2006) provides more detail on the results of the technological review at the heart of the project. http://www.dft.gov.uk/stellent/groups/dft_transstats/documents/page/dft_transstats_614032.pdf.

The brief indicated that DfT wished to commission an investigation of the feasibility of introducing 'new technology' approaches to the collection of travel diary data in the National Travel Survey (NTS) as a supplement the current paper-based diary method. The main aims and objectives of the study were:

- Identifying the extent to which new technologies have the potential to improve the quality of NTS diary data without placing undue burden on respondents;
- Examining the extent to which new technologies may improve the process of converting raw data into analysable form;
- Identifying the likely costs and potential risks of introducing new technologies to the NTS;
- Recommending which, if any, of these new technologies are worth pursuing on the NTS; and
- Suggesting the design of feasibility studies where appropriate.

The work was conducted in 4 work packages:

- 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;
- Work package 2 explored the accuracy and consistency of current methods of estimating trip durations and distances;
- Work package 3 identified which of the technologies should be considered for implementation in the short to medium term; and
- Work package 4 outlined how selected technologies might be trialled.

Key Issues

The project team began their work with a series of discussions with NTS staff from DfT and the National Centre for Social Research (NatCen are the organisation who manage the NTS data collection), and with key NTS customers in order to familiarise themselves with the main issues that were to be taken into consideration when assessing the suitability of candidate technologies. After these discussions, the following list of objectives for, and constraints on, the role of new technologies in the NTS was drawn up and agreed with DfT:

- To maintain a data stream for NTS customers which is in no way inferior to the existing data stream, maintaining comparability and containing all the key items.

- To provide, where possible, solutions to known and emerging problems:
  - under-reporting of trips – particularly short trips or trips regarded by the respondent (wrongly) as unimportant or irrelevant
  - respondent fatigue or under-reporting during the middle/late stages of the diary
  - non-response and/or under-reporting by some respondent types (males, low income, low education, people for whom English is not their first language)
  - problems in identifying the element of walk trips that occur on the public highway
  - problems obtaining an accurate estimate of the length and duration of short trips (for which the problem of rounded estimates is particularly serious)
- To be able, where possible, to serve new customer needs and requirements from inside or outside DfT
- To avoid adding unnecessarily to the cost or administrative complexity of the NTS.
- To be capable of phased implementation (thereby reducing risk).
- To be compatible with any changes to NTS procedures which are being contemplated.
- To comply with all relevant DfT/Government policies.

Work package 1: Review of the Relevant Technologies

Information for the review of relevant technologies was gathered from a variety of sources including:

- An Internet search conducted and followed up by vendor phone calls and emails as necessary.
- A request for information posted on a transport researchers' bulletin board.
- Targeted contact with key individuals and organisations (practitioners, suppliers etc).
- A questionnaire 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.
- A literature review conducted for studies involving the use of technologies in travel / activity surveys.

The main conclusions from the review of relevant technologies, summarised in Table E1, 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 dataset 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 sub sample of NTS respondents.

Table E1: Comparisons of Technology Options for NTS Evaluation Criteria

Evaluation Category	GPS / Mobile Phones	PDA / PC-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	PC-based solutions (online or off line) can be inexpensive PDA costs (equipment and data transmission) are still significant	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 to computer literate 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

Work package 2: Analysis of distance and Duration Data

The analysis of the accuracy and consistency of current methods of estimating trip durations and distances involved comparison of the estimates produced, in the main, by respondents themselves with “objective” estimates calculated in the basis of the reported trip end post codes.

The “respondents’ estimates” of distance are derived from information supplied by respondents on their seventh diary day (but note that, in up to 1/3 of cases, the distance estimates attributed to respondents are the result of assistance from interviewers or insertion/editing during data processing). The respondents’ estimates of duration are deduced from the difference between their reported trip start and finish times (again there will have been some degree of assistance from interviewers and some correction during the editing phase). The objective estimates were variously derived by using MapPoint to calculate trip distances and durations via quickest or shortest road routes and by estimating crow-fly distances. It is not suggested that these "objective" estimates can be regarded as correct, or even as necessarily more accurate than the respondent's estimate, but the comparison is nonetheless revealing.

The main conclusions from this analysis were:

- Although the mean and distribution of respondents' estimates is similar to that of the MapPoint estimates, there is usually a considerable difference between a respondent's estimate of trip length for a particular journey (duration and distance) and the lengths calculated by MapPoint using trip end postcodes for that journey.
- It was not possible to produce any satisfactory explanation (model) for these differences and we therefore conclude that they are due to random or unobserved factors. However, there was a tendency for the differences to be more marked for:
    - short trips,
    - trips to unfamiliar destinations, and
    - estimates attributed to males (although this effect is very weak and is only apparent for car trips).
- The reported duration of trips on foot or by bike bore no clear relationship to durations calculated for those trips using MapPoint (this is probably attributable partly to the fact that the assumptions underlying MapPoint's calculations are less applicable to non-motorised modes).
- At an aggregate level, respondents' estimates of trip lengths in a given database can be explained fairly satisfactorily on the basis of distances calculated from the trip end post codes provided that key characteristics of the journey and the respondent are taken into account.
- The relationships identified appear to be fairly stable over time.

The implications of these findings for the current project are:

- that there is a prima-facie case for having access to more accurate records (such as might be provided by some form of automatic location tracking);
- that most is to be gained, in terms of increased accuracy, by identifying a technology that might be applied to short trips;
- that there is no identifiable subgroup whose accuracies might be particularly improved if they were targeted to receive technologies designed to improve the accuracies of distance or duration estimates; and
- that more would be gained by having access to more accurate data for trips to unfamiliar destinations than for trips to familiar destinations;.

Work package 3: Assessment of the Candidate Technologies

In the assessment phase of the project the following eight criteria, against which the new technology options should be judged, was drawn up and agreed with DfT:

1. <u>Additional accuracy, precision or reliability for relevant data items</u> (we distinguish between (i) improvements due to more accurate recording; (ii) adjustment, or increased

confidence following audit and (iii) the improved weighting that might result from additional data being available – e.g. establishing the representativeness on one week's data).

2. Compliance with NTS policies/objectives (we identify the following sub-issues: (i) maintenance of comparable data streams and interoperability with other systems; (ii) safety in operation; and (iii) privacy/data-protection issues).
3. Minimal risk factors (we identify the following sub issues: (i) equipment malfunction, data loss due to power failure, software viruses etc; (ii) potential loss/theft of equipment; (iii) lack of track record in other travel surveys; and (iv) rapidly evolving technology – i.e., what we test in 2007 may not exist or be supported by 2008 or 2009)
4. Likely acceptability to NTS respondents (we distinguish between (i) ex-ante acceptability to the typical NTS respondent and (ii) ex-post acceptability to the sample of respondents who willingly agreed to accept it).
5. Likely ease of use by NTS respondents (or, more precisely, to those subgroups of respondents who would be using it).
6. Practicality (by which we mean the absence of practical difficulties to be overcome in aspects such as field staff training, logistical issues in equipment delivery, operational integration of mixed survey modes within a household)
7. Access to added value items (e.g. additional data items available "free" as a by-product of using the new technology).
8. Affordability - capital and running costs of equipment and associated software over the medium term.

Ten technology options were identified and assessed against the criteria. They were:

1. Equip a sample of NTS respondents with wearable GPS equipment so as to obtain a separate record of their movements that can be compared with the written diaries to provide an accuracy and completeness audit of current procedures.
2. Ask a sample of NTS respondents for permission to passively monitor their movements during the travel week via their mobile phone. The resulting record to be used to obtain a separate record of their movements that can be compared with the written diaries to provide an audit of current procedures.
3. Equip a sample of NTS respondents with accelerometers (also known as activity monitors) to obtain a separate record of their movements that can be compared with the written diaries to provide an accuracy and completeness audit of current procedures for capturing walk trips and stages.
4. Equip a sample of NTS respondents with pedometers to assist them in estimating the length of their walk trips and stages.
5. Give a sample of NTS respondents the option of recording their data and travel diary via an on-line survey form.
6. Give a sample of NTS respondents the option of recording their data and travel diary via an off-line electronic survey form.
7. Give a sample of NTS respondents the option of recording their data and travel diary via a GPS-enabled PDA (such that the GPS log is collected passively and independently of the travel diary data).
8. Give a sample of NTS respondents the option of recording their data and travel diary via a GPS-enabled PDA (such that the GPS log is used to prompt completion of the diary).

9. Obtain access to data being collected from GPS-equipped private vehicles in order to explore and analyse the importance of the longitudinal dimension of travel data as well as to evaluate the use and/or applicability of that dataset for augmenting or replacing some component or samples of the NTS.
10. Arrange for the vehicles belonging to a sample of NTS respondents to be equipped with GPS equipment so as to obtain a record of their vehicle's movements over an extended time period (possibly several months). The resulting record could then be compared with the respondent's written diary to provide both an audit of current procedures and an indication of what might be gained by adding a longitudinal dimension to the data.

The assessment of these ten candidate applications against the eight criteria is summarised in Table E2.

Conclusions

As a result of this assessment, the project team concluded that:

1. It would be appropriate immediately to proceed with feasibility studies for:
   - ***provision for respondent completion of diaries electronically*** *(a combination of options 5 and 6 above)*, and
   - ***provision of pedometers to prompt improved recall of walk trips*** (option 4 above).

2. It would be appropriate, in the near term, to proceed with feasibility studies for:
   - ***use of wearable GPS for audit*** (option 1 above)***,***
   - ***use of remotely monitored mobile phone for audit*** (option 2 above), and
   - ***a separate longitudinal study of GPS-equipped cars*** (option 9 above).

3. The case for proceeding with the following should be revisited in the medium term:
   - ***use of GPS-enabled PDA for passive logging*** (option 7 above)***,***
   - ***use of GPS-enabled PDA for passive logging or for prompting recall*** (option 8 above)***,***
   - ***equipping a sample of NTS respondents' cars with GPS*** (option 10 above), and .
   - ***use of accelerometers to assist in the recall of walk trips*** (option 3 above).

DfT have indicated their agreement with this ranking and have given preliminary indication of their relevant plans.

Indicative designs for feasibility studies for the applications deemed suitable for immediate or near term implementation are outlined. In each case the objectives of the feasibility study are identified and an indication is given of the issues that should be considered in each stage of the study.

