Developing and Deploying a New Wearable GPS Device for Transport Applications

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1 Background

Various areas of transport research require data on both geographic and temporal aspects of travel and also the performance of the transport system. However, as noted by Stopher (2004), in interview surveys, most people can provide only rather inaccurate data about where they go, and often do not provide accurate information about when they travel or how long their travel takes. In other research areas, the transport analyst has need of accurate information about speeds of travel in different locations at various times of the day, and also may need to obtain precise information about routes travelled through the transport networks. Prior to the development of GPS capabilities for use by the general public, obtaining such data was extremely difficult, if not impossible. GPS offers the capability to obtain very precise information about where a person, vehicle, or consignment is at a given time, what route is being travelled, how fast the object of concern is travelling, where the object started out on the travel, and where it goes to. All of this information is provided at a level of accuracy of plus or minus a few metres for location, and to the nearest second or less for temporal issues.

Since the mid-1990s, when the U.S. Federal Highway Administration (FHWA) undertook a proof of concept test of the use of a GPS device to measure travel behaviour (Wagner, 1997), there has been a rapidly escalating application of GPS to travel survey measurement. The early devices were restricted to being used in a car, because they were cumbersome in nature, and had no integral power supply; they required the ability to plug into the electrical supply of the car itself, using the accessory or cigarette lighter socket. Also, the earliest devices comprised a GPS antenna/receiver that was connected to a Personal Data Assistant (PDA), and required the respondent to enter data as his or her travel proceeded. Following the successful proof-of-concept test, there were initially a number of independent studies that used either the same GPS/PDA devices developed for FHWA, or used other off-the-shelf devices. However, these proved to be somewhat unsatisfactory. In parallel with these efforts, the Dutch also developed a GPS device, with its own battery power. This was designed to be able to be taken on a bicycle (Draijer, Kalfs, and Perdok, 2000) and it probably represented the first “wearable” device. However, this device weighed in at 2 kilograms, making it rather a heavy device to carry, especially on a bicycle.

In the next few years, work in the U.S. began on developing what Stopher and others have subsequently called a passive GPS device (Stopher, 2001; Stopher and Bullock, 2001; Stopher, Bullock and Horst, 2002). This is a device that requires no input by the survey respondent, during use of the GPS device. The device was designed to be on while it was receiving power from the car’s accessory socket, and to be off when power was no longer provided (Wolf, Guensler, and Bachman, 2001; Wolf et al., 2003). This device still, however, remained an in-vehicle device, because it did not have any power supply of its own. In procedures pioneered by the Institute of Transport and Logistics Studies (ITLS), the additional information that was previously captured on the PDA was collected in a prompted-recall survey. The procedure for this involved processing the GPS data into trips, presenting these trips on maps and in tabular form, and presenting these to respondents and asking them to recall the trips in question and answer a few questions about the travel shown on the map (Stopher, Bullock, and Horst, 2001). These questions were to ascertain the trip purpose of the driver, to identify any passengers accompanying the driver, and to determine their trip purposes and whether or not they were members of the same household as the driver. Also, a question on parking costs was usually included.

In subsequent work at ITLS, the prompted recall survey was also developed into an internet survey, with animation of each trip, to allow respondents to indicate if there had been an intermediate stop that was not detected by the researchers, or to indicate that what was presented as two trips was really one trip (Stopher and Collins, 2005).

More recently, a wearable version of the GPS device was developed from the in-vehicle device. This device consisted of the same recording box as was used in the in-vehicle device, which was carried in a small bag, together with a battery pack, and an antenna/receiver about the size of a standard computer mouse, which was mounted on the bag strap, so that it would sit on the shoulder of the wearer. The device weighed close to 500 grams, thus representing a significant improvement over the Dutch wearable device, but still representing a significant weight of device. Attempts were made to use this device in two research projects in Australia. In the first one, respondents to the Sydney Household Travel Survey were asked to take GPS devices for several days, with the purpose of checking the validity of the home interview survey results, as is reported elsewhere (Stopher, Xu, and Fitzgerald, 2005). In this case, only those households that indicated that at least one person in the household was a regular public transport user were asked to take a wearable device, and one was then provided for each such regular public transport user. Out of some 72 households that received devices and provided data, only 20 were given wearable devices, with a total of 21 persons providing data from wearable devices. We obtained 56 days of data from these 21 persons, for an average of just under three days per person. It should be kept in mind that households were recruited for the GPS in this survey if the interviewer arrived at the house at least three days before the diary day, so that the GPS device could be used for 1 to 4 days in total. Two problems with the device were its weight and its appearance. A number of people raised objections to wearing the device, which is shown in Figures 1 and 2.

