

## Assessing the accuracy of the Sydney Household Travel Survey with GPS

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**Abstract** Over the past few years, GPS has been used in a number of surveys in the US to assess the accuracy of household travel surveys. The results have been somewhat alarming in that most of these exercises have shown that the standard trip-based CATI survey conducted in the US under-reports travel by about 20–25%. It was decided to use GPS to assess the accuracy of the Sydney Household Travel Survey, a continuous survey conducted by face-to-face interviewing. The procedure used was for the interviewers to recruit households for the household travel survey in the normal manner, and then, if the household met certain criteria, to endeavour to recruit the household to also undertake a GPS survey. A small sample of about 50 households was obtained, and GPS devices successfully retrieved that measured data on the same day as the travel diary was completed. In addition, participants in the GPS survey completed a prompted recall survey a week or two later, using maps and tabulations of travel obtained from the GPS devices, to identify mode, purpose and occupancy for trips measured by the GPS, and also to check for accuracy in defining trip ends and total number of trips. Based on the analysis of the GPS compared to the diary results, it was found that respondents under-reported their travel by about 7%, which is much less than in the US CATI results. Respondents were also found to under-report travel distances and over-report travel times. There was also a high incidence of non-reporting for VKT.

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Both Camden FitzGerald and Min Xu were at the Institute of Transport and Logistics Studies at the time this work was undertaken.

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## Introduction

Most household travel surveys rely on some form of self-reporting by respondents about the travel that they undertake during the survey period. There have been many changes in the way in which household travel surveys are conducted over the past 40 or 50 years, whether surveys are conducted as retrospective or prospective, and are undertaken by post, face-to-face interview, telephone interview, or Internet, or some combination of these. Ultimately, however, they all rely on the ability of people to report accurately the number of trips they make, the origin and destination addresses of their trips, the time at which each trip was made, and often the duration of the trip both in time and distance (Stopher 2004). Unfortunately, people are notoriously poor at providing accurate reports of any of this information. Transport planners have been well aware of the inaccuracies of such reporting for some time. However, it has only been with the recent advent of practicable Global Positioning System (GPS) devices that can be used by survey respondents, that a fairly accurate idea could be obtained as to the actual levels of error associated with these self-report surveys.

It would also seem reasonable to postulate that self-administered surveys (by mail and Internet) might suffer from the greatest problems of underreporting, because there is no interviewer to intervene in the recall process and prompt the respondent to think more carefully. Further, we could also speculate that telephone interviewer surveys might be less accurate than face-to-face surveys, and that the extent of the experience of the interviewers in this type of survey might have further effects. However, in using GPS devices as a method to check the validity of self-report surveys, experience to date has been restricted almost entirely to evaluating telephone interviewer surveys (Wolf et al. 2003, 2004; Zmud and Wolf 2003; Forrest and Pearson 2005; Wolf 2006). In this paper, we report on what we believe is the first instance of using a GPS survey to validate a face-to-face interview survey. In this case, the household travel survey is the Sydney Continuous Household Travel Survey, and validation with GPS devices took place in the first half of 2004, and was commissioned by the NSW Roads and Traffic Authority (RTA). The objective of the study was to collect GPS data that can be used to provide information about underreporting of travel activities in face-to-face household travel surveys. Each year the survey covers approximately 5,000 households in Greater Metropolitan Sydney. The data gathered from these surveys is used to assist transport planners and has been and is being used to re-estimate the Sydney Strategic Travel Model. Subjects are issued a 1-day place-based travel diary and are aided by verbal activity recall in a face-to-face interview (Battellino and Peachman 2003).

## Background

The use of GPS data collection for a small subsample in a household travel survey provides the opportunity to examine differences in reported and measured trip rates, the characteristics of trips that are not reported, start and end times, travel times and distance travelled. The most critical short-coming of self report travel surveys is trip reporting. Wolf et al. (2003) analysed data from three locations in California and found missed trip percentages of about 18% in two cases and over 34% in a third case. In a subsequent study,

Wolf (2006) showed that from six household travel surveys conducted in the USA using CATI and GPS for comparisons between 2001 and 2004, the rate of missed trips ranged from 11% to 81%. In a CATI household travel survey in Laredo, Texas, Forrest and Pearson (2005), also reported that only 44% of trips recorded by a GPS were able to be matched successfully with a trip reported by CATI. None of these are adjusted for missing GPS trips, (something that has been done in this study). Hence, these rates of missing trips should actually be higher. It is also important to note that all of these studies were undertaken using in-vehicle GPS devices, so that the underreporting refers specifically to car trips. However, transport planners have known that short walking and bicycling trips are probably the most poorly reported trips in a survey. These trips were specifically not included in any of the above reports, (something that has been done in this study).

Wolf et al. (2003) reported that the main reasons for under-reporting of trips were the length of the survey, forgetfulness of respondents, or respondents considering the trips unimportant, and selective omission on the part of the respondent. Wolf et al. (2004) found that the duration of unreported stops (which would result in fewer trips being reported) averaged less than 6 min. Generally, the reason for not reporting these stops was that either the respondent thought it wasn't important, or that the respondent forgot. Forrest and Pearson (2005) found significant underreporting of home-based nonwork and non-home-based trips, while there was some overreporting of home-based work trips, with the differences still remaining after trip concatenation, (concatenating a sequence of trips in the GPS data that were reported as a single trip in the CATI survey).

Zmud and Wolf (2003) analysed additional characteristics relating to missed trip reporting. They found that those who were most likely to misreport their travel were households with three or more vehicles, households with incomes under US\$50,000, respondents who were less than 25 years old, and households which had more than three workers. They also found that over 70% of missed trips had a duration of less than 10 min.