Table E2: Assessment of applications against criteria

Criteria	Applications									
	Wearable GPS for audit	Passive mobile phone for audit	Activity monitor for audit	Pedometer to augment	On-line questionnaire	Off-line questionnaire	GPS enabled PDA for audit	GPS enabled PDA for prompted recall	Longitudinal study of GPS-equipped cars	Equip respondents' cars with GPS
1 (i) Added accuracy inherent in data				*	*	*		***		**
1 (ii) Improvement following audit	***	*	*				**			
1 (iii) Added accuracy via improved weighting									*	**
2 (i) maintenance of data streams	***	***	***	***	***	***	***	***	***	***
2 (ii) safety in operation	***	**	***	***	***	***	**	**	***	***
2 (iii) privacy/data-protection	**	**	***	***	***	***	**	**	**	**
3 (i) low risk of equipment malfunction, or data loss	**	***	***	***	***	***	**	**	***	***
3 (ii) low risk of equipment loss/theft	**	**	**	***	***	***	*	*	***	***
3 (iii) track record	***	*	***	**	***	***	**	**	***	**
3 (iv) low risk of obsolescence	**	***	**	***	***	***	**	**	***	***
4 (i) ex-ante attractiveness to all respondents	*	*	*	***	*	*	*	*	***	**
4 (ii) ex-post acceptability to willing sample	***	***	***	***	***	***	***	***	***	***
5 Ease of use	***	***	***	**	***	***	**	*	***	***
6 Practicality	**	***	**	***	***	***	**	**	***	***
7 Added Value data items	***	**	**	*			**	**	***	***
8 Affordability	*	***	***	***	***	***	*	*	**	*

(*** indicates high score, ** indicates medium score, and * indicates low score)

Contents

1 Introduction

1.1 Background

In February 2006 The Department for Transport (DfT) issued an invitation to tender for Research Project UG599. The Institute for Transport Studies at Leeds University joined with National Centre for Social Research (NatCen) and GeoStats to respond to this invitation and were awarded the contract. Work commenced in April 2006 and was completed in August of that year. This report summarises the findings from the research project and indicates DfT's immediate plans to act on these conclusions. A separate report (Wolf et al, 2006) provides more detail on the results of the technological review which was at the heart of the project. http://www.dft.gov.uk/stellent/groups/dft_transstats/documents/page/dft_transstats_614032.pdf.

1.2 The Brief

The brief indicated that DfT wished to commission an investigation of the feasibility of introducing 'new technology' approaches to the collection of National Travel Survey (NTS) travel diary data as a supplement the current paper-based method. The approaches for consideration were (a) the use of GPS or mobile phone technology and (b) electronic (e.g. PDA) or on-line diaries.

The main aims and objectives of the study were set out as:

- Identifying the extent to which new technologies have the potential to improve the quality of NTS diary data without placing undue burden on respondents;
- Examining the extent to which new technologies may improve the process of converting raw data into analysable form, in terms of speed, efficiency, and accuracy;
- Identifying the likely costs and potential risks of introducing new technologies to the NTS;
- Recommending which, if any, of the 'new technologies' explored are worth pursuing on the NTS; and
- Suggesting the design and estimating the costs of an appropriate feasibility study, if this would be required before full implementation.

The brief envisaged a comprehensive evidence review of the use of 'new technologies' on similar surveys conducted in the UK and internationally, consideration of the feasibility of introducing these technologies in the NTS and an examination of the accuracy of distance data currently collected in the 7^{th} day of the NTS diary.

1.3 The National Travel Survey

The NTS is a high quality voluntary survey of private households. It is the main source of data on personal travel within Great Britain and is a key source of information for interested parties, within and outside government, on how and why different sectors of the population travel, and how this changes over time.

The NTS began as a series of periodic surveys starting in the 1960s but has evolved into a continuous survey involving some 15,000 households per year. The basic data (household characteristics, personal characteristics and one-week travel diaries for all household members) has remained largely unchanged throughout this period but the procedures and details have evolved to reflect changing needs and new technologies. The current procedures involve Computer Assisted Personal Interviewing (CAPI) to obtain household and personal data and the self-completion of travel diary booklets by all household members (aided by use of a memory jogger pad and the assistance of survey staff during a short 'pick-up' interview). More detailed data, including trip lengths, are required for the final (7th) day.

1.4 Technological Developments

Recent years have seen significant technological developments of potential value in travel surveys. Two fields are identified as being of particular relevance; firstly the possibility of automatic logging of person (or vehicle) locations using GPS or mobile phone technology and secondly the possibility of direct entry of data by respondents using computers or PDAs connected to a designated website or using customised software.

Alongside these developments there has been a very significant increase in use of home computers and a majority of households now have internet access. The rising generation are particularly comfortable using the web and mobile phones and interacting with intelligent IT devices. It has been suggested that this generation find it as easy (perhaps even easier) to complete electronic forms than hardcopy forms.

These developments and trends open the prospect of a wide range of new survey methods and, unsurprisingly, the international research community has not been slow to devise new methods and introduce them within experiments. Several research trials and experiments which have sought to test the limits of what it is reasonable to ask a traveller to record via electronic diaries and to explore what can be deduced about travel behaviour by "instrumenting" the traveller. In addition to these academic and research studies, there have been several implementations "for real". 'A number of public sector bodies have sponsored trials or full scale implementations of relevant technologies in the context of travel surveys (e.g. Atlanta 2000/01, the statewide survey conducted in 2001 by the California Department of Transportation (DOT), various regional travel surveys by the Texas DOT in 2002-2006, Kansas City Regional Council 2004, Reno Regional Study 2005, and the Oregon DOT's continuous statewide survey pilot study in 2005). Others have conducted one-off investigations (e.g. in connection with the Swedish road user charging studies).

Technology does not stand still and a number of further developments are already in the pipeline (notably the increased accuracy of GPS to be provided by the new Galileo satellites and the increased up-take of mobile phones which provide web access).

This study takes into account relevant recent developments which are already occurring or are guaranteed in the short term and notes the existence of others, such as the likelihood that "ordinary" mobile phones will have internet access and database management functions.

1.5 The Approach

The work was conducted via four work packages:

1. Review of new technologies
2. Establishment of accuracy of current distance estimates
3. Identification of most promising prospects for NTS
4. Outline design of feasibility studies

The relationship between them, and with a familiarisation phase, is indicated in Figure 1.

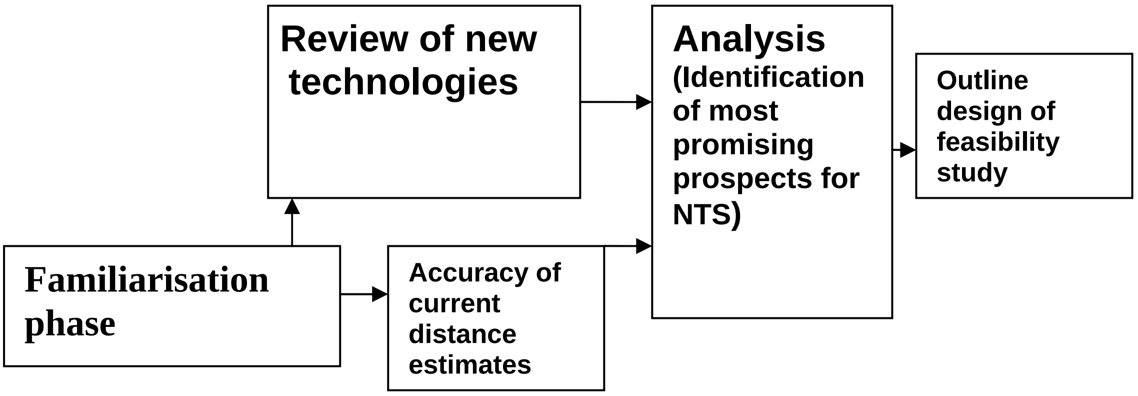


Figure 1: Project Structure

1.6 Familiarisation phase

In order to ensure that the work was relevant and well targeted, the team began by familiarising themselves with the NTS procedures and with the medium term objectives, constraints and options for NTS.

Following discussions with NTS staff at DfT and NatCen (the current contractors undertaking the NTS fieldwork) and with key NTS customers, the following list of objectives for, and constraints on, the role of new technologies in the NTS was drawn up and agreed with DfT:

- To maintain a data stream for NTS customers which is in no way inferior to the existing data stream, maintaining comparability and containing all the key items.
- To provide solutions to known and emerging problems:
  - under-reporting of trips – particularly short trips or trips regarded by the respondent (wrongly) as unimportant or irrelevant
  - respondent fatigue or under-reporting during the middle/late stages of the diary
  - non-response and/or under-reporting by some respondent types (males, low income, low education, people for whom English is not their first language)
  - problems in identifying the element of walk trips that occur on the public highway
  - problems obtaining an accurate estimate of the length and duration of short trips (for which the problem of rounded estimates is particularly serious)
- To be able, where possible, to serve new customer needs and requirements (from inside or outside DfT), such as:
  - increased interest in longitudinal aspects of behaviour and behavioural change
  - increased interest in routes taken (for exposure studies)
- To avoid adding unnecessarily to the cost or administrative complexity of the NTS.
- To be capable of phased implementation (thereby reducing risk).
- To be compatible with possible changes to NTS procedures. For example:
  - consideration has recently been given to dropping the 7th day detail on post codes and/or distance/duration estimates (although it does appear that these will stay for the immediate future);
  - consideration has been given to a revised diary format which takes the destination of one trip as the origin of the next[1].

o To comply with all relevant DfT/Government policies; for example:
  - not wishing to encourage any form of mobile phone usage in vehicles; and
  - fully respecting all relevant legislation with respect to privacy and data protection.

---

[1] This change was considered but the project concluded that such a change should not be made to the diary. The report from the diary review project gives further details.

2 Review of New Technologies

A fuller version of this chapter, complete with appendices, has been produced (Wolf et al, 2006) and is available on the DfT website. The following text summarises all of the key points.

2.1 Introduction and method

The objective of Work Package 1 was to establish an ‘inventory of facts’ regarding new technologies that might be implemented as a supplement to the current paper-based diary method used in the National Travel Survey.

2.1.1 Sources of Information

The inventory of facts was drawn up in the light of the key issues identified in Section 1.6 using the following approaches:

- An Internet search followed by vendor phone calls and emails as necessary to obtain details of products available. 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.
- Request for information posted on a transport researchers’ bulletin board.
- Targeted contact with key individuals and organisations (practitioners, suppliers etc).
- A questionnaire 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 deemed relevant. Data was gathered on 29 studies by this means.
- A literature review conducted for studies involving the use of technologies in travel / activity surveys (again, 2002 was deemed to be the relevant cut off date). Specific references were sought in respect of studies whose existence was known to the study team but for which a questionnaire had not been returned.

The technologies identified in the original brief were the use of GPS or mobile phone technology and the use of electronic diaries. Following discussion with DfT, an additional category, pedometers / accelerometers, was added to this list.