Figure 1: Early Wearable Device

The second instance of using this device was in an evaluation of a pilot Travel Behaviour Change program, aimed at households that had just moved in the Canberra area. As with the Sydney project, the idea was again to give wearable devices only to individuals who indicated that they regularly used public transport. All other individuals received in-vehicle devices. In this case, respondents were asked to use the device for a week. There was both a before and an after survey, and 17 persons took the wearable devices in the before survey, and 28 in the after survey. From this total of 45 wearable devices accepted for use, we obtained a total of 245 days of data, 103 from the before survey and 142 for the after survey. Thus, in the before survey, each person accepting a wearable device provided an average of just over 6 days of data, while we received just over 5 days per person of data in the after survey. Given that some people will not leave home on some days of the week, these represent a high level of

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conformance to the requested task. One of the anecdotal objections that was made more than once in this case was to the effect that wearing such a device to work at a new job was simply not acceptable. The individuals felt they would be the laughing stock of their new employer, or that questions might be raised as to their suitability to the new job.

Figure 2: Early Wearable GPS Device Shown by a Mobile Telephone

These experiences led us to consider the specifications of a more desirable wearable device. The desired specifications and reasons for them are described in the next section, and are then followed by a discussion of what was actually possible to do.

2 Objectives

The objective of this work was to develop a GPS device that would be much smaller and more lightweight, providing easy portability, so that it could be carried by respondents in a survey. The device would need to have a form factor that made it acceptable for people to carry it with them, needs to be self powered, and must have the storage capacity to store the data that would be collected from a week to a month of travelling with the device. Such a portable device would also offer potential to be applied in a number of other interesting applications, such as being used on board vehicles to track the vehicle routes and performance, etc. The device would also need to be deployed, to find out whether or not it would be accepted by the public, and whether it could record adequate data on travel.

3 Ideal Specifications for a New Wearable Device

The first requirement for a new device has to do with the weight. Clearly, the early wearable devices were too heavy and the weight of the device would be a significant detraction for a person to be willing to carry the device all the time for a number of days. The weight is also very much an issue that relates to the form factor. We felt that the weight of the entire assembly – antenna/receiver, logger, and battery power – should be less than 100 grams. This, we felt, would remove the bulkiness of the device as a deterrent to use.

The form factor was also an issue. Initially, we discussed the potential to use either a watch or a mobile telephone form factor. However, we soon found that the miniaturisation required for a watch was not yet feasible, especially if this has to contain the battery and the antenna/receiver. We, therefore, opted for the mobile telephone form factor. We also discussed the possibility and considered seriously making this an operating mobile telephone. This seemed to offer some potential promise for several reasons. First, we felt that offering people a device the size of a mobile telephone would be quite acceptable. Second, if the device also operated as a mobile telephone, then the offer of the device would be its own incentive. In fact, by offering possible free calling during the time the device was to be used as a GPS recording device, this would offer a significant financial incentive.

However, we determined, after further investigation, that this was not currently a feasible option. Several problems would arise. First, for people that already had a mobile telephone, they would be less interested to use this device, because it would have a different phone number from the one that people already knew for them. Second, the GPS/phone would not have the customisation of their own phone, such as phonebook numbers, ring sounds, and other customisation. Third, although theoretically one could simply transfer the SIMM card from the person's regular phone to the GPS/phone, most people would not know how to do this, and this could cause problems. Also, there is considerable variation as to whether the SIMM card is used to store customisation or not. Again, there is software that can transfer all customisation details from one phone to another, but expecting to be able to do this for each respondent seemed impractical. Further, the amount of cost involved in offering some amount of free calling was also likely to be considerably higher than the amount normally considered suitable for incentives, so would likely be beyond the budget for most exercises that would use the device. On balance, we determined that having a functioning mobile telephone for the device was not practical.