In terms of trip characteristics, trip length in time and distance are the two attributes that can be assessed quantitatively. It is well known that people tend to round clock times when reporting the beginning and ending times of trips as well as the time that a trip took (Rietveld 2002; Stopher 2004). Such rounding may have very small effects on long trips but can be of substantial importance for short trips. Most rounding is to the nearest 5 or 15 min. This means that a trip that was actually from 3:23 pm until 3:42 pm is likely to be reported as taking 15 min (not 19) and to have started at 3:30 and ended at 3:45 pm. Because these problems are well known, transport planners generally have not relied on estimates by survey respondents for trip duration or trip distance, preferring instead to derive these from transport networks. Departure time of the trip is used more often to categorise the trip to a time of day period, where the rounding issue is less important. When trip duration is used from a survey, it is more often used as a check on whether or not correct origin and destination locations have been assigned to the trip, by ensuring that the estimate from the respondent (whether asked for as an outright response to a question such as "How long did this trip take?" or by finding the difference between reported departure and arrival times) is of the same order of magnitude as the network-derived value. In this study, however, we report on the accuracy of people's time and distance estimates related to what is shown by the GPS.

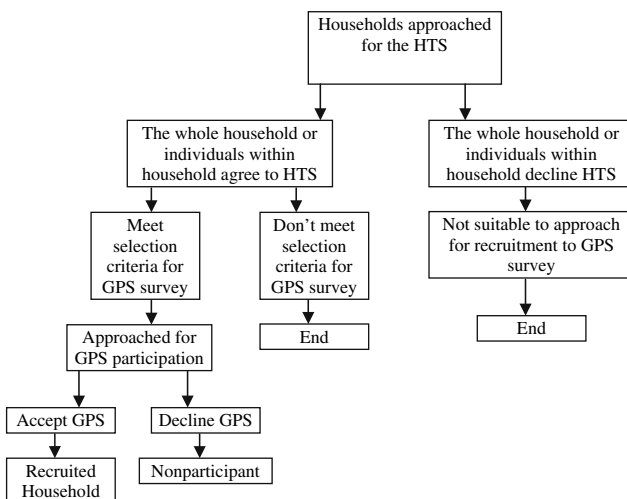
In one of only two investigations to date of its type, Chalasani et al. (2005) found that survey respondents estimated distance relatively well. They found that differences between shortest-path derived distances and respondent estimates were almost independent of trip length and that the mean difference was around 0.6 km for trips by car driver and passenger. Forrest and Pearson found substantial numeric differences in CATI reports of

VKT compared to the GPS, but, because of the small sample sizes involved, were unable to establish statistical significance in the differences. Interestingly, they also reported that higher income groups showed less accuracy in reporting their travel by CATI, whilst households with one person had the highest reporting accuracy and two-person households the lowest.

## Methodology

A sub-sample of households already taking part in the HTS was asked to take part in the GPS survey. By using the same households, we were able to ensure comparability between the two surveys. It minimised the potential for bias and any other adverse effects the GPS survey might have on response rates for the HTS. The contact method for recruitment was face-to-face with no incentives being given. To be eligible, a household had to be likely to have members who would travel on the travel day, and to have a travel day that was at least 3 days after the recruitment visit (In the recruitment process for the HTS, there are varying numbers of days between the recruitment visit and the travel day). The three days to the Travel Day was used to permit time for delivery of the GPS devices and for households to get used to using them. Within eligible households, household members were eligible if they were over 15 years of age and had consented to the survey. In the recruitment visit, some preliminary data were obtained including key destination addresses, such as workplaces of each worker, and school addresses of students. A schematic of the recruitment process is provided in Fig. 1. The GPS prompted recall surveys were always conducted after the HTS interview so that they could not influence responses to the HTS.

Two types of GPS devices were used for the survey: an in-vehicle and a wearable GPS device. An in-vehicle GPS was provided for each car of each sampled household that agreed to participate in the survey. This device is plugged into the cigarette lighter/accessory socket, and requires no intervention by the driver of the vehicle. It records all



**Fig. 1** Schematic of recruitment process for GPS survey

travel undertaken by the car, so long as it remains plugged into the socket. Each eligible person in the household that did not use a car, or was more likely to use public transport, was asked to take and use a wearable GPS device for the same period. It is able to obtain data in buses and cars as well as when people are walking, cycling and in any other modes of travel relevant to this study.

A prompted recall survey was conducted to confirm the trip information received by the GPS and to gather information not obtainable by GPS. This included trip purpose, the number of passengers and the number of passengers that are household members. The survey was also used to determine who the driver was, whether any of the stops recorded were erroneous due to traffic delays or signal loss and if there were any stops that were not detected by the GPS processing algorithms. Information relating to fares and ticket type was also gathered for public transport users. Respondents could choose to complete this survey by telephone, Internet, a face-to-face interview, or by post.

A pilot survey was undertaken in August to October 2003. The pilot survey used the method described in this section for the main survey. Twelve households were recruited for the pilot survey, to which 21 GPS devices were sent. Of these 12 households, ten provided either partial or complete data, one household withdrew from the study, and one was not contactable for the prompted recall survey. Also, among the ten households that performed the GPS and prompted recall surveys, one household provided only a partial response, with one of the three devices only providing useable data. This resulted in data being obtained from 15 devices. Minor changes were made, as a result of the pilot survey, to the prompted recall survey form wording, and to some of the instructions. We also provided revised instructions to the interviewers concerning recruitment. However, nothing material changed in the process, so that the data collected in the pilot survey could be combined with the main survey data. It was also noted that, out of all these households, only one public transport trip and no walk trips were recorded in the diaries, whilst the wearable devices recorded two walking trips and one public transport trip. Thus, with this exception, the pilot survey suggested that almost all travel of the households in this sample was recorded by the GPS devices.

The main survey fieldwork commenced in February 2004 and the last household completed its survey in early September 2004. GPS units were delivered by courier on the following business day after recruitment, ensuring respondents were in possession of and using the GPS devices for a minimum of 2 days prior to their assigned travel day for the HTS. Details were also obtained at recruitment allowing for the GPS units to be picked up by a courier.