2.1.2 Key issues

For each technology category, a list was drawn up of key issues needing to be explored.
For GPS, mobile phone systems and activity monitors the key issues were identified as:

- The extent of use of these technologies in travel surveys (and other activity based surveys if appropriate), worldwide;
- The scope and purpose of the use of the new technology in each case;
- The specification, capital cost and maintenance costs of equipment and necessary software (noting recent or imminent changes in specification, price trends, evidence of availability of bulk deals, competitiveness of market etc.)[2];
- The ability of the technology to collect the types of travel data currently collected in the NTS diary (based on experience elsewhere and bearing in mind recent or anticipated changes in the equipment specifications);
- Evidence of achievable accuracy (not just manufacturers' claims!) – noting any issues such as coverage, signal loss or degradation, selective availability, urban canyons, underground journeys, the importance of correct configuration settings, and possible differences likely to be made by Galileo (the new European Satellite System – see Section 2.2.1 for more details);
- Evidence of ease of use or respondent burden relative to "conventional" methods (noting problems experienced by particular types of people, particular situations, equipment form factors such as an in-vehicle kit versus a wearable kit);
- Evidence of public response to the new technology – including any impact on response rates or completion rates. Evidence of the relative acceptability of different technologies (e.g. of mobile phones compared to portable GPS equipment) and of any differences in response or attitude between different person types (e.g. reflecting their age, gender, familiarity with internet etc);
- Practical implementation issues (e.g. robustness of device / kit, logistical problems of equipment delivery and return);
- Insurance or legal issues, (privacy, liability, road safety); and
- Risk factors (e.g. equipment or software malfunction, virus attacks) and how to minimise them.

For electronic self-completion diaries the key issues were identified as:

- The extent of use of these methods of data entry in travel surveys (and other activity based surveys if appropriate), worldwide;
- The scope and purpose of the use of these data entry methods;
- Capital and maintenance costs of any equipment and necessary software (also noting price trends, evidence of availability of bulk deals, competitiveness of market etc);
- The ability of such methods to collect the types of travel data currently collected in the NTS diary – with particular emphasis on the extent of complexity that can be supported;
- The reliability and accuracy of travel data collected by these methods;
- Evidence of ease of use or respondent burden relative to "conventional" methods (noting the circumstances in which it is reasonable, and legal, to ask people to use this method of data entry)
- Evidence of public response to this method of data entry – including any impact on response rates or completion rates. Evidence of any differences in response or attitude between different person types (e.g. reflecting their age, gender, familiarity with internet etc);
- Distribution of accessibility to personal computers and to the Internet (for on-line questionnaires);
- Practical implementation issues (e.g. robustness of software and hardware, logistical problems of equipment delivery and return);
- Insurance or legal issues, (e.g. privacy, liability, safety); and
- Risk factors (e.g. equipment or software malfunction, virus attack) and how to minimise them.

2.2 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 2.4, Combined Technologies. We also recognize that there are other location-based technologies such as RFID tags and readers, and

[2] Cost estimates were provided whenever feasible. In cases where costs were dependent upon

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.

2.2.1 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

---

prevailing labour rates or the scope of work for a particular study, the cost drivers have been noted.

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 come to market (a representative sample of these can be seen in the Appendix, Table A-1).

Inventory of Relevant Facts

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

2. 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)

3. 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

4. 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 (computer assisted telephone surveys) for auditing diary/CATI reporting accuracies, although prompted-recall surveys have recently become popular as well. In a research study funded by 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 any national travel surveys. 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[3]. 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 are available in small form factors, although some issues remain with power supply and with respondents remembering to carry the device for all trips.

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.

[3] 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.

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.

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 Table1. 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 (e.g., type and cost of public transport ticket) cannot be obtained from GPS or GIS data. The mode of deployment (wearable or in-vehicle) of the GPS device clearly impacts the ability to capture all trips or trip 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.

Costs Associated with the Technology

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

1. ***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.

2. ***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 2.2.2 on mobile phone data transmission costs.
3. ***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.
4. ***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.

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)	No
Drivers only: where they parked and the cost	Parking location poss ble where could be determined if accurate GIS parcel-level database is available. Cost not poss ble
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

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).

Practical implementation issues

1. ***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.

2. *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.

Risk factors

The following risk factors are identified in the literature:

- 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).

2.2.2 Mobile Phones

Mobile phones are an attractive mode of data collection because of their market penetration (estimated at 84% of the United Kingdom population[4]) 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).

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

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

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 (NCHRP 70-01, 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[5].

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[6], a technology provider firm for mobile phones,

[5] The use of mobile phone data to track participants is currently a hot political topic in the United States, especially with the step-up of government surveillance programs following the terrorist attacks of September 11, 2001. The use of this type of data is currently regulated by The Electronic Communications Privacy Act of 2000. This piece of legislation allows the use of “anonymised” data, which is the main application in congestion monitoring systems; however, individual cell phone tracking, necessary for travel surveys, can only be performed if express consent is obtained from the participants. (http://www.cdt.org/security/000927hr5018.shtml).

[6] Information on the “gpsOne” was obtained at: http://www.cdmatech.com/products/gpsone.jsp.

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.

Table A-2 in the Appendix lists representative mobile phone products – with and without and with GPS functionality.

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

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 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.

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.

Costs Associated with the Technology

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

1. The ***cost of the mobile devices*** – ranging from £50 up to £400, depending on the features desired (see Appendix 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.
2. The ***cost of any custom programming for the mobile phone*** required. These costs are dependent upon current labour rates for programming services.
3. 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. Table A-3 in the Appendix 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.
4. ***Algorithm development*** - to overcome the shortcomings of the data collected. These costs are dependent upon current labour rates for programming and engineering services.
5. ***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 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.

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	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

Practical Implementation Issues

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

1. ***Accuracy -*** Insufficient positional accuracy, unless augmented by GPS, to determine precise trip origins, destinations, or route details;
2. ***Power requirements*** – (if GPS-augmented);

3. ***Data loss*** - due to power or transmission failures;

4. ***Equipment access*** - access to the most advanced technology mobile phones (if the application requires a sophisticated mobile devices that can support custom logging and data transmission);

5. ***Legal/safety issues*** - potential conflict with the DfT policy regarding use of mobile phones in personal vehicles (if the applications requires active input from the respondent).

2.3 Technology Group 2: Computer-Based Self-Completion Diaries

This group of technologies includes online or 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.

2.3.1 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:

1) that the respondent cannot skip or omit fields (i.e., the application can require an entry before allowing the respondent to continue);
2) 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
3) that details of travel previously entered can be 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%[7]), 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.[8] The most common place from which respondents accessed 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.

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 much if other respondents still had the option of using alternative, low technology,

[7] 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.
[8] Source: Individuals accessing the Internet – National Statistics Omnibus Survey.

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 mobility 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) and is currently being enhanced to support self-completion travel surveys in a study to be conducted in Autumn 2006 in Zurich.

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).

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.

Costs Associated with the Technology

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

1. ***Custom survey programming*** - dependent upon prevailing labour rates for programming services
2. ***Survey web-site hosting and response data storage*** - dependent upon size of survey and number of responses collected

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:

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

Practical Implementation Issues

The main implementation issues associated with this technology are:

1. ***Accessibility*** - internet accessibility of the desired sample participants (can be addressed by using a multi-modal approach to survey methods).
2. ***Acceptability*** - the willingness and ability of the target group to enter their own data
3. ***Respondent burden*** - consistency checks that become burdensome to respondents, encouraging underreporting
4. ***Data loss*** - the possibility of data loss or incomplete recording in the event of system malfunction.

5. ***Distribution -*** deployment of web-enabled devices for participants who do not have Internet access

2.3.2 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 Table A-4 contains a range of PDAs on the market today. PDAs have recently converged with mobile phones[9], 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 2.4.

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+

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

[9] 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.

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 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.

Inventory of Facts

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

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.

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.

Costs Associated with the Technology

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

1. ***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.
2. ***Survey software or programming costs*** are dependent upon commercial software rates and/or current labour rates for programming services.
3. ***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.

4. ***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.
5. ***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.

Practical Implementation Issues

1. ***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).

2. ***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.

3. ***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.

4. ***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.

2.4 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

31 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 Tables A-6 and A-7 list examples of integrated PDA/GPS and of GPS devices for PDAs, respectively. The main potential 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.

2.5 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[10]. 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 Tables A-8 and A-9 list examples of accelerometers and pedometers, respectively.

[10] 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).

2.6 Use of Commercial Databases on Person Movements

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

In the past several years, applications of GPS technologies in markets such as in-vehicle navigation, stolen-vehicle-alert services, vehicle fleet monitoring and mileage-based insurance products, are 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 / safety 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, 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.

2.7 Summary and Conclusions

2.7.1 Summary of Findings

Table 5 provides a summary of technology categories and evaluation criteria responses discussed in detail in the previous sections.

Table 5: Comparisons of Technology Options for NTS Evaluation Criteria

Evaluation Category	GPS / Mobile Phones	PDA / PC-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	PC-based solutions (online or off line) can be inexpensive 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

2.7.2 Conclusions

Our main conclusions are as follows:

1. 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 diaries.
2. 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 have memory / storage limitations as well.
3. 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
4. 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.
5. New hybrid / merging technology devices such as smart phones show considerable promise, but are still in their infancy.
6. 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.
7. 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.
8. 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.
9. 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.
10. 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

11. 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.

3 Establishment of accuracy of current estimates of trip distance and duration

3.1 Purpose of the analysis

Among the key potential benefits of GPS or mobile phone technology is more accurate recording of trip distances and durations. However, in order to conclude whether this accuracy would represent a real improvement over the existing method (whereby distances are derived from respondents' estimates of distance for trips made on the seventh diary day and durations are deduced from the difference between stated trip start and finish times) it is necessary to seek to quantify the level of error in the existing estimates[11].

Our assessment of the accuracy of the current procedures seeks to establish the accuracy of the estimates currently produced and thus to conclude whether, *prima facie*, there is a case for using new technology in an attempt to improve on the existing procedures. We also seek to establish whether, if there appears to be any error, it is associated with particular groups of respondents (defined by their socio-economic characteristics or trip patterns) or particular types of trip (e.g. by particular modes, of particular lengths or frequencies, for particular purposes or in particular types of area) –thus indicating which types of respondent or trip are most in need of assistance, technological or otherwise, in producing their estimates.

Our assessment also seeks to comment on the suggestion that the NTS respondents' estimates of distance should be dispensed with and replaced by distance estimates computed directly from trip end post codes.