By deciding on the form factor, we had effectively specified the weight and physical dimensions of the device. There were also several other factors to be considered. Ideally, we felt that it would be good to have a battery life that would outlast the normal length of time that a device would be used. This would mean having a battery that would last for over a week. Investigation of power options showed that this was not likely to be feasible, especially within the size and weight limits dictated by the small form factor. At the time that we obtained the initial prototypes of the device, the battery life was between 6 and 10 hours. We felt that this needed to be increased to as close to 24 hours as could be achieved, so that the device normally would work, provided it was recharged each night.

We also needed a device that would be sufficiently sensitive to be able to be placed in a pocket or bag, or clipped to the belt, and still provide position information. Orientation of the device also needed to be as flexible as possible, to allow for the possibility that the device might not be the "right way up" at all times. Acquisition of position from a cold start was another issue, and we specified that this needed to be less than 30 seconds, even if the device was in motion.

Because the device was to be designed to log data continuously for later downloading, we needed to specify a memory capacity. We determined that the ideal for this would be 16 Mb, because this would allow flexibility to collect more than a month of data. Our prior experience had showed that the average person, travelling around their home location for about a week, would require less than 1 Mb of storage. Finally, because the device was to be wearable, we knew that there would be collection of a considerable amount of data while the device was stationary. From both storage and battery power viewpoints, we felt that it would be preferable if the device would stop recording under conditions where no effective movement was taking place. Therefore, we specified that the device should stop recording data points when there has been no movement for 30 seconds, but should resume recording as soon as movement resumes.

4 Actual Specifications for a New Wearable Device

The actual specifications that could be achieved were not always the same as those we had specified for the ideal case. In terms of the form factor, we succeeded in having a device developed that is about the size and weight of a mobile telephone, as shown in Figure 3. The *Neve Steplogger* uses a uBlox antenna/receiver and custom circuitry for processing and storing data, unlike the device shown in Figure 2, which uses a Garmin GPS receiver. The device weighs 103 grams, and is shorter, but thicker than a standard mobile telephone.

In addition, the device also comes with a case that has a clear front and a belt clip on the back. The loop for the key ring was an afterthought. However, after seeing early prototypes, we suggested this addition as a method to make it more likely that the device would be carried. Given that we had backed away from making the device a functioning mobile telephone, the key ring idea was an alternative to try to make sure that the device would be carried by respondents. It is suggested that respondents attach there existing key ring to this ring, so that the device is always with their keys. This also means that the device will normally hang in an almost vertical position when attached to the key ring on which there is an ignition key, thereby providing an optimal orientation when in the car. Comparing Figure 2 and Figure 3, it can be seen that this new device is very much smaller than the first generation of wearable device. The device shown in Figure 3 includes the battery, the antenna/receiver, and the logger.

The battery life of the device is significantly less than had been desired, but is the maximum that is currently available at this size. The battery runs for about 18-20 hours if the device is unused. If recording position for a normal period of an hour or so per day, then the battery will last between 12 and 16 hours. Normally, this is sufficient, provided that respondents remember to plug the device in to a charger overnight. The battery recharges fully in about 2 hours and cannot be overcharged. Therefore, leaving the device plugged in overnight will not result in any harm to the device.

Figure 3: New GPS Device Compared to Mobile Telephone

When we were testing the device, we found that it was very easy to unintentionally turn off the device, when it was dropped into a pocket or a bag. The red and white button on the front of the device is the on-off switch, or more correctly was originally the on-off switch. As a result of the unintended turning off of the device, we requested that this switch turn the device on only, but not off. This is now the function of the switch. It is an on-switch and the device cannot be turned off by the user.

In tests that we have made with the device, once it has acquired position, it is able to hold position with the device in various configurations. We have found it can keep position when in the pocket of an outside article of clothing (although not when in a pocket of an inside article of clothing, such as being in a jacket pocket when a raincoat is worn over the top. In most situations, it keeps a signal when clipped to the belt, or when placed in a handbag.