Once the GPS devices were retrieved and the data downloaded, a GIS software package was used to modify and display the trip data (Stopher et al. 2005). The software uses 2 min as the minimum duration of a stop to define a trip end. An example of a resulting map from the software is provided in Fig. 2, while the summary table produced is shown in Fig. 3. The maps and tables were used in the prompted recall survey as aids for respondents to report on their travel, and were distributed with the prompted recall survey forms. For households that chose the Internet as their method for doing the prompted recall survey, a Java CD was sent to the household with log-in details to the ITLS server. Every trip on which questions were asked was shown in the form of an animated line moving over a map shown within the web browser (Collins and Stopher 2005). All responses were stored directly in the database. The data from the HTS was sent by the HTS survey contractor to ITLS. This was then cleaned and edited for analysis with the GPS data.



Fig. 2 Example of route map output from GIS



**Summary of Travel Activity for John Citizen  
Sunday, 29/2/2004**

Location at Start of Day:	Street	Suburb
	DELANEY DR	BAULKHAM HILLS

STOP NUMBER	TIME OF ARRIVAL AT STOP	TIME SPENT TRAVELLING TO STOP (min)	DISTANCE TRAVELLED TO STOP (km)	LOCATION OF STOP		MAP	NOTES
				Street	Suburb		
1	9:01	4	1.7	ROUNDBOUT	BAULKHAM HILLS	MAP A	
2	11:40	6	3.5	CARRINGTON RD	CASTLE HILL	MAP A	
3	11:52	6	3.0	VICTORIA RD	CASTLE HILL	MAP A	
4	12:33	6	2.0	PRESIDENT RD	KELLYVILLE	MAP A	
5	12:43	6	4.0	DELANEY DR	BAULKHAM HILLS	MAP A	

Fig. 3 Example of summary table

### Response and completion rates

Figure 4 shows a schematic of the overall response to the main survey. A total of 118 individuals from 70 households were recruited to take part in the GPS study. Table 1 shows details of the numbers by the method selected by households for the prompted recall survey. The telephone was the method most widely chosen by respondents, followed by the Internet. All prompted recall surveys were sent to respondents within 2 weeks of their travel day with the exception of one household. This was sent 16 days after the travel day. Households that elected the self administered method were generally slow in returning the completed forms and a number of phone calls had to be made to remind them to post them back to ITLS.

Households that failed to comply returned no data from the GPS device. Reasons for this occurring included faulty cigarette lighters and respondents deciding not to use the devices. Respondents who chose the face-to-face option were most likely to not comply, whilst those choosing the phone option had the lowest rate (21%). Some households provided GPS data, but did not complete the prompted recall survey. These are shown as GPS data only in Table 1 and Fig. 4. Some households were incomplete, because some, but not all, members of the household returned data from a GPS device. There were 11 incomplete households, made up of 15 eligible individuals. An incomplete household refers to a household where one or more household members did not provide any data from their GPS device/s. Among these households were nine households from which the prompted recall survey was completed by all household members who did return GPS data. They are denoted as complete partial households. One household provided GPS data only from some household members (the other household member/s did not provide any data), and one household, denoted ‘mixed’, had at least one member who did not provide GPS data, at least one member who provided GPS data only, and at least one who provided GPS

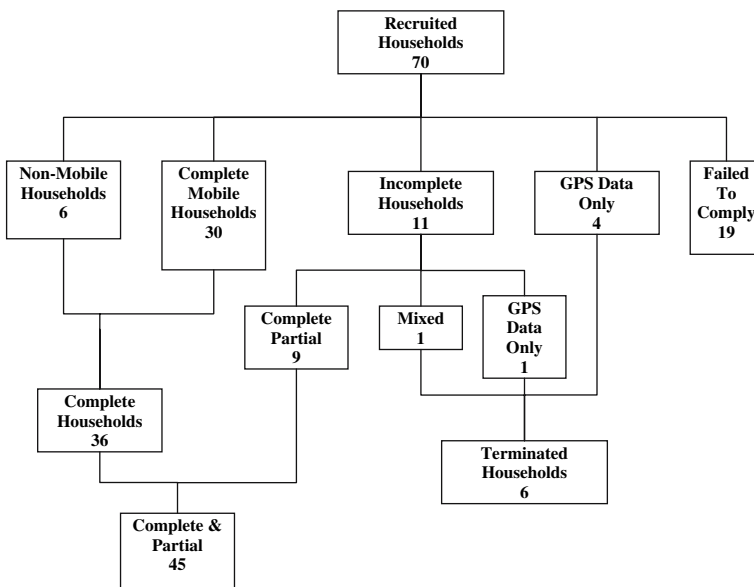


Fig. 4 Overall response of the recruited households

**Table 1** Completion rates of GPS/prompted recall

Primary disposition	Secondary disposition	Method of prompted recall survey response				Total
		Phone	Internet	Post	Face-to-face	
Households recruited		33	17	13	7	70
Failed to comply (refusal after recruitment)		7 (21%)	6 <sup>a</sup> (35%)	3 (23%)	3 (43%)	19 (27%)
GPS data only		1 (4%)	3 (27%)	0 –	0 –	4 (8%)
Incomplete households		5 (15%)	2 (12%)	3 (23%)	1 (14%)	11 (16%)
	GPS data only	0	1	0	0	1
	Mixed	0	1	0	0	1
	Complete partial	5	0	3	1	9
Terminated households		1 (4%)	5 (29%)	0 –	0 –	6 (9%)
Complete households		20 (61%)	6 (35%)	7 (54%)	3 (43%)	36 (51%)
	Complete mobile households	18	5	5	2	30
	Non-mobile households	2	1	2	1	6
Complete and partial households		25 (76%)	6 (35%)	10 (77%)	4 (57%)	45 (64%)

<sup>a</sup> One of these failures to comply was due to using it on the wrong day. We have data but not for comparison with the Sydney HTS Travel Day

and prompted recall data. A complete household is one that returned data from the devices and also completed the prompted recall survey. Households that returned no data from the GPS device but indicated that they did not travel on the Travel Day are also shown. These households are considered as completing the survey.