3.2 Method used

A full description of our analysis can be found in Cronberg and Bonsall (2006). The main points are, however, fully covered in this current paper. {Taj - can we add a link to the report]

The analysis involves comparison of the respondents' estimate of trip length and duration with a more objective estimate. In the absence of any knowledge of the true distance or

[11] Under the current procedures respondents are asked to provide length estimates for all trips they make. In up to 1/3 of cases the trip length estimate in the NTS database have had some input from interviewers or office staff during the data editing process. Our analysis should thus be interpreted as relating to trip length estimates produced by current NTS procedures rather than respondent

duration of any trip we have used objective estimates of the trip length calculated on the basis of the trip-end post codes reported for the trip in question. Three estimates of distance were available by this means; an estimate by the MapPoint software based on the quickest route by car, an estimate by the MapPoint software based on the shortest route by car, and the crow-fly distance calculated directly from the post code co-ordinates.

We recognise, of course, that the respondent's estimate of trip distance *should* differ from the software's computed distance for a minimum-time-by-car route for those journeys on which the respondent did not follow the minimum-time-by-car route. This is particularly likely to be the case for many bus and coach journeys (where services do not generally follow the routes which would be quickest by car) as well as for a proportion of other journeys (e.g. cycle journeys avoiding busy roads, car journeys avoiding motorways). It is therefore more appropriate to describe the difference between the respondent's estimate and the MapPoint estimate simply as a "difference" rather than as an error.

Two estimates of trip duration were available from the MapPoint software; an estimate based on the quickest route by car, and an estimate based on the shortest route by car (in each case assuming free-flowing traffic conditions). These estimates of duration may be appropriate for car journeys but, given the lower speeds generally achieved by modes such as walking, cycling and frequently-stopping buses, are likely to have limited relevance for non-car journeys.

In order to provide an overview of the data, we first present and compare indicative statistics on the values of indicators derived from different sources. We then use linear regression models to explore the data in more detail.

The initial analysis included:

- comparison of the distributions of distance estimates attributed to respondents with those calculated by MapPoint;
- comparison of the mean values of the different estimates and of the differences between these means.
- investigation, at the level of the individual trips, of the difference between the respondent's estimate and that produced by MapPoint for the same trip.

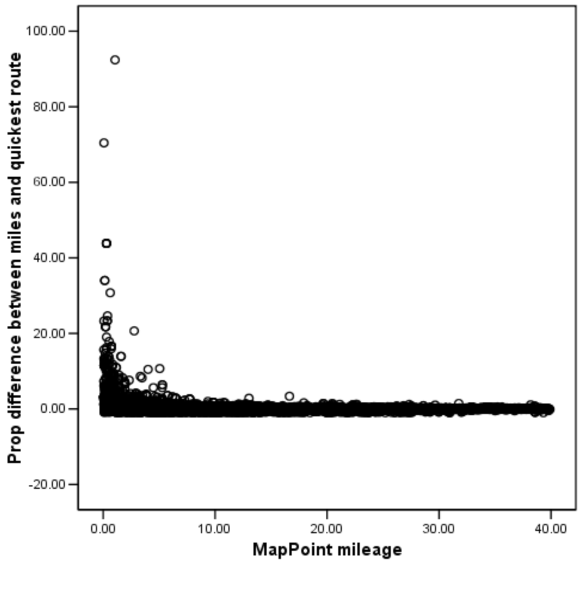
---

estimates per se (although, in the interests of economy of phraseology, we will usually refer to them simply as "respondents' estimates").

The regression models were of two types; the first sought to explain the difference between the respondent's estimate and that produced by MapPoint for the same trip (the dependent variable being the proportionate difference between the two estimates), the second sought to explain the respondent's estimate as a function of the MapPoint estimate (the respondent's estimate being the dependent variable and MapPoint estimate being one of the independent variables). In each case we explored the extent to which the models could be improved by the addition of independent variables describing the respondent or the journey (e.g. the respondent's age, gender or employment status, the journey purpose or type of destination).

Separate models were estimated for each main mode of transport (car, other motorised, bike and walk). Separate models were produced for trips whose length fell below 0.8 miles and the rest. This cut off point was suggested by a discontinuity in the shape of the distribution of the relationship between the respondent's estimate and the MapPoint estimate (see for example Figure 2). This discontinuity is at about 0.8 miles and the relationships above and below this point can be approximated by a straight line – thus allowing us to use linear regression rather than a more complex formulation.

Figure 2. Relationship between the proportionate difference and MapPoint mileage for journeys by car (2002-03)



Our approach involved building models using data from 2002 and 2003 (combined) and then testing their robustness by comparing them with identical models built using the 2004 data.

3.3 Results from preliminary inspection

Comparison of the distribution of respondents' estimates (Figure 3) with that of the MapPoint quickest road route estimate (Figure 4) indicates an overall similarity. The means of the two distributions are similar (6.24 and 6.21 respectively) as are the standard deviations (16.75 and 16. 36 respectively). However, the uneven distribution apparent in Figure 3 suggests that many respondents' estimates have been rounded to whole miles or multiples of 5 miles.

Figure 3. Distribution of respondents' estimates of journey distance (All eligible journeys, 2002-03) (distribution truncated at 40 miles)

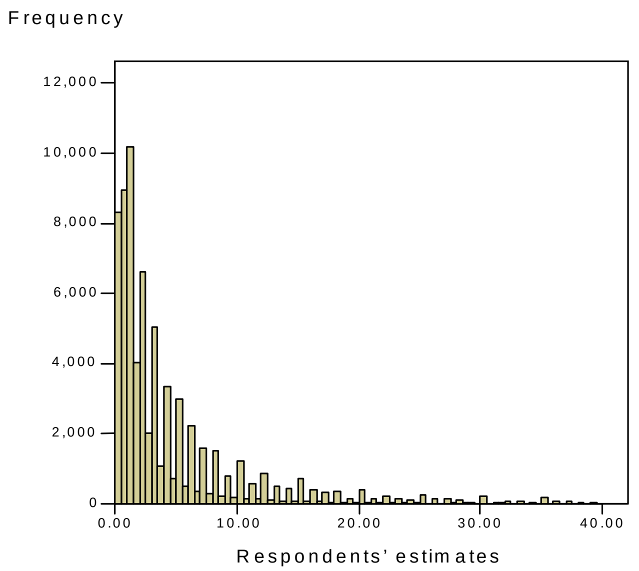


Figure 4. Distribution of journey distances, based on MapPoint calculation of quickest route (All eligible journeys, 2002-03) (distribution truncated at 40 miles)

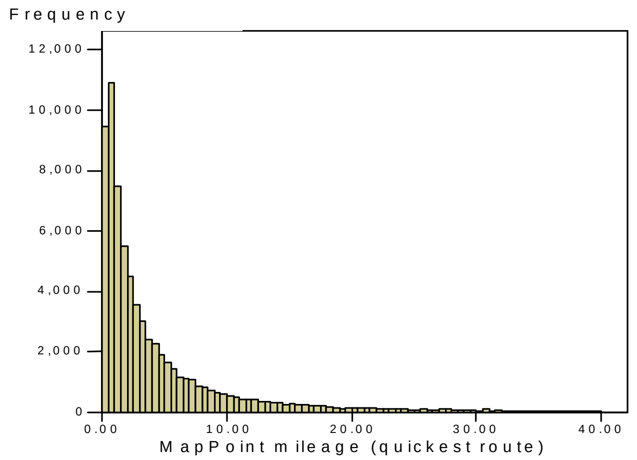


Table 6 summarises a comparison of the mean values of the distances estimated by respondents with the mean values calculated on the basis of the trip end post codes (a fuller version of the table is presented in Cronberg and Bonsall, 2006). This comparison suggests, *inter alia*, that:

- overall, there is a remarkable match between the means of the respondents' estimate and of the MapPoint quickest route estimate;
- the match between respondents' estimate and MapPoint quickest route is better for car trips than for any other mode;
- the match with MapPoint quickest routes is less good for short trips;
- for walk trips, the crow-fly distance gives a better match than any of the road routes;
- for bike trips, the MapPoint shortest route gives the best match;
- the mean of the respondents' estimates are generally higher than those produced by MapPoint and, to an even greater extent, than the crow fly distance. The main exceptions to this rule are walk trips, bike trips, and short car trips (for each of which the mean respondents' estimate is lower than the MapPoint shortest route);
- the respondents' estimates for multi stage trips exceed the MapPoint estimates by an even greater degree, and this is even more marked for 3-stage trips than for 2-stage trips (an unsurprising result because multi stage trips are rarely direct).

Table 6: Summary statistics relating to lengths of trips in the 2002/3 data set

	Mean value (miles)				**Ratio**		
	1. Respondent's estimate	2. MapPoint time (quickest)	3. MapPoint time (shortest)	4. Crowfly distance	1/2	1/3	1/4
Single stage trips:							
All single stage trips	6.23	6.24	5.62	4.49	1.00	1.11	1.39
Trips by car	8.31	8.22	7.40	5.96	1.01	1.12	1.39
Trips by bike	1.96	2.32	2.11	1.54	0.84	0.93	1.27
Trips by foot	0.65	1.00	0.91	0.60	0.65	0.71	1.08
Other motorised	7.26	6.93	6.23	4.99	1.05	1.17	1.45
Trips as car driver	8.13	8.03	7.21	5.80	1.01	1.13	1.40
Trips as car passenger	8.65	8.59	7.76	6.27	1.01	1.11	1.38
Car trips to familiar destinations	9.56	9.41	8.48	6.89	1.02	1.13	1.39
Car trips to rural destinations	11.15	11.38	10.23	6.24	0.98	1.09	1.79
Car trips of under 3 miles	1.73	2.15	1.99	1.43	0.80	0.87	1.21
Car trips by males	9.35	9.25	8.31	6.73	1.01	1.13	1.39
Car trips by females	7.37	7.30	6.59	5.28	1.01	1.12	1.40
Multi stage trips							
All 2 stage trips	11.64	11.24	10.25	8.47	1.04	1.14	1.37
All 3 stage trips	19.77	18.98	17.31	14.63	1.04	1.14	1.35

Table 7 summarises a comparison of the mean values of the durations estimated by respondents with the mean values calculated on the basis of the trip end post codes (again, a fuller version of the table is presented in Cronberg and Bonsall, 2006). This comparison suggests, *inter alia*, that:

- overall, there is a remarkable match between the means of the respondents' estimate and of the MapPoint shortest route estimate (for car trips, however, the MapPoint quickest route provides as close a match as the MapPoint shortest route and, for many car journeys – including those to rural destinations, trips by males or by people under 50, the MapPoint quickest route provides the best match);
- the match between means of the respondents' estimates and the MapPoint estimates seems to vary with the type of trip to a greater extent for durations than for distances;
- the match between the respondents' estimates and the MapPoint estimates is better for car trips than for any other mode (a not unexpected finding given that MapPoint's estimates of duration are intended to relate to car journeys);
- for car trips, the match with MapPoint shortest routes is less good for short trips;
- the means of the respondents estimates of duration generally fall between the two means produced by MapPoint (shortest route and quickest route). The exceptions to this rule are walk trips, bike trips and multi-stage trips (for each of which the mean respondents' estimate is considerably above either of the MapPoint estimates) – again this is not an unexpected result given that MapPoint's estimates of duration are intended to relate to car journeys);
- among multi-stage trips, the respondents' estimates of duration exceed the MapPoint estimates by a particularly large margin for trips involving a bus journey.