Time required to acquire position has been found to be highly variable. If the device remains static, position acquisition appears to take from as little as 15 seconds to as much as 120 seconds. If the device is put in motion immediately that it is taken out of a building, then acquisition of position may take as long as 15 minutes or more, depending both on speed and the presence or absence of tall buildings, dense tree canopies, etc. This appears, as best we have been able to determine, to be about the norm for current GPS devices. Indeed, the earlier versions of a wearable device have a similar position acquisition time, and newer GPS receivers do not seem to have made much difference in this. For the StepLogger (the device shown in Figure 3), the manufacturer experimented with improving the shielding of the antenna/receiver, and provided some gains in this area from the original design. However, the device can still be slower than desired in acquiring position.

So far as memory is concerned, we found ourselves at the mercy of the chip manufacturers. At the time that the specifications were developed, we had every expectation of being able to obtain 16 Mb of memory for the device. However, when it came time to order this component, it was found that the manufacture of 16 Mb chips had been discontinued. The choice was then to go with a 32 Mb chip, which would have encountered a delay of several months to acquire the needed number of chips, or to go with a smaller 8 Mb chip that was readily available. Because of the need to begin testing and deployment of the devices in the early part of 2005, the decision was to go with the 8 Mb chip. However, this could be changed in the future. In addition, the device comes with a slot that can accept a standard memory card, which is available up to 1 Gb, currently, and will probably be available in multi gigabytes in the not too distant future. At present, this capability is not utilised, partly because we have not resolved the issue of security of the memory card. In the current design, the memory card could be removed by a respondent and used in some other device that accepts the same type of memory card.

There are a number of functions of the final device that are also able to be changed by the user, through the software dialogue box (Figure 4). One of these is the frequency of position recording. Currently, we are recording position every second, which we have found to be ideal for walking and public transport trips. Longer periods can be set through the software interface, with logging intervals being able to be set to any interval required. Another feature that is programmable is whether or not the device logs all data points or whether it attempts to detect when it is stationary and does not record those points. Currently, we are using the devices with no recording of data points, when the device appears to be stationary (i.e., when the velocity is zero). We also currently have them set to “sleep” after 180 seconds if there are not the required number of satellites in view. The device sleeps for 90 seconds at which time it “wakes up” for another 180 seconds to again search for satellites. Once the required number of satellites have come into view and position has been acquired, the device continues to record data until no GPS signal is being received such as when the device is inside a building or a tunnel. This saves both on storage requirements of the logging data and on power consumption. It is possible, and more desirable, if battery life allowed for, to have the device on “continuous tracking” in which case the device never sleeps. Instead, it is constantly looking for satellites and when GPS signal is received it is constantly recording data.