The Internet option, while a fairly new concept, was originally taken up by 19 households. Two households that encountered technical problems with the Internet were subsequently sent a mail-back version of the prompted recall and are counted in the 'post' column, reducing to 17 the total respondents using the Internet for the survey.

Overall, the best responses to the survey were from those households that chose the telephone or the postal option for the prompted recall survey (76% and 77% complete and partial households respectively). The face-to-face option surprisingly performed less well, with only a 57% completion rate. However, this option was chosen by the fewest households and had the highest failure to comply proportion. The Internet performed least well of the four options, with only a 35% completion rate. Overall, there was a 64% completion rate for using the GPS devices, (including households with no travel on the Travel Day). From the households that participated, 39 households (87%) completed the prompted recall.

## Analysis methodology

Analysis was performed on a trip-level basis, comparing individual trip records from the HTS with the corresponding trip records from the GPS survey. A manual comparison of trips was performed to match trip records from each data file (GPS and HTS). Trip numbers were matched first, followed by checks on start and end times, travel times, trip



purpose and distance. One individual was excluded from the analysis when trip records could not be matched. Another individual was excluded because there was no diary, despite there being GPS data.

Global Positioning System technology is not perfect, and misses some trips, predominantly short trips that are too short for the device to gain position, plus trips where respondents intentionally do not take the GPS device with them, or unplug an in-vehicle device. The prompted recall survey is designed to detect such missed trips, but respondents do not always remember them or desire to report them, unless there is an obvious gap in travel. The majority of trips that were not captured by the GPS and prompted recall survey were missed for two reasons: respondents did not take the device with them or did not activate it; and respondents with in-vehicle devices would not have recorded walking, passenger or public transport trips. Trips that were missed by GPS are excluded from the comparisons and are irrelevant for assessing the accuracy of the HTS. Also excluded are all non-driver trips reported in the HTS for people that were provided with only an in-vehicle device.

The number of reported trips was compared with the number that was recorded (after GIS processing and editing as a result of the prompted recall surveys), to determine the level of under- or over-reporting. The characteristics of the trips that failed to be reported were examined, followed by an investigation into the differences in reported and recorded start and end times, travel times, and trip distances. A comparison of the trip purpose stated in the HTS with what was reported in the prompted recall survey was also conducted.

## Results

Table 2 provides a comparison of the demographic data for households in the GPS sample and the Sydney Household Travel Survey for the period 2003–2004, and Table 3 provides similar data for persons in the two samples.

From Table 2, we can see that the samples are similar, although the GPS sample has fewer households living in semi-detached or townhouse dwellings, and has fewer one-person households. Couples with children tend to dominate the GPS sample more than the HTS sample, and non car owners are underrepresented, whilst those with more than three cars are overrepresented. However, only the differences in household size from this table were found to be statistically significantly different. The other differences are not significant. In Table 3, under 15 year olds are excluded, because they were not eligible to carry GPS devices and are not included in the GPS sample statistics.

Table 3 shows that there are generally only small differences in gender, age, country of birth, marital status, work status, and income between the HTS and the GPS sample. Overall from Tables 2 and 3, the most notable differences are for household size, where one-person households are underrepresented and large households with five or more persons are overrepresented, country of origin, where New Zealand and England are about twice as high in the GPS sample as for the HTS, workers, where there are about 9% more workers and 11% fewer non-workers in the GPS sample than in the HTS, and income, where the lowest income category appears underrepresented in the GPS sample and the middle income range of \$41,600–51,999 is overrepresented in the GPS sample.

Table 4 presents summary statistics for the GPS and prompted recall data and for the HTS data for the same individuals and households. It should be noted that where no data were available, trips were excluded for that particular variable. A total of 68 persons from 49 households participating in the HTS, producing 407 trips were analysed. With the

**Table 2** Household demographics for the Sydney HTS and GPS samples

Demographics		Sydney HTS	GPS sample (%)
Variable	Level	(unweighted) (%) ( <i>N</i> = 2461 HH)	( <i>N</i> = 70 HH)
Housing type	Detached house	70.7	77.1
	Semi-detached/town house	11.8	5.7
	Flat/unit/apartment	17.1	17.1
	Other	0.3	0.0
Household size	1 person	18.1	5.7
	2 persons	33.2	28.6
	3 persons	18.7	22.9
	4 persons	18.3	21.4
	5+ persons	11.7	21.4
Household type	Lone person	18.2	5.7
	Couple only	24.9	22.9
	Couple with children	37.3	55.7
	One parent	8.3	8.6
	Other	11.3	7.1
Number of vehicles	0	11.3	7.1
	1	40.8	31.4
	2	34.5	37.1
	3	9.5	12.9
	4+	4.0	11.4

addition of the data received from the pilot survey, these figures increased to 81 persons from 59 households, generating 465 trips. All figures reported from here on include respondents from the pilot survey. After matching trip records from each data file, 86% of trips could be matched within 12.5 min of the starting times.

Table 4 shows that both time and distance are consistently overestimated in the HTS, although by varying amounts, depending on the specific variable. Average vehicle occupancy (which was obtained through the prompted recall for the GPS survey) is approximately the same. Because of sample size issues, we did not test average VKT per person per day, and there were too many missing values on vehicle occupancy to make the test. In the other tests, walking and car passenger have too few observations for the result to be considered reliable, while the average car driver travel time is significantly different between the GPS and the HTS. Neither VKT per trip nor average travel time per trip are significant at 95%. These tests are based on comparing the means of all valid observations for each of the diary and the GPS, and not a paired means test.