Table 7: Summary statistics relating to duration of trips in the 2002/3 data set

	Mean value (minutes)			Ratio	
	1. Respondent's estimate	2. MapPoint time (quickest)	3. MapPoint time (shortest)	1/2	1/3
Single stage trips					
All single stage trips	19.16	13.65	19.25	1.40	1.00
Trips by car	19.80	16.94	24.25	1.17	0.82
Trips by bike	15.94	7.93	10.33	2.01	1.54
Trips by foot	14.87	4.59	5.65	3.24	2.63
Bus and coach trips	27.52	15.71	21.97	1.75	1.25
Trips as car driver	19.48	16.73	24.08	1.16	0.81
Trips as car passenger	20.39	17.31	24.53	1.18	0.83
Car trips to familiar destinations	21.27	18.37	26.44	1.16	0.80
Car trips to rural destinations	22.59	21.69	30.76	1.04	0.73
Car trips of under 3 miles	7.39	7.34	9.07	1.01	0.81
Car trips by males	21.14	18.43	26.56	1.15	0.80
Car trips by females	18.60	15.59	22.17	1.19	0.84
Multistage trips					
All 2 stage trips	44.02	21.00	30.78	2.10	1.43
All 3 stage trips	64.16	32.48	47.35	1.98	1.36

Table 8 shows the proportion of trips, where the respondent's estimate is within 10% and 20% of the estimate predicted for that trip by MapPoint.

Table 8: Proportion of trips where the respondent's estimate is within 10% and 20% of the estimate predicted for that trip by MapPoint (quickest route except for bike and foot where MP shortest route was used)

	Distance		**Duration**	
	Within 10% of MP estimate	**Within 20% of MP estimate**	**Within 10% of MP estimate**	**Within 20% of MP estimate**
All trips	26.8	44.9	11.1	22.7
Trips by car	32.5	53.2	14.3	29.3
Trips by bike	18.3	33.3	10.7	20.2
Trips by foot	12.8	24.6	2.9	5.9
Other motorised	24.3	42.1	10.4	21.7
Trips as car driver	33.8	54.7	14.2	29.2
Trips as car passenger	30.3	50.3	14.5	29.6
Car trips to familiar destinations	34.4	55.3	14.5	29.5
Car trips to rural destinations	38.1	59.7	12.5	26.5
Car trips by males	33.5	54.5	14.0	28.8
Car trips by females	31.6	51.9	14.5	29.8

It is evident that, overall, about 27% of distance estimates fall within 10% of the MapPoint estimate for that trip, and about 45% fall within 20% of it. The results for car trips are marginally better (at 32.5% and 53.2% respectively) while those for trips on foot are rather worse (at 12.8% and 24.6% respectively. It is, of course, important to recognise that the walk trips, in particular, will include short trips for which a small absolute difference could easily show up as a greater than 20% difference (e.g. a difference of ¼ mile in a one mile journey, which might be attributable to rounding, would show as a 25% difference).

Unsurprisingly, the overall result for duration estimates is substantially poorer - with 11.1% of duration estimates falling within 10% of the MapPoint estimate for that trip, and 22.7% falling within 20% of it. Again, the results for car trips are better (at 14.3% and 29.3% respectively) while those for trips by foot only achieve 2.9 and 5.9% respectively. The very poor result for walk trips is probably associated with the unsuitability of the MapPoint estimate for that type of trip.

Summarising this section; we have established that although, at an aggregate level, the mean values of the respondents' estimates match those derived from the trip-end post codes quite closely, there is usually a considerable difference between an individual respondent's estimate for a specific journey and the estimate derived from the trip end post codes reported for that journey.

3.4 Results from the regression models of difference

None of the models of difference were able to provide much explanation of the difference between the respondent's estimate and the map Point calculation for trip distance or duration (R square values were typically less that 0.1) – though the models for duration gave slightly better explanation than those for distance and the models for short trips tended to give slightly more explanation than those for long trips. The only independent variables to add significantly to the explanation were:

- the dummy variables relating to trip length - which suggested, unsurprisingly, that the proportionate difference decreased with trip length;
- the familiarity of the destination (deduced from the journey purpose using a categorisation to indicate whether the trip is likely to be made on a regular basis) – which suggested, again unsurprisingly, that the difference is reduced for familiar destinations;
- gender – with a slight tendency, in some of the distance models for the proportionate difference to be less when the respondent was female (only evident for car trips 0.86 miles or longer and for bike trips under 0.8 miles).

The coefficients which emerge when the best of the models built on the 2002/3 database are applied to the 2004 database are similar, but not identical, to those found in the 2002/3 database. We cannot therefore report that the explanations are absolutely constant over time but can report that they appear to be fairly stable.

3.5 Results from the regression models of respondent's estimates

Generally speaking, it proved possible to produce tolerably good explanations of the respondent's estimates using the MapPoint calculation along with variables describing the respondent and their journey.

The degree of fit between distances reported by respondents and distances calculated using the trip-end postcodes varies according to the characteristics of the traveller and the journey they are making.

The models providing the greatest level of explanation (r^2 in the region of 0.95) are those for those for distance of journeys by car and other motorised vehicles. Models of journey duration, and of distances for walk and bike journeys are rather less good (r^2 in the region of 0.3). The variables adding most explanation were the “objective” estimate derived from the trip end post codes, the MapPoint trip length quartile (reflecting the fact that the underlying model is only piecewise linear), the destination purpose (a categorisation to indicate whether the trip is likely to be made on a regular basis) and the respondent’s gender. Of the various “objective” estimates, the MapPoint calculation for the quickest road route generally offered most explanation but the crow-fly route was more useful for some walk and bike trips.

3.6 Implications of our results

These findings not only have important implications for the current project but also have some wider implications.

3.6.1 Implications for the Technology project

Firstly, given the generally good match between the mean estimate provided by MapPoint and by respondents, it appears that current procedures are producing an overall estimate of trip distance which is probably fairly accurate. Note, however, that this degree of match is only achieved at some cost in terms of interviewer time in providing assistance and office staff time to correct initial estimates. Note also that, as was anticipated, the match is less good for non car modes. If this degree of overall match with MapPoint estimates (which, it must be recalled, are only a proxy for the true trip lengths) is regarded as satisfactory, there would appear to be little to be gained <u>at the aggregate level</u> by employing technology to produce more accurate trip length data.

Secondly, given the significant and largely unpredictable differences between the estimates provided for the same trip by MapPoint and by respondents (even with the assistance of interviewers and a degree of correction at the editing stage), there is prima-facie evidence of significant and un-correctable error in individual estimates of trip distance. This suggests that <u>at the level of individual trips</u>, much might be gained by employing technology to produce more accurate trip length data.

Thirdly, given the particularly significant differences associated with short trips, most is to be gained in terms of increased accuracy if a technology can be found to address the inaccuracies in the recording of short trips. (note however that an alternative, low-technology approach would be to seek to overcome the problem caused by rounding of estimates – for instance by making sure that the “example” of a completed record steers clear of rounded numbers or multiples of 5 or 10 minutes or miles).

Fourthly, given the particularly significant differences associated with trips to unfamiliar destinations, most is to be gained, in terms of increased accuracy, if a technology can be found to address the inaccuracies in the recording of those trips

Finally, given that no identifiable subgroup is yielding estimates that are notably worse than those of the population at large, there would be no reason (if increased accuracy were the only criterion) to focus deployment of technological solutions on any particular group of respondents.

3.6.2 Wider Implications

The success of the models of respondents’ estimates of distance suggests that, for the purpose of estimating aggregate mileages (e.g. for accident exposure studies), there is little to be gained by retaining the question which seeks the respondent’s estimate of trip mileage <u>in addition to</u> the questions on trip-end post codes. (Equally, one might have said there is little point in retaining the post code questions in addition to the journey length questions - but we assume that, given the other potential uses of post code data (e.g. to facilitate links to GIs or land use data), the post codes are more likely to be retained).

Notwithstanding the general comment just made, the relationship between actual distances or durations and traveller’s estimates of them is itself an interesting topic and should be of particular relevance in the following contexts:

- if distance-based road charges are under consideration (how well would travellers be able to estimate such charges – and, would they get better at it if/when such charges were introduced?
- in trying to understand traveller’s perception of congestion and delay (how accurately do people perceive delays, journey times or speeds?)

If, in future, it becomes possible to access respondents’ original estimates of distance (prior to any “correction” or editing by survey staff), we see considerable value in a more detailed analysis of the relationship of these estimates to objective estimates of the distance by different types of respondent on different types of journey. Such an analysis is clearly beyond the scope of the current project but might yield

1. valuable insights about travellers' perceptions and thus contribute to improved understanding of traveler behaviour, and
2. useful information on how to target any effort to improve on existing NTS procedures – for example, if it became apparent that the raw estimates by a particular group of respondents were particularly unreliable (and that this had been masked by their having been "corrected" at some cost in terms of staff time during the pick-up interview or editing process), then the need for a more efficient solution might be established.

4 Analysis

Work package 3 comprised four tasks:

- to identify options for use of "new technologies" within NTS
- to establish the criteria against which new technology options should be judged
- to critically assess each of the applications identified as prima-facie-desirable
- to conclude which, if any, of the applications are worth pursuing and indicate the steps to be taken.