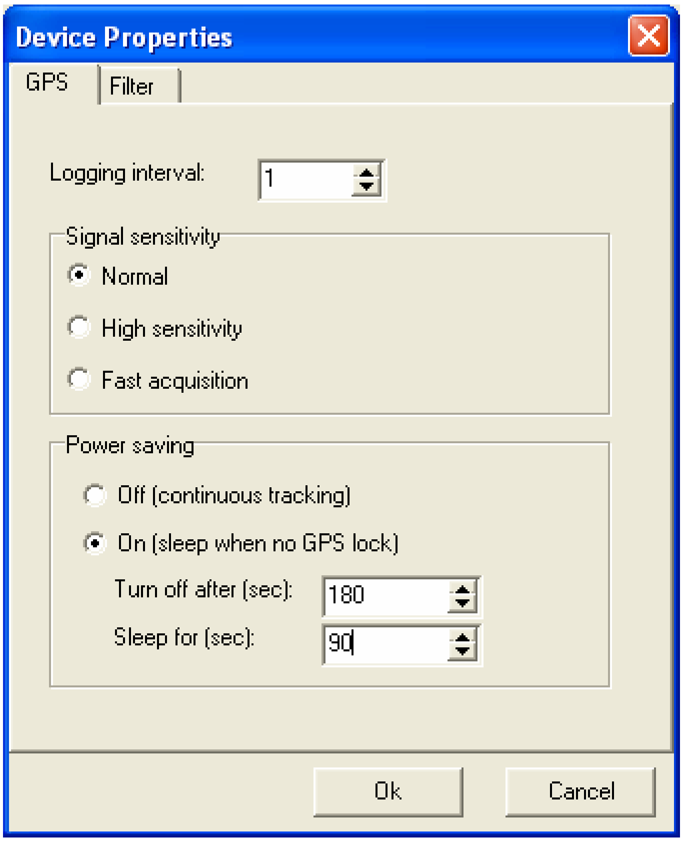

Figure 4: Software Dialogue Box for the Step Logger

There are four lights on the front of the device which assist in determining how the device is functioning. On the extreme left, as one faces the device, is a status light. This light flashes once every 5 seconds, when the device is on, irrespective of whether there is GPS reception. When the device is turned off, or the battery has been exhausted, this light is off. Next to it is the battery status light. When the device is running low on power, this light will flash. This occurs for about the last half hour before the battery is totally drained. When the device is plugged in and is charging, the battery light is on and steady. Once the device is fully charged, but still plugged in, the battery light turns off. The third light from the left is the GPS indicator. This light is on and steady when the device is receiving GPS data and recording its position. Thus, in normal operation, the leftmost light would be flashing and the third light from the left would be steady. This means the device is successfully recording position. The rightmost light is the memory light and comes on as a steady light when the memory of the device is full. It indicates that no further data are being stored. When the device is turned on, all four lights will flash together five times at one second intervals. After that, the status light should flash every 5 seconds, and the other lights will be off until position is acquired, when the GPS light will come on.

On the bottom of the device, there are three sockets. One of these is for the power input to recharge the battery. It is a simple circular socket that accepts a standard one-pin plug. The charger is capable of receiving 90 to 264 volts AC, with a cycle rate of from 47 to 63 Hz, therefore being suitable to just about any domestic electrical system in the world. Output is 6 volts DC and 2.5 amps, which, as noted earlier, will recharge the battery in about 2 hours. The other two sockets are for data transfer, although only one of these is currently used.

The data are downloadable using the Winstep® software provided by the manufacturers (Figure 5). While download times are clearly dependent on the amount of data recorded, we have figured on roughly 30 - 45 seconds/day of data, which is clearly an acceptably short period of time. The resulting data file is of *.dat format, which can easily be converted to *.csv or other formats as required.

