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Exploring the Use of Passive GPS Devices to Measure Travel

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ABSTRACT: Global Positioning System devices are emerging as a potential means to collect improved data on the spatial aspects of personal travel. In many applications, the GPS device is coupled with a Personal Data Assistant of some type and the respondent who is using the GPS device is required to enter various data items at the start of each trip made with the device. This procedure has the disadvantage that it relies on the memory of the respondent to use the PDA, and also is subject to being missed if