4.1 Options for use of "new technologies" within NTS

Given the evidence (from work package 1) on the performance of the new technologies in different contexts, the medium term objectives, constraints and options for NTS (see section 1.6) and evidence on the performance of current procedures (from work package 2), the following were identified as prima-facie-desirable applications of the new technologies in NTS:

1. Equip a sample of NTS respondents with **wearable GPS equipment** so as to obtain a separate record of their movements that can be compared with the written diaries to provide an accuracy and completeness audit of current procedures.
2. Ask a sample of NTS respondents for permission to passively monitor their movements during the travel week via their **mobile phone.** The resulting record to be used to obtain a separate record of their movements that can be compared with the written diaries to provide an audit of current procedures.
3. Equip a sample of NTS respondents with **accelerometers** (also known as activity monitors) to obtain a separate record of their movements that can be compared with the written diaries to provide an accuracy and completeness audit of current procedures for capturing walk trips and stages.
4. Equip a sample of NTS respondents with **pedometers** to assist them in estimating the length of their walk trips and stages.
5. Give a sample of NTS respondents the option of recording their data and travel diary via an **on-line survey form**.
6. Give a sample of NTS respondents the option of recording their data and travel diary via an **off-line electronic survey form**.
7. Give a sample of NTS respondents the option of recording their data and travel diary via a **GPS-enabled PDA for passive recording** (such that the GPS log is collected passively and independently of the travel diary data).

8. Give a sample of NTS respondents the option of recording their data and travel diary via a **GPS-enabled PDA for prompted recall** (such that the GPS log is used to prompt completion of the diary).
9. Obtain access to data being collected from **GPS-equipped private vehicles** in order to explore and analyse the importance of the longitudinal dimension of travel data as well as to evaluate the use and/or applicability of that dataset for augmenting or replacing some component or samples of the NTS.
10. Arrange for the **vehicles belonging to a sample of NTS respondents to be equipped with GPS equipment** so as to obtain a record of their vehicle's movements over an extended time period (possibly several months). The resulting record could then be compared with the respondent's written diary to provide both an audit of current procedures and an indication of what might be gained by adding a longitudinal dimension to the data.

4.2 Criteria against which the new technology options should be judged

A list of criteria against which the new technology options should be judged was drawn up in consultation with DfT. The list, ordered in descending order of importance, is as follows:

1. **Additional accuracy, precision or reliability for relevant data items** (we distinguish between (i) improvements due to more accurate recording; (ii) adjustment, or increased confidence following audit and (iii) the improved weighting that might result from additional data being available – e.g. establishing the representativeness on one week's data).
2. **Compliance with NTS policies/objectives** (we identify the following sub-issues: (i) maintenance of comparable data streams and interoperability with other systems; (ii) safety in operation; and (iii) privacy/data-protection issues).
3. **Minimal risk factors** (we identify the following sub issues: (i) equipment malfunction, data loss due to power failure, software viruses etc; (ii) potential loss/theft of equipment; (iii) lack of track record in other travel surveys; and (iv) rapidly evolving technology – i.e., what we test in 2007 may not exist or be supported by 2008 or 2009)
4. **Likely acceptability to NTS respondents** (we distinguish between (i) ex-ante acceptability to the typical NTS respondent and (ii) ex-post acceptability to the sample of respondents who willingly agreed to accept it).
5. **Likely ease of use by NTS respondents** (or, more precisely, to those subgroups of respondents who would be using it).

6. **Practicality** (by which we mean the absence of practical difficulties to be overcome in aspects such as field staff training, logistical issues in equipment delivery, operational integration of mixed survey modes within a household)
7. **Access to added value data items** (e.g. additional data items available "free" as a by-product of using the new technology).
8. **Affordability** - capital and running costs of equipment and associated software over the medium term.

4.3 Critical assessment of the applications identified as prima-facie-desirable

Each of the 10 applications identified in Section 4.1 was assessed against each of the 8 criteria listed in section 4.2. The result is presented in Table 9. The assessments are expressed on a scale of 1 to 10, with 10 being the best. Note that each score line is independent and it would not be appropriate simply to sum the scores in each column to identify the "best" overall score. Note also that there is inevitably a large measure of subjective judgement about some of the scores. For example, in the context of criterion 7, it is difficult to compare the value of data on routes taken by the respondent on all journeys (as would be provided by a wearable GPS) with that of longitudinal data on routes traversed by the respondent's vehicle (as would be available if the vehicle were equipped and logged over a period of time).

4.4 Conclusion as to what action, if any, should be taken on each of the identified applications

Based on the findings from work packages 1 and 2 and the critical assessment summarised in Table 9, recommendations can be made on which applications should immediately proceed to a feasibility study, which show great promise in the near term (and should be considered soon), and which should be revisited in the medium term.

Table 9: Assessment of applications against criteria

Criteria	Applications									
	Wearable GPS for audit	Passive mobile phone for audit	Activity monitor for audit	Pedometer to augment	On-line questionnaire	Off-line questionnaire	GPS enabled PDA for audit	GPS enabled PDA for prompted recall	Longitudinal study of GPS-equipped cars	Equip respondents' cars with GPS
1 (i) Added accuracy inherent in data				4[12]	2[13]	2[12]		9		6
1 (ii) Improvement following audit	*8*	*4*	*4*				*7*			
1 (iii) Added accuracy via improved weighting									*4*	*5*
2 (i) maintenance of data streams	10	10	10	9[14]	10	10	10	9[13]	10	10
2 (ii) safety in operation	8	7	8	9	10	10	7	7	10	10
2 (iii) privacy/data-protection	7	6[15]	9	10	9	10	7	7	7	7
3 (i) low risk of equipment malfunction, or data loss	7	8	8	9	9	8	6	5	10	9
3 (ii) low risk of equipment loss/theft	6	5	5	10	10	10	3	3	10	8
3 (iii) track record	9	3	8	7	9	9	7	6	9	7
3 (iv) low risk of obsolescence	7	8	7	8	9	9	6	6	9	9
4 (i) ex-ante attractiveness[16] to all respondents	4	3	4	9	3	3	3	2	10	5
4 (ii) ex-post acceptability to willing sample	8	9	8	9	9	9	9	8	10	9
5 Ease of use	8	9	8	7[17]	8	8	6	4[16]	10	9
6 Practicality	7	9[18]	7	9	9[19]	8[18]	6	6	10	9[20]
7 Added Value data items	8[21]	6	5	3			7[20]	7[20]	8[20]	8[20]
8 Affordability	4	8[22]	4	9	9	8	3	3	7[23]	3

[12] Assumes that respondents record more of their walk trips – and more accurately
[13] Marginal improvement attributable to automatic error checking, branching, and fill-in for repeat trips
[14] Possible risk that novelty results in additional walk trips
[15] Potential for bad publicity (even though would only be done with full consent) most marked for phones
[16] Most of these technologies are likely to appeal only to a minority of respondents (thus only applicable with a sub sample. Since participation would be voluntary, a low score against this criterion need not matter)
[17] Training required?
[18] Assumes network providers are tracking phone locations without having to load software into the phone, also assumes respondent already has a mobile phone on the requisite network
[19] Assumes that Offer is restricted to respondents with compatible equipment
[20] Some hassle to get car to dealer to be equipped with GPS (but this could be dealt with by an outside agent)
[21] GPS data provides second-by-second speeds, locations, and routes; this is most reliable with passive, wearable units.
[22] Assumes respondent already has a mobile phone on the requisite network

4.4.1 Immediate feasibility study recommended

We conclude that some of the applications studied during this project have the potential to contribute to the continuing improvement of NTS procedures and that the extent of this potential improvement, and of the costs of achieving it, could be established quite quickly through a feasibility study. The applications falling into this category are:

1. **Online electronic diary**. This is by far the easiest technology to implement and support, with manageable costs and the ever-increasing market penetration of broadband access.
2. **Offline electronic diary.** This can complement the online survey for respondents who do not have convenient broadband assess during their survey week. The interface could be similar if not identical to the online survey.
3. **Use of pedometer to assist recording of walk trips.** This augment to the existing NTS could be introduced immediately and/or in tandem with the online / offline surveys. It is important that when offered initially, no incentive (verbal or otherwise) is made to get the respondents to walk more often as this would impact the travel survey results (it is possible that ongoing health promotion campaigns might cause people to associate pedometers with increased walking).

4.4.2 Further investigation recommended in the near term

We conclude that a further group of applications have the potential to contribute to the continuing improvement of NTS procedures but that, for various reasons, they are not yet quite ready to be tested. We suggest that feasibility studies for this group should be planned in the near term. The applications falling into this group are:

1. **Wearable GPS for audit.** The relevant technologies continue to advance. A reliable, cost-effective off-the-shelf device with sufficient power and storage capacity for the NTS should be available within a year or so. Experience with wearable GPS in travel surveys is expected to increase and a further review of the state of the art would be worthwhile in 1-2 years time.
2. **Separate longitudinal study of GPS-equipped cars**. Data on the movements of personal vehicles is already being collected in large quantities across the UK and the number of cars so equipped is growing rapidly. The characteristics of the drivers of the first tranche of equipped vehicles may be atypical but it is anticipated that, with growing numbers, it will soon be possible to find a fairly representative sample. It is recommended

[23] Assumes cost of equipment is covered by primary service provider; cost to DfT is for use of data

that negotiations be opened with the owners of such databases with a view to conducting statistical analyses to explore the value of the additional information obtained by moving from a one week log to logs of progressively greater lengths (such analysis would inform the representativeness of the current one week NTS diary). We would expect the data to be ready to support this analysis within a year.

3. **Passive mobile phone for audit.** Although this mode of tracking has great promise, network providers need to demonstrate that they can provide a reliable and affordable system to providing user traces. Accuracy and privacy may emerge as issues. It is recommended that network suppliers (or the specialist agencies which offer phone-tracking services) should be invited to offer a demonstration and quote a cost for a limited trial. If this is convincing, a trial more extensive trial could be mounted within a year or two.

4.4.3 Reconsideration recommended in the medium term

We conclude that, although the remainder of the applications identified in Table 9 have the potential to contribute to the continuing improvement of NTS procedures, there are good reasons for delaying their further consideration. We suggest that these applications should be revisited in the medium term. The applications falling into this group are:

1. **Equip respondents' cars with GPS.** If the longitudinal study of GPS-equipped cars described above, indicates that longer term data from GPS-equipped cars is of sufficient value, a next step might be to consider equipping the cars of a sample of NTS respondents in advance of their diary week and then obtaining longitudinal data on these people's car use. Note that this option would incur a significant cost (probably in the region of £350 per car) so would only be appropriate if the additional information is thought to warrant that expense. This would make it possible to explore, within a "normal" NTS sample, the added value of longitudinal car use data as an add-on to the normal NTS one week diary.
2. **GPS-enabled PDA for audit**. A few small-scale pilot studies suggesting that this technology combination may prove to work well but that some significant practical issues remain to be fully resolved. It is recommended that this technology be reassessed in 2-3 years time.
3. **GPS-enabled PDA for prompted recall**. Considerable possibilities would be opened up by use of such devices as a replacement for the traditional face-to-face interview method. However, given the unresolved practical issues involved (see above) this option

can not be recommended for NTS in the near term. It is recommended that this technology be reassessed in 2-3 years time.