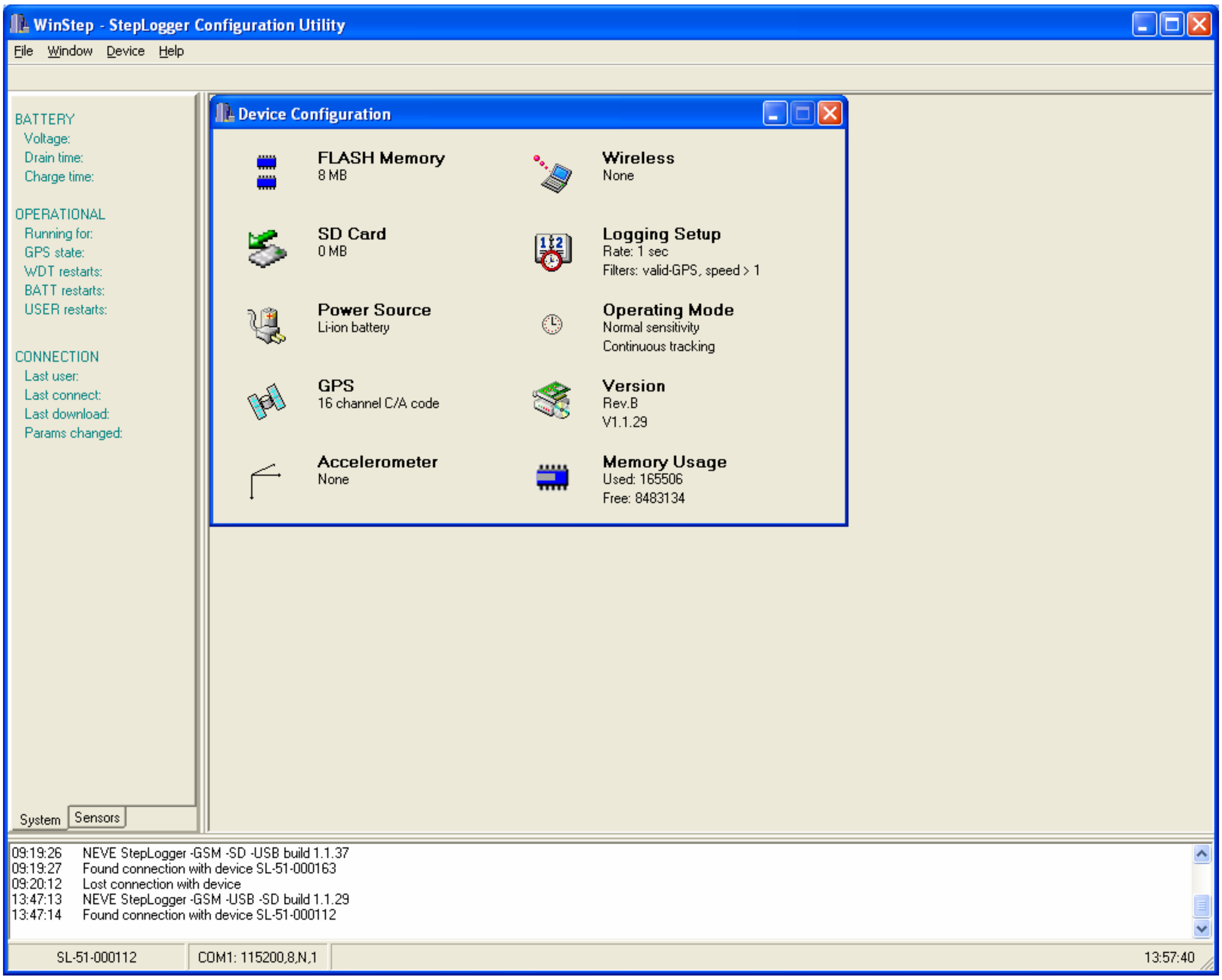

Figure 5: WinStep Data Downloading Software Screenshot

5 Deploying the Device

5.1 The South Australia TravelSmart Pilot Survey

Possibly one of the advantages of this device is that there is no obvious value of it to the average person. Therefore, there is little reason for a person to try to keep the device beyond the survey period. Even though the devices are quite expensive (currently about AU$950 each), there is little potential commercial or other value in the devices from the viewpoint of the average survey respondent. This was also true of the earlier GPS devices we have used, whether in-vehicle or wearable. It is an important point to bear in mind. If we make the devices too functional, we may encounter serious problems about getting them returned. However, the black box nature of this device is probably a considerable asset at this point.

We are currently field-testing the devices as part of a pilot study for evaluating travel behaviour change policies in three regions of Adelaide, South Australia, namely Port Adelaide, Charles Sturt and Holdfast Bay. In this study, the aim was to recruit a total of 50 households and have every eligible person[1] in the household record one week's worth of GPS data. As with Canberra, in addition to all the other advantages of using this technology for recording personal travel data, the other distinct advantage is that we are

[1] For ethical and pragmatic reasons we are only including persons over the age of 14

able to record over extended periods of time – shortly we will also be testing the practicality of collecting data using these devices over one month in Adelaide.

While the developments in form factor will (we believe) lead to greater uptake and use of the device, there is still the initial challenge of getting people to agree to take it in the first place. Based on our experiences in Canberra and Sydney, we adopted initially the following recruitment process for the pilot. First, a package of materials was sent out to potential respondents, which comprised a pre-notification letter, subject information statements, a consent form, and a household and vehicle form. At this point, respondents were given the option of sending back the forms in the post, or sending back the consent form only stating they would give information over the telephone, or simply do nothing. For those who sent forms back in the post, the survey firm called to arrange delivery of devices with a similar procedure adopted for those who chose the phone option. Telephone follow-ups were also made to those who did nothing to try to encourage their participation.

Recruited households were sent the GPS devices by courier – we have found this to be preferred over other options such as registered mail. Households were then called on the evening of delivery to confirm they have received the devices and were reminded to start using them the next day. Devices were used for the week and then a call was made to remind them to have the devices ready for pickup by the courier on the next working day. The devices were then couriered back to ITLS, where the data were downloaded and processed using the procedures described previously.