#### Missing trips analysis results

Table 5 summarises our analysis of the missing trips that were uncovered by the GPS. A total of 502 trips recorded, of which 465 could be matched to HTS trips. The remaining 37 trips (7.4%) were not recorded by the HTS. Whilst 7.4% is still a significant level of

**Table 3** Person demographics for the Sydney HTS and GPS samples

Demographics		Sydney HTS	GPS sample (%)
Variable	Level	(unweighted) (%) ( <i>N</i> = 6430 persons)	( <i>N</i> = 118 persons)
Gender	Male	52.5	50.0
	Female	47.5	50.0
Age	15–49 years old	63.1	65.3
	50+ years old	36.9	34.7
Country of birth	Australia	63.3	65.3
	New Zealand	2.2	4.2
	England	5.3	9.3
	Other	29.4	21.2
Marital status	Married	58.5	64.4
	De facto	6.9	5.9
	Separated	2.2	3.4
	Divorced	4.3	0.8
	Widowed	4.7	0.0
	Never married	23.4	25.4
Work status	Worker	64.9	73.7
	Non-worker	35.1	23.7
Household income per annum	No personal income	10.5	10.2
	Up to \$10,399	15.0	5.9
	\$10,400–25,999	23.0	24.6
	\$26,000–41,599	17.0	18.6
	\$41,600–51,999	7.4	11.0
	\$52,000–77,999	10.1	12.7
	\$78,000 and over	7.2	8.5

**Table 4** Summary statistics of trips

Variable	GPS	HTS diary	Difference (HTS–GPS)	Significance of difference (%)
Average travel time/per trip	12.96 min	14.22 min	1.26 min	<95
Average walking travel time/per trip	8.1 min	8.6 min	0.5 min	<95
Average car passenger travel time/per trip	11.4 min	16.29 min	4.89 min	95
Average car driver travel time/per trip	12.29 min	14.69 min	2.40 min	95
Average VKT/per trip	8.07 km	8.85 km	0.78 km	<95
Average VKT/per person/per day	42.40 km	42.77 km	0.37 km	Not tested
Average vehicle occupancy	1.44	1.45	0.01	Not tested

**Table 5** Missed trips

Source	Total GPS trips	Total trips in Sydney HTS	Difference in trips (HTS–GPS)	% of total trips	Total respondents processed
HTS	439	407	–32	7.3	68
Pilot	63	58	–5	7.9	13
Total	502	465	–37	7.4	81

underreporting, it compares very favourably to the US CATI studies, that range from a low of 11% to a high of 81% (Wolf 2006). We speculate that this is in part due to the use of face-to-face interviewing, compared to telephone interviewing and, in part, a result of the continuous nature of the Sydney Household Travel Survey, which means that interviewers have years of experience in this survey and are probably able to probe more effectively for trips that might otherwise have been missed. It is also possible that having the GPS devices may have led household members in the sample to report their data more accurately in the place-based diaries. There is no way, from this study, to determine if this is true.

Table 6 provides a more detailed analysis of the missed trips. Comparison of data from the GPS and prompted recall survey with the HTS data resulted in forty trips from the total of 465 reported in the HTS being excluded from the following analysis because they could not be matched adequately. First, we analysed the effect of the number of trips a household made in a day on the underreporting of trips. We hypothesised that people who travel more would be more likely to miss reporting some of their trips. We also examined the time of the day of trips to determine if this may have an impact on the under-reporting of trips. Next, we looked at trip distance, to determine whether, as found in other studies, short trips were more likely to be omitted than long trips. It is reasonable to expect similar trends by time and distance. Finally, the duration of the activity and the nature of the activity were also examined in relation to underreporting.

The findings, shown in Table 6, from these analyses, were that people making many trips were more likely to underreport their travel, as were those making trips after 5 pm. Shorter trips in both time and distance were more likely to be underreported, as were those associated with activities with a short duration (under 10 min). Finally, trips for social visits showed by far the highest rate of underreporting, followed by those for picking up or dropping off a passenger. It should be noted that the statistics in Table 6 are based on lower numbers of trips for Start Time and Distance, because of item nonresponse in the HTS survey on these two questions.

As might be anticipated, people are much less likely to omit longer trips. Of those trips that ended in an activity of 10 min or less duration (which were 50% of the total missed trips), only 17% had a travel distance longer than 10 km, or a travel time longer than 15 min. In contrast, 50% of these missed trips had a travel time of 5 min or less, and 44% were less than 2 km. Again, with those missed trips where the activity at the end of the trip had a duration of between 10 and 60 min (19% of missed trips), 43% were for a distance of less than 2 km, although somewhat longer travel times were involved, with 57% of these trips taking less than 15 min. Even for activities lasting more than 1 h (31%), 55% were under 2 km in length, and 55% were also under 5 min in travel duration. Only 9% of these missed trips had either a duration of more than 15 min or a distance greater than 10 km. Similar patterns were observed with respect to the time of day of the missed trips. Of those that started before 9 am, 57% were short in travel time and distance, and of those starting after 5 pm, 47% had a short travel time and 60% a short travel distance. Only in the midday

**Table 6** Characteristics of trips missed by the HTS diary

Characteristic	Range	Trips missed	Total trips in HTS	% of total trips (HTS + missed)	% of missed trips (total of 37)
Travel load	Light ( $\leq 5$ trips)	5	172	2.8	13.5
	Medium ( $>5$ and $<10$ trips)	15	147	9.3	35.1
	Heavy ( $\geq 10$ trips)	17	146	10.4	51.4
Start time	Before 9 am	7	68	9.3	18.9
	12:01 pm to 4 pm	10	123	7.5	27.0
	After 5 pm	15	135	10.0	40.5
Travel time	Less than or equal to 5 min	17	170	9.1	45.9
	More than 5 min up to 15 min	13	144	8.3	35.1
	More than 15 min	7	151	4.4	18.9
Distance	Less than or equal to 2 km	18	99	15.4	48.6
	More than 2 km and less than 10 km	14	130	9.7	37.8
	More than or equal to 10 km	5	91	5.2	13.7
Activity duration	Less than or equal to 10 min	18	145	11.0	48.6
	More than 10 min and up to 60 min	7	104	6.3	18.9
	More than 60 min	12	216	5.3	32.4
Trip purpose	Home	7	131	5.1	18.9
	Shopping	5	64	7.2	13.5
	Drop-off/pick-up somebody	4	42	9.1	10.8
	Social visits	3	20	13.0	8.1
	Work related business	3	77	3.8	8.1
	Other	5	131	3.7	13.5
	Not reported	10			27.0

period (9 am to 5 pm) were the percentage of short trips lower, with 40% having a short travel time and 33% a short distance. Table 7 summarises the relationships between travel load and each of the activity duration, travel time, and distance.