4. **Activity monitor to audit.** The recent reductions in cost of this technology bring it into contention as a potential audit tool for the National Travel Survey. However, it is not yet known whether the devices can distinguish between walking, cycling and other forms of exercise with sufficient precision or whether the distance estimates are sufficiently reliable. We expect that these questions will be answered in due course through research being conducted elsewhere and that DfT should arrange for any new evidence to be reviewed in a few years time.

5 Outline of Feasibility Studies

An outline is now presented of the issues that should feature in a feasibility study for each of the applications identified in the previous section as suitable for immediate or near term application. Those recommended for immediate implementation are described in more detail than the others but, in each case we identify what we see to be the precise objectives of the study and provide an outline of procedures that could be adopted.

Most of the applications described here involve use of the technology by volunteer respondents. This overcomes the potential acceptability problems but raises the question as to whether any improvement in data quality (e.g. more complete trip records, more accurate trip distances or durations) which becomes apparent among the volunteers can be taken as indicative of the scale of improvement that could be expected among the rest of the respondents and whether any global adjustment might be justified. An important and overarching issue to be addressed in all the feasibility studies outlined here is therefore the representativeness of the results.

5.1 Electronic Diary Trial (Online and offline surveys)

Objectives:

- To establish the costs and benefits of allowing respondents to choose to enter their diary data electronically (on-line or off-line) during the survey week – (the completed diary then being made available to the interviewer when they visit to collect all household members' diaries).
- To establish the costs of administration
- To establish the extent of any saving in field staff time
- To establish the implications for data completeness and quality (and whether this varies with respondent characteristics). In particular to discover whether use of an electronic diary with automatic logic checks and branching results in better quality data
- To conclude on the most appropriate procedures and logistics
- To establish the level of willingness to complete electronic diaries and how this varies according to respondent characteristics. In particular to discover whether the offer of electronic diary makes some people more willing to provide travel record data
- To recommend whether to proceed to full-scale implementation

Outline of procedures:

(1) Preliminary phase:

- Gather info from ongoing NTS sample on:
  - whether would have been interested in participating using offline software
  - whether would have been interested in participating using online software
  - type/functionality of and/or access to computer, internet connection etc.
- Analyse data to determine sampling strategy, software specification etc.
- Develop specification for software. One of the key issues would be to determine the appropriate extent of logic checks (there is a balance to be struck between building in checks which are sufficiently thorough to save costs later in the data-cleaning process, and checks which are so thorough as to be perceived by respondents as frustratingly obstructive and which may as a result impact negatively on response rates). Another key issue would be to ensure that data is produced in a format equivalent to that produced by the "standard" interview process, allowing the existing procedures of checking by interview staff and office staff to be conducted as normal[24]
- Develop a methodology for handling mixed survey mode responses within a household (including consideration of the implications, if any, for the conditions under which a household receives its incentive vouchers).
- Decide whether to continue with trial

(2) Pre-Trial phase

- Programme software for online and offline survey for individual diary data (off line software might comprise that subset of the online software which does not require access to remote data).
- Prepare instructions for respondents and for interviewers (close working with NTS/ NatCen staff will clearly be required)
- Pre-test instructions, procedures and software with a extra sample of 10 to 20 households recruited as if for NTS but being asked to use the electronic mode of data recording (possible break point in project)
- Revise software as necessary
- Train interviewers

(3) Trial phase

- Oversample up to 400 households using normal NTS criteria. (Oversampling is recommended to protect the base sample in the event of an unforeseen problem. The idea would be that the households containing individuals who opted for the electronic mode of completion could, in extremis, be omitted from the 'main' NTS sample. The aim would be to recruit 200 individuals for the online version and 200 individuals for the offline version. If some households yield more than one volunteer the total number of households required in the 'extra' sample will be reduced accordingly - the level and distribution of interest expressed during the pre-trial phase should allow the extent of this 'extra' sample to be estimated)

- Offer the option to individuals or households until quota is reached (other individuals in the household being processed as normal)[25].
- include debriefing questions to check that electronically recorded record is accurate (and ask what they thought of the process, suggestions for improvements etc).

(4) Analysis/Reporting Phase

- Compare records of online, offline (corrected and uncorrected) and matched samples who used normal methods
- Analyse results of debrief interviews (and particularly any corrections required at that stage)
- Conclude on costs, procedures, response rates (item and unit non-response) and achieved accuracies
- Make recommendations as to the permanent adoption of the electronic diary option and on the possibility of the concept being extended such that the resulting records no longer have to be checked by the interview staff[26].

5.2 Pedometers for prompting improved recall of walk trips

Objectives:

- To establish the costs and benefits of providing respondents with pedometers to assist in their recollection and recording of walk trips.
- To establish the costs of reliable equipment (noting recent publicity suggesting that some cheaper models are not reliable).
- To establish the costs of administration.

---

[24] This includes, for example, a requirement for a hard copy image in the same format as the existing diary, compatibility with interviewers' computers and the possibility of viewing the completed file on the interviewers computer.

[25] The cost of briefing NTS interviewers about the electronic diary option could be minimised if the trial were restricted to interviews being conducted by a subset of interview staff. This would, of course, lengthen the trial period. Alternatively, if the interviewer training were to coincide with the annual training exercise (in December each year) it would be possible to brief interview staff en-masse and then offer the electronic option to all respondents until the quota is achieved.

[26] Although such an extension might be seen as streamlining the procedures, it could reduce the interviewer's ability to maximise household data quality by comparing records of different household members and could result in the loss of a valuable check on data quality.

- To establish the implications for data completeness and quality (and whether this varies with respondent characteristics) – particular issues would include:
  - assessing evidence of more compete recall of walk trips
  - assessing evidence of more accurate estimation of walk trip distances over the complete week and for individual trips
  - assess the extent to which issuing pedometers may encourage additional walking (and whether the effect persists into the third week)
- To establish the level of willingness to use pedometers and how this varies according to respondent characteristics
- To conclude on the most appropriate procedures (e.g. to conclude whether it is feasible to ask respondents to use the pedometer to record individual trips – or simply a weekly total, and whether the pedometers should be offered to respondents as an incentive/reward)
- To recommend whether to proceed to full-scale implementation

Outline of procedures

(1) Preliminary phase

- Review information on pedometer/activity monitor costs and specifications (simple or capability to store multiple trips with time base….) (note this would have been done in our WP 1 if pedometers had been in the brief!)
- Gather information from ongoing NTS sample on:
  - whether would have been willing to use Pedometer during survey period
  - what incentive, if any they would think appropriate (or, would they use the pedometer for the week-long survey if they could keep it afterwards?)
  - their prior familiarity with pedometers and their calibration
  - would passion of a pedometer encourage them to walk more?
- Analyse results to determine:
  - sampling strategy (and whether there seems to be sufficient interest from representative subgroups)
  - whether deployment should occur for an entire household or just one individual per household
  - whether the pedometer should be left with the respondent as a reward/ incentive (cost implications of this)
- Decide on procedures:
  - should pedometer be calibrated for the respondent during the initial visit and/or should pedometer record be retained for interviewer to inspect/analyse?

- should respondents report a cumulative total (by week or by day) or should we ask the respondent to reset after each walk trip and to report for all walk trips throughout the week (perhaps being provided with a special form to facilitate this)?
- should respondents be asked to "test" the pedometer by wearing it for a couple of weeks in advance of the survey week (eg in the period following the placement interview) in order to get any novelty effect out of the system?
- should specific instructions be provided about not making extra trips during survey week?
- should respondents should be instructed to use the DfT-provided pedometer rather than one they might already own (for quality control reasons) even if their own is superior and they know how to use it?.
- what minimum age should apply? It might not be appropriate to ask young children to wear a pedometer (they might lose it, they might forget to wear it, or they might hurt themselves if they fall on it) and their general level of activity might give a false impression of the amount of walking they do. For example, it would be difficult to distinguish walking from playing and might be unrealistic to instruct them only to wear their pedometer when walking.
- should interviewers use data from pedometer-equipped respondents to refine the estimates provided by un-equipped respondents in the same household?
- what debriefing questions should be asked (to help interviewer to interpret pedometer record, to probe on how pedometer was used and by whom, to check that procedures worked OK and were acceptable, to ascertain whether respondents think that use of pedometers prompted more accurate recording, or whether they prompted additional trips, and whether they have any suggestions for improvements)?
- what training/briefing should be provided for interviewers (and when/where/how should this be effected?)

- Decide whether to proceed with trial

(2) Pre-trial phase

- Obtain pedometers
- Prepare instructions for respondents and interviewers
- Train interviewers
- test procedures with 20 households
- Decide whether to proceed with full trial

(3) Trial phase

- Oversample using normal NTS criteria. Oversampling is recommended to protect the base sample in the event of an unforeseen problem such as evidence of increased trip making. The idea would be that the households containing individuals who used a pedometer could, in extremis, be omitted from the 'main' NTS sample. The aim would be to recruit 400 individual participants thus the maximum oversampling required would be 400 households but since one would usually expect more than one volunteer per household, it might be significantly less than this – evidence from the pre-trial phase would allow this to be estimated).
- Offer the option to individuals until quota is reached, (treating the rest of the household as normal).

(4) Analysis/reporting Phase

- Compare records from individuals who were equipped pedometers with those from a matched sample of normal respondents.
- Compare records from individuals who were equipped pedometers two weeks in advance with those who got them at start of survey week (to test for trip generation effect)
- Analyse qualitative results of debrief interviews
- Conclude on costs – noting for example that a permanent stock of up to 4,500 pedometers would be required to service the NTS sample
- Conclude on the success of the procedures
- Conclude on impact on data completeness and quality.
- Make recommendations concerning the more widespread use of pedometers and, if there is any evidence of increased accuracy, for the scale of adjustment needed to correct past data.

5.3 Wearable GPS for audit

Objectives:

- To establish the costs and benefits of equipping a sample of respondents with wearable GPS in order to conduct an audit of their travel record.
- To establish the level of respondents' willingness to wear GPS for the purpose of audit and to complete any necessary procedures (e.g. charging). To establish how this varies according to respondent characteristics and whether any incentive or reward might be required.

- To establish whether respondents can be relied on to complete the necessary procedures (e.g. charging, remembering to wear the unit at all times) and to establish how this varies according to respondent characteristics.
- To demonstrate how the resulting record can be used to audit the respondent's travel record.
- To identify and establish the costs of reliable equipment.
- To conclude whether an ongoing GPS-based audit should be conducted and if so at what scale.
- To conclude whether an ongoing GPS-based audit could be conducted by NTS contractors or whether an outside agency should be involved (and if so which agencies might be considered)
- To establish the indicative costs of an ongoing GPS-based audit.
- To recommend whether to proceed to full-scale implementation

Outline of procedures

(1) Pre-trial phase

- Gather information from ongoing NTS sample on:
  - whether would have been willing to wear GPS for survey period
  - whether would be able or willing to recharge unit as necessary
  - what incentive, if any they would think appropriate(?)
- Analyse results to determine:
  - sampling strategy (and whether sufficient interest from representative subgroups)
  - whether any additional incentive or reward required
  - procedure for recharging
- Decide on procedures. For example:
  - is it necessary to have all members of a given household being monitored? (probably not)
  - how and when should equipment be delivered and recovered?
  - what training is required for interviewers and for respondents?
- Devise procedures for the auditing process (including specification of data formats, reporting interval etc)
- Prepare instructions for interviewers and respondents
- pre-test procedures with 20 individuals (possible break point if significant problems emerge)

(2) Trial phase

- Oversampling is recommended to protect the base sample in the event of an unforeseen problem such as evidence of an unwanted impact on trip making behaviour. The idea would be that the households containing individuals who used a wearable GPS could, in extremis, be omitted from the 'main' NTS sample. The aim would be to recruit 200 individual participants thus the maximum oversampling required would be 200 households but since one would usually expect more than one volunteer per household, it might be significantly less than this – evidence from the pre-trial phase would allow this to be estimated).
- Offer the option to individuals until quota is reached, (treating the rest of the household as normal).
- Include debriefing questions to check that procedures worked OK and ask what they thought of the procedure, suggestions for improvements etc.

(3) Analysis/reporting Phase

- Compare records from GPS unit with that from normal diary from the same individuals
- Conclude on usefulness of the resulting data
- Analyse results of debrief interviews
- Conclude on likely costs,
- Conclude on appropriate procedures and sampling method
- Make recommendations.

5.4 Longitudinal study of GPS-equipped cars

Objectives:

- To establish the possibility, and likely cost, of using existing datasets on the movements of GPS-equipped cars to establish the representativeness of a single recording week (in the context of the record of trips made over a longer period such as a year)
- To explore the feasibility, and likely cost, of using data from GPS-equipped cars owned by NTS respondents to establish (for the population as a whole and for specified subgroups within it):
    - the extent of any revealed under-reporting of car trips during the recording week
    - the accuracy of reported trip timings and durations during the recording week
    - the accuracy of reported trip start and finish locations during the recording week
- To gauge the level of interest among NTS customers in data on:

- changes in car-based travel behaviours within a household over time (ie, longitudinal analysis)
- variability of car-based travel behaviours within a household over time
- data on routes taken on car trips
- improved accuracy of location, distance, and duration data for car trips.

Outline of procedures

(1) Preliminary phase

- Establish the relevant dataset owners and the data items they hold (including data on the drivers)
- Draw up a specification analysis required to establish representativeness of a single week within progressively longer periods
- Draw up a specification for data required from dataset owners (accuracy, recording frequency, permissions obtained, format/presentation)
- Obtain costs for access to required data – alternatively, if access to raw data is problematic, for completed analysis
- Decide on data supplier and who should do the analysis
- Establish the most appropriate procedure (in terms of cost and feasibility) for obtaining records from GPS-equipped cars which can be matched with NTS diary records for those car drivers (e.g. whether to equip the cars of a sample of NTS respondents prior to their diary week, or whether to approach a sample of drivers whose cars are already GPS-equipped seeking to include them in the NTS sample).

(2) Analysis phase (perhaps undertaken by data set owner)

- Analysis to demonstrate, for selected sub-groups of the population, the representativeness or otherwise of a single week within progressively longer periods

(3) Demonstration Phase

- Obtain /prepare (raw and needing processing, or pre-processed by data supplier) examples of the kind of data which could be provided to NTS customers
- Seek customers' response to the possible availability of such data

(4) Report results

- Conclude on costs and feasibility of using existing datasets on the movements of GPS-equipped cars to establish the representativeness of a single recording week
- Conclude on the feasibility of obtaining data from GPS-equipped vehicles which can be matched with data from NTS diaries (in order to audit the accuracy and completeness of the NTS diary data)

- Conclude on the level of interest among NTS customers in data which provides more detail/ more accuracy and/or a longitudinal dimension.
- Make recommendations.

5.5 Remotely monitored Mobile phone for audit

Objectives:

- To establish the costs and benefits of obtaining a log of movements of a sample of NTS respondents in order to conduct an audit of their travel record.
- To establish the level of respondents' willingness to have their movements monitored for the purpose of audit and how this varies according to respondent characteristics and whether any incentive or reward might be required.
- To establish whether respondents can be relied on to keep their phone with them at all times and turned on (and whether this varies according to respondent characteristics).
- To establish whether the resulting record can usefully be used to audit the respondent's travel record
- To establish whether the respondent's own phone can be used, and if not, to establish the costs of appropriate models to be loaned out.
- To conclude whether an ongoing mobile-phone-based audit should be conducted and at what scale (and if so which agencies might be considered as potential suppliers of the data)
- To establish the indicative costs of an ongoing mobile-phone-based audit.
- To recommend whether to proceed to full-scale implementation

Outline of procedures

(1) Pre-trial phase

- Prepare specification for data required (frequency of report, format of data, accuracy of location, size of sample)
- Obtain firm cost and claimed accuracy from selected suppliers
- Select one or more suppliers to provide the data
- Gather info from ongoing NTS sample on:
    - whether would have been prepared to have their location monitored via their own phone (and to put up with implications on restricted phone use, recharging and any other procedures needed) during the survey period

- whether would have been prepared to have their location monitored via a supplied phone (and to put up with implications for recharging and any other procedures needed) during the survey period
- what type of phone and network supplier they have
- what incentive, if any they would think appropriate(?)

- Analyse results to determine sampling strategy (and whether sufficient interest from representative subgroups)
- Decide on approach (own phone v. supplied phone - depending on costs from network providers, preparedness to use own phone etc)
- Prepare instructions and procedures

(2) Trial phase

- Offer individuals in the normal NTS sample the option of having their movements monitored until a quota (approx 200) is reached..
- Obtain necessary permissions, provide instructions to respondents, provide suppliers with the nominated phone numbers and recording period.
- Include debriefing questions to check that procedures worked OK and ask what they thought of the procedure, suggestions for improvements etc.
- Obtain the records, in agreed format, from the suppliers

(3) Analysis/reporting Phase

- Compare records from monitored phones with that from normal diary from the same individuals
- Conclude on usefulness of the resulting data
- Analyse results of debrief interviews
- Conclude on likely costs
- Conclude on appropriate procedures and sampling method
- Make recommendations.

6 DfT Response to recommendations

This research project was commissioned by the Department for Transport to investigate the feasibility of introducing 'new technology' approaches to the collection of travel diary data in the National Travel Survey, in order to supplement the current paper-based diary method. The approaches for consideration were the use of GPS or mobile phone technology for tracking individuals and/or vehicles and the use of electronic/on-line diary completion.

This report sets out the results of the comprehensive review undertaken by the research team commissioned to undertake the project. It identifies to what extent various new technologies have the potential to improve the quality of NTS diary data; identifies the likely costs and potential risks of introducing new technologies to the NTS; and provides recommendations on the forms of technology that are worth pursuing further, both in the short and medium term.

The Department agrees with the assessment made by the research team of the various technologies considered. The Department's intentions with regard to taking forward the recommendations of the study are detailed below.

Immediate

Online Survey/Offline Survey - The Department intends to commission a feasibility study to develop the tools for online/offline diary completion; to identify the likely take-up rate by respondents and practical implementation issues; and to fully test the procedures in a pilot exercise.

Pedometer - The Department is interested in the potential use of pedometers to improve data collected on walks and will take forward discussions with the main NTS contractor (National Centre for Social Research) to assess likely benefits and to identify practical implementation issues.

Near Term

Wearable GPS for audit - The Department agrees that this approach offers much promise for validating and augmenting NTS diary information, although implementation will be dependent on the further development of reliable, cost-effective devices with sufficient storage and power capacities. The Department will review the availability of devices during 2007/2008 before making a final decision on taking this forward.

Separate longitudinal study of GPS cars - The Department agrees that data collected on personal vehicle movements provides a valuable data source. It is likely that data collected through the Department's future traffic monitoring contracts will be utilised to improve our understanding of personal travel patterns.

Passive mobile phone for audit - The Department agrees that further investigation is required to assess whether mobile phones can provide sufficiently accurate data to meet the needs of the NTS. This will be examined alongside the review of wearable GPS monitors planned for 2007/08.

Later Consideration

GPS-enabled PDA for audit and **GPS-enabled PDA for prompted recall -** The Department agrees that these technologies may have the potential to enhance NTS data in the future but as yet are not sufficiently developed or tested to offer a short to medium term option. The Department's planned review of wearable GPS monitors planned for 2007/08 will examine to what extent these other GPS/mobile phone technologies have developed since the current review.

Equip respondents' cars with GPS - The Department does not propose taking this option forward at present, while the use of data on vehicle movements from other sources is being explored.

Activity monitor for audit - The Department does not propose pursuing this option at present, while the more cost effective pedometer approach is considered. However, if the cost of activity monitors continues to fall the Department will re-consider their use.

Acknowledgements

The authors of this report are pleased to have this opportunity to acknowledge the contributions of their colleagues to the completion of this report. In particular they would like to thank Alexandra Cronberg for her work on the analysis of trip distance and duration data, and Marcelo Oliveira, Lauren Leary and Michelle Lee for their work on the technology review. The authors also most particularly want to thank the NTS team at DfT (Barbara Noble, Tracey Budd and Olivia Christophersen) for their encouragement and guidance. Thanks are also due to the numerous other individuals who assisted us in this study by providing details, variously, of their use of NTS data or their experience with the new technologies. Particular thanks in this regard are due to Dorothy Salathiel, Russell Harris, and Lucy Yu.

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.

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?)

Cronberg, A and Bonsall P (2006) "Analysis of the accuracy of NTS respondents' estimates of trip distance and duration". Technical annex 1 of Research Project UG599 (Review of the Potential Role of 'New Technologies' in the National Travel Survey), Department for Transport, London

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).

Wolf, J., Bonsall, P., Oliveira, M., Leary, L. and Lee, M. (2006). "Review of relevant technologies" Report on work package 1 of Research Project UG599 (Review of the Potential Role of 'New Technologies' in the National Travel Survey), Department for Transport, London .

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.

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 Entreprise 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