Following consultation with the project sponsor, we also tested the impacts of a monetary incentive of $5 for every household member over 14 years of age (i.e., $5 per device). Forty households in the Pilot were offered the incentive (with the initial expectation that 20 would take part), while the remaining 80 households were not offered the incentive (with the initial expectation that 20 would take part). The recruitment and refusal rates are summarised in Table 1. The overall recruitment rate (based on eligible and contactable households) is approximately 26 percent, which is about what we might have anticipated. The unforeseen factor in this has been the number of households, which have been genuinely non-contactable (invalid telephone numbers, return-to-sender, etc.). They accounted for 18 percent (22/120) of the original sample. Further details of this pilot survey are provided elsewhere (see Stopher, et al., 2005).

Table 1: Sample Disposition for the GPS Pilot Survey – Initial Sample

	AU$5 Incentive/device	No Incentive	Total
Total Sample	**40**	**80**	**120**
Known Ineligible (Invalid numbers, known ineligibles, return-to-sender)	5	17	22
Known Eligible Households	**25**	**36**	**61**
Eligibility Rate#	83%	68%	73%
Unknown disposition	10	27	37
Potentially Eligible Sample##	**33**	**54**	**88**
Refusals	18 (55%)*	19 (35%)*	37 (42%)*
Recruits	7 (21%)*	16 (30%)*	23 (26%)*

Known Eligible/ (Known Eligible + Known Ineligible)
Known Eligible + Unknown*Eligibility Rate
* Percentage of potentially eligible sample

The other surprise was the lack of impact of the incentive in overall recruitment rates. In fact, the refusal rate was actually significantly higher for those households offered the incentive (55 percent) compared to those offered no incentive (35 percent). Based on our previous experience, Australians generally react negatively to small monetary incentives, so it may be a case of either providing a more meaningful incentive (for instance, the original Lexington GPS study provided a US$50 incentive), or, more realistically, not providing an incentive at all.

In terms of why participants do not want to participate, Table 2 provides a summary of the reasons given based on an exit question for those that refuse. It is revealing that over half the refusals do take the trouble of providing a genuine reason suggesting some sense of feeling that an explanation is due. Of these participants, the majority cite issues that are commonly given for non-participation in surveys, such as health-related issues (either for themselves or a family member), language barriers, and non-mobility. Interestingly, only a handful of refusals have cited issues, which might on the surface seem to be most of a barrier to this survey, namely carrying the device, the length of time, and the perceived personal security threat.

Table 2: Summary of Reasons Given for Non-Participation

Reason	Count
Not Interested	18 (49%)
Health-related reason	6 (16%)
Language barrier	3 (8%)
Don't go anywhere	3 (8%)
Impractical, can't carry device around	2 (5%)
Survey is too long	1 (3%)
Threat to personal security	1 (3%)
Other	3 (8%)
TOTAL REFUSALS	37

All 23 households from the initial sample were sent GPS devices and all 23 returned them after one week of use. Because this sample fell well short of the goal, we undertook a second recruitment for the GPS survey, but this time, sampled households were those for which we were able to obtain a telephone number, to match the household address that was used in the sampling. Sampled and matched households were sent only a pre-notification letter, after which they were recruited by phone and were then sent the package of materials to complete, together with the GPS devices for the household. (Recruitment included obtaining some basic household data to allow us to know how many devices to send to each household.) The results of this recruitment push are shown in Table 3.

Table 3: Sample Disposition for the GPS Pilot Survey – Second Sample

	Total
Total Sample	**160**
Unused Sample	18
Known Ineligible (Invalid numbers, known ineligibles, return-to-sender)	42
Known Eligible Households	**93**
Eligibility Rate#	69%
Unknown disposition	7
Potentially Eligible Sample##	98
Refusals	61 (62%)*
Recruits	32 (33%)*

Known Eligible/ (Known Eligible + Known Ineligible)
Known Eligible + Unknown*Eligibility Rate
* Percentage of potentially eligible sample