In general, Table 7 suggests that people with high travel loads are more likely to miss reporting trips with a short activity duration, short travel time, or short travel distance, whereas those with lighter travel loads appear to be more likely to miss reporting trips with mid-range duration, travel time, or distance.

Finally, looking at the demographics of those who missed trips, males were found to be more likely to miss trips than females, although the females who missed trips, missed more of them (average of 2.8 missed trips per female and 2.25 per male). Respondents under the age of 50 were also more likely to miss trips, with only two respondents over the age of 50 missing trips (although they missed an average of four per person). There was little effect of marital status or country of origin on missed trips. However, people with lower incomes

**Table 7** Analysis of missed trips by travel load

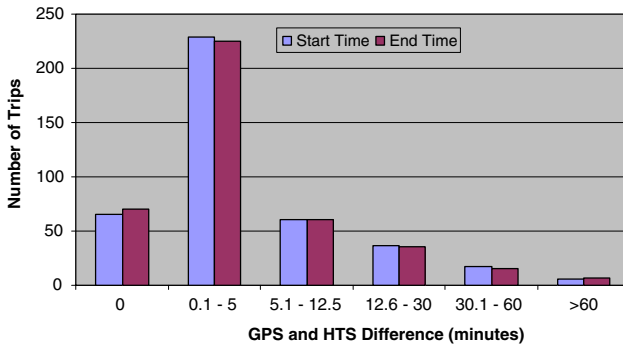
Travel attribute	Low travel load (<5 trips/day) (%)	Medium travel load (5–10 trips/day) (%)	High travel load (>10 trips/day) (%)
Activity duration			
<10 min	60	39	56
10–60 min	40	39	11
>60 min	0	23	33
Travel time			
<5 min	40	23	63
5–15 min	40	54	21
>15 min	20	23	22
Travel distance			
<2 km	100	15	58
2–10 km	0	69	26
>10 km	0	15	16

(less than \$26,000) were twice as likely to miss trips as those in medium income groups, but high income groups (over \$78,000) also were much more likely to miss trips. No differences were observed in relation to household size or type of household. People from households with four or more cars missed reporting trips much less than other households, and non-car owning households did not miss reporting any trips. Other than that, car ownership did not appear to have an effect. Workers were found to be more likely to omit trips than non-workers, with the 74% of workers in the sample responsible for 84% of the missed trips, and the 24% of non-workers were responsible for only 16% of the missed trips.

#### Analysis of accuracy of reporting

The distribution of differences between the start and end times of trips reported by respondents to the HTS and those recorded by the GPS is presented in Fig. 5. The start time was not reported for ten trips and the end time for 11 trips. The numbers in the figure exclude these missing data. The results are remarkably similar between start and end time misreporting, with about 16% reporting the start time correctly and about the same percentage reporting end time correctly, with about 55% of reported start and end times being within 5 min of the correct time. This would seem consistent with the findings of Rietveld (2002). At the other end of the scale, only about 5% of respondents misreported by more than 30 min, and 9% misreported by between 12.5 and 30 min. Thus, as might be expected, most start and end times have probably been rounded by most respondents, but with rounding to the nearest 5 or 10 min in most cases.

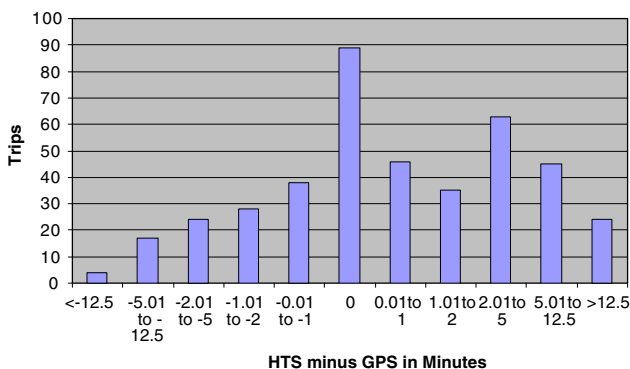
A total of 413 trips were analysed for travel duration with 12 having no reported travel duration in the diary. The reported travel duration was more accurate than the reported start and end times—93% reporting within 12.5 min of the recorded travel time, (see Fig. 6). Seventy-eight percent reported within 5 min of the recorded travel time. The largest over-reporting of travel duration was 57 min while the largest under-reporting was 44 min.



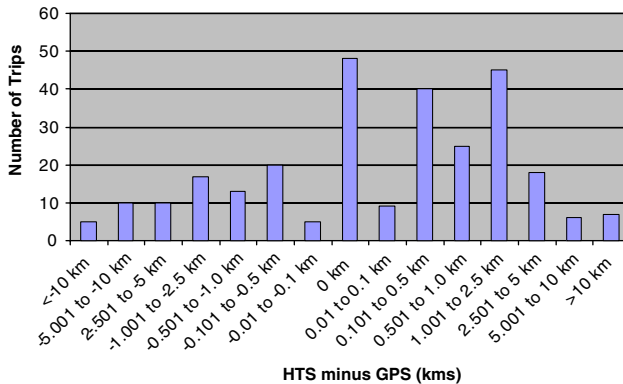
**Fig. 5** Start and end time differences

There were 89 cases (22%) of the exact same travel time reported as that recorded by GPS. Over half of the trips were over-reported, although only 6% were over-reported by more than 12.5 min. Twenty-seven percent of trips were under-reported, with almost all (99%) of these being under-reported by 12.5 min or less. A total of 25% more trips were over-reported than were under-reported (51.6–26.9%), meaning that people are twice as likely to indicate that their trip was longer than it really was than either give it exactly, or under-report their travel time.

TPDC has long been aware of the general inaccuracy of reported distance in the HTS and, though retaining the question at this stage, does not use the data for analysis. All distance analysis is based on GIS-calculated distance from the origin and destination of each trip. In the HTS, distance was asked only for private vehicle driver trips. Therefore, trips on public transport, walking, and bicycling could not be analysed although GPS data were available for them. Figure 7 shows the misreporting by distance for the 278 trips using the private vehicle mode, all of which had their distance reported by respondents for the HTS. If a trip was reported as 1 km or less, it was recorded as 1 km. As with travel time, trip distances are more likely to be over-reported than under-reported, and more than 10% are over-reported by more than 2.5 km, with slightly less than 10% being under-reported by that amount. Only about 17% of trips were reported as the correct distance,



**Fig. 6** Misreporting of travel time by HTS



**Fig. 7** Misreporting of trip distance in the HTS

although 40% were within 1 km of the distance recorded by the GPS. The average over-estimation is 0.78 km.

There appears to be a fairly consistent relationship between the errors in reporting trip length and the overall length of the trip. From an analysis of trip distance versus reported travel time, we found that 81% of very short trips (less than 1 km) had a travel time within 5 min, whilst 84% of short trips (1–5 km), 78% of medium trips (5–15 km), and 60% of long trips (more than 15 km) had a travel time within 5 min of actual time. From this, apart from the very short trips, the absolute accuracy of reported travel times declines with increasing trip length. A similar result appears with respect to reporting the start time of the trip correctly. About 71% of very short trips, 71% of short trips, 73% of medium trips, and 47% of long trips have their start times reported within 5 min of the actual start time.

For travel distance, similar levels of accuracy were found for those making very short, short, and medium trips, where 69% of those making very short trips reporting the distance to within 1 km, 62% of those making short trips and 67% of those making medium trips reporting with similar accuracy. However, of those making long trips, only 25% were able to report to within 1 km of the actual distance. Of this latter group, 8% were wrong by more than 15 km, whereas none of those making very short trips erred by this much (as might be expected), 1% of those making short trips were this wrong, and none of those making medium distance trips erred by this much. Perhaps more surprising is that those making very short trips (less than 1 km) were prone to misreport distance by more than 5 km, with 9% so reporting and 22% being wrong by between 1 and 5 km. For those making short trips, only 2% were wrong by more than 5 km, and only 3% of those making medium distance trips were wrong by more than 5 km.

We also looked at the time of day in relation to reporting start times, and found that trips were more likely to be misreported on the start time in the morning, than later in the day. Of those trips that started before 9 am, 23% had a misreported start time by more than 12.5 min, while 14% of those starting between 9 am and 5 pm were misreported and 12% of those starting after 5 pm were misreported. A similar pattern emerges for reporting the duration of the travel, with 15% of trips that started before 9 am being incorrect by more than 15 min, whilst only 4% of those beginning between 9 am and 5 pm, and 3% of those after 5 pm were misreported by this much. Misreporting by between 5 and 15 min also was more common for early trips, although the middle of the day was worst in this range, with



19% of trips misreported. There were 16% misreported for the early trips (before 9 am) and 12% for evening trips (after 5 pm). Not surprisingly, similar results were observed with distance reporting. In this case, trips beginning before 9 am had 12% with an error of between 5 and 15 km, and 5% more than 15 km wrong, whereas, between 9 am and 5 pm, these percentages dropped to 8 and 2 respectively, and after 5 pm to 7 and 0 respectively. In summary, trips beginning before 9 am are more likely to be misreported on start time, duration, and distance than trips beginning in the middle of the day (9 am to 5 pm), and even more so than trips beginning in the evening (after 5 pm). This is also further confirmed by looking at combined misreporting of start time and distance, where 60% of those that were badly reported on start time are also badly reported on distance.

We examined misreporting against a few of the demographics. In particular, we found that casual workers and part-time students were most likely to misreport start times (50% and 32% misreporting by more than 12.5 min, respectively), whilst retired people were most likely to be accurate. On travel time reporting, part-time workers and part-time students were most likely to be in error, while retired people were again the most accurate. For distance reporting, casual workers were most likely to misreport by large amounts, whilst part-time workers and part-time students were the most accurate. There were no other obvious correlations between misreporting and demographics.

## Conclusions

The various prompted recall methods met with a range of success in achieving a high response rate. The Internet survey, while a popular choice for many respondents, had a high rate of drop-outs and non-completes. The face-to-face option experienced a high drop-out rate for the GPS survey as a whole but was successful at getting all respondents to complete the prompted recall part of the survey. However, it was not chosen by many respondents. The phone recall method was chosen by most respondents and, despite problems encountered in contacting these respondents, had the lowest non-compliance rate. The self-administered option was also successful in getting all respondents to complete the survey.

Several inaccuracies have been noted. The start and end times match quite well between the GPS and the HTS, but this is not the case for the number of trips, the trip distance or the travel time. While trip distance was well reported (100% of private vehicle trips), the accuracy of reporting was not as good as for travel time. Both travel time and trip distance were over-reported. For both time and distance, people were twice as likely to report their travel to be longer than it was than to be shorter, although the level of the erroneous reporting was greater for distance. There were no consistent demographic effects on misreporting of start times, travel times or trip distances. The level of under-reporting of trips is a concern, with 7.4% of trips missed by the Sydney HTS. The characteristics of these missed trips are that the majority of are short trips (both in time and distance), trips starting after 5 pm, trips with a short amount of time spent at the destination, and trips by respondents who have many trips in 1 day. Our analysis has also examined the demographics of those who omitted trips and concluded that there are no strong indications that specific subgroups of the population are more likely than others to omit trips, although there appears to be some evidence of gender, income, worker, and age effects. However, the number of missed trips was small, so that it is not possible to conclude that these are significant effects.

This study demonstrates that GPS can be used successfully to supplement travel diary surveys. When utilised in conjunction with household travel surveys, GPS technology can be used as a basis of comparison as well as a method to produce correction factors for such variables as trip rates, trip distance, and travel time. Future research may focus on the use of correction factors obtained from this technology to expand sample statistics to wider general populations. In this study we have found a high level of over-reporting of trip distance and trip duration suggesting the benefits of using GPS as a supplement to household travel surveys. Indeed, we believe that GPS could be used as a replacement for travel diaries, and this idea is explored in other papers (Stopher et al. 2006a).

The GPS part of this study gathered more than one day's worth of data. Only 1 day was used for this study. However, if more were to be collected, this could be used to test for variability across days, as we have done with subsequent data (Stopher et al. 2006b).

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## References

- Battellino, H., Peachman, J.: The joys and tribulations of a continuous survey. In: Stopher, P., Jones, P. (eds.) *Transport Survey Quality and Innovation*, pp. 49–68. Elsevier Science, Oxford (2003)
- Chalasan, V.S., Denstad, J.M., Engerbretsen, Ø., Axhausen, K.W.: Precision of geocoded locations and network distance estimates. *J. Transportation Stat.* **8**(2), 1–15 (2005)
- Collins, A., Stopher, P.: Conducting a GPS prompted recall survey over the Internet. Paper presented to the 84th annual meeting of the Transportation Research Board, January 2005
- Forrest, T., Pearson, D.: Comparison of Trip Determination Methods in Household Travel Surveys Enhanced by GPS *Transportation Research Record* 1917, pp. 63–71. Transportation Research Board, Washington D.C (2005)
- Rietveld, P.: Rounding of arrival and departure times in travel surveys: an interpretation in terms of scheduled activities. *J. Transportation Stat.* **5**(1), 71–82 (2002)
- Stopher, P.R.: GPS, location, and household travel. In: Hensher, D., Button, K., Haynes, K., Stopher, P. (eds.) *Handbook on Transport Geography and Spatial Systems*, vol. 5, pp. 433–449. Elsevier, Oxford (2004)
- Stopher, P., Jiang, Q., FitzGerald, C.: Processing GPS data from travel surveys. Paper presented to the 28th Australasian transport research forum, Sydney, September 2005
- Stopher, P., FitzGerald, C., Greaves, S., Biddle, T.: What can we learn from GPS measurement of travel. Paper presented to the 29th ATRF meeting, Brisbane, September 2006a
- Stopher, P., FitzGerald, C., Bretin, T., Zhang, J.: Variability in day-to-day travel—analysis of a 28-day GPS survey. Paper to be presented to the 29th annual meeting of the Australasian transport research forum, Brisbane, September 2006b
- Wolf, J.: Applications of new technologies in travel surveys. In: Stopher, P.R., Stecher, C.C. (eds.) *Travel Survey Methods—Standards and Future Directions*, pp. 531–544. Elsevier, Oxford (2006)
- Wolf, J., Loechl, M., Thompson M., Arce, C.: Trip rate analysis in GPS-enhanced personal travel surveys. In: Stopher, P., Jones, P. (eds.) *Transport Survey Quality and Innovation*, pp. 483–498. Elsevier Science, Oxford (2003)
- Wolf, J., Bricka, S., Ashby, T., Gorugantua, C.: Results from the 2004 Kansas City GPS-enhanced household travel survey. Paper presented to the TRB conference on data for understanding our Nation's Travel November 2004
- Zmud, J., Wolf, J.: Identifying the correlates of trip misreporting—results from the California statewide household travel survey GPS study. Paper presented to the international conference on travel behaviour research, Lucerne, Switzerland, August 2003

### Author Biographies

**Peter Stopher** is Professor of Transport Planning at the Institute of Transport and Logistics Studies of the University of Sydney. He has more than 40 years of experience as an educator and consultant in transport planning and has published many papers and books in transport-related topics. He is currently writing a book on Survey Design and Management. He teaches and researches in transport policy and planning, survey methods, environmental analysis, and travel demand modelling, and is pioneering the use of GPS devices in transport surveys.

**Camden FitzGerald** is a Transport Planner. He has worked on projects evaluating bus interchange operations and analysing pedestrian activity at rail stations. He has extensive experience in data analysis including three-and-a-half years experience as a Research Analyst working on numerous projects. He worked on a project evaluating the reporting error of the Sydney Household Travel Survey diaries. This involved matching GPS data to the diary data and evaluating the demographic characteristics of households and people that under and over report travel time, travel distance, and start and end time. He has also looked extensively at the variability in peoples daily travel using GPS data collected from 50 households over a 28 day period. Other experience includes analysing GPS data in order to develop a programme for determining mode of transport and purpose of travel. He has also collected and analysed data for a nation-wide passenger transport task profile and assessed the sources of variation in travel demand elasticities. He is very adept at collecting and analysing data from a variety of sources and in a variety of manners and has co-written numerous reports and papers on such work. Other experience includes processing GPS data (measuring household travel) using GIS package TransCAD and analysing the data. A large component of this has been evaluating TravelSmart<sup>®</sup> Programs in Canberra, New South Wales, Adelaide and Victoria. He also has experience in survey design and management. Camden is currently completing a Masters in Transport Management.

**Min Xu** is a senior project officer at the Transport and Population Data Centre, NSW Department of Planning, Australia. She has a PhD in Transportation Engineering from the University of South Australia. Her main work and research interests include conducting and managing household travel surveys, travel behaviour studies, travel demand and traffic forecast modelling.