The response rate for the second method is higher than the no incentives response rate of the first recruitment method, showing that this method is a better method for recruiting. At the time of writing, 42 of the households in the pilot group have returned GPS devices, with 94 persons using the GPS devices (2.24 per household). From a preliminary analysis, these 94 persons provided an average of 6.4 days of data. (We would expect 6.3 approximately, assuming that there is an underlying non-mobility rate of 10 percent.) On the average, we have retrieved data on 20.4 trips per person, which gives an average of 3.2 trips per person per day. The average distance of recorded trips is 5.4 kms and the average duration is 11.6 minutes. This covers trips by car (as driver or passenger), by public transport, walk, and bicycle. The numbers of trips are, at this stage, a mix of linked and unlinked trips, because any trip that involved a wait at a location to board a vehicle during the trip will have been recorded as separate trips (broken by the wait), whilst any trips in which no wait occurred would be recorded as a single trip. In some instances, if the person waited in a location where the signal was lost, but did not wait for more than a few minutes, the segments of the trip would not have been separated.

5.2 Initial Insights From the Pilot Survey

At this point, several insights can be described. First, there appears to be little merit in offering a modest incentive to use the GPS devices in the South Australian context. Second, the recruitment and completion rates for the GPS survey as a panel survey are comparable to the rates normally experienced today in Australia for a one-time cross-sectional survey using a more conventional paper diary. Therefore, it appears that the GPS survey itself is well accepted at this point as an alternative to a paper diary. Third, the compliance with taking the device with a person whenever he or she travels appears to be high, at about 91 percent. Therefore, it appears that the device that has been designed is acceptable to people to use. Anecdotally, one person complained of the device running out of power during the course of his day, noting that he normally is out for over 14 hours each day and travels a lot. This suggests that any improvement in battery life that we can achieve would be worthwhile. Also, these devices were not provided with a cable to plug into a cigarette lighter socket in a car, but this would also be useful for the future, to assist those who travel a great deal during the day.

Finally, it is noteworthy that problems of privacy do not arise as a significant problem mentioned by people concerning using these GPS devices. It is almost universally the case that professionals, discussing the use of such tracking devices, assume that privacy issues will be the foremost issues that will result in refusal to participate in such a survey. In common with our experience with the earlier designs of devices, we have found this not to be the case.

6 Conclusions

We believe that wearable GPS devices have a significant future in transport planning applications. The substantial miniaturisation that we have been able to achieve with the newest device makes it much more likely that people will use the device. So far, while a 26 percent recruitment rate is lower than one would ideally like, there is the potential that this rate may yet rise. We are subsequently experimenting with alternative methods of recruitment, from which it may be possible that higher response rates can be achieved. Preliminary evidence shows that, at least in South Australia, a small monetary incentive is of little value in improving response, and may even have acted as a deterrent. It will be important to determine whether there are any apparent biases in the recruited respondents, compared to the full population.

We also believe that there are potentials to make the GPS devices more useful. There is already the possibility to make them into functioning mobile telephones, although we decided that this was not as useful as it first seemed. The manufacturer also tells us that it would be easy to add the capabilities of an MP3 player. Other possibilities may also be considered. To the extent that functionality can be added that does not increase the risks of people not returning the devices, this may also help to make the devices more acceptable for use. However, we are very much mindful of the fact that making the devices too useful to users may result in a problem about getting the devices returned at the end of the study.

A third direction of potential development is the addition of a second positioning capability, so that when GPS signals are lost, some other positioning process, less accurate than GPS, may be able to take over. One possibility here is the use of triangulation to mobile phone antennae. Other possibilities are also being explored. The devices described herein also have a capability for GPRS communication, although we did not choose to activate this. With this activated, data on position can be collected in real time. Another possibility would be to add a button to the device that a person would press each time a new trip is started and each time a trip is ended. This information could be sent by GPRS, while position information is still stored on the device.

We have also recently learned of some new developments for the technology that is described here. There is now available a new antenna/receiver that promises much greater sensitivity, such that it can even record position inside a building, and is able to provide position acquisition in about 5 seconds. We are about to begin testing this to see if it lives up to the manufacturer claims for it. Second, we have determined that there is a capability to record the time when movement begins and when movement ceases, even if position is not acquired at the time the trip begins or ends. This will provide much better information for use in the software for inferring missed travel and stops. There is also supposed to be a new battery with about 30 percent longer life than the present one we are using, but of similar weight and dimensions.

With the many potential future directions for development, we believe this technology represents a major future means of tracking person travel. It is simply a matter of determining in which directions to move with it, and to develop the new capabilities.

7 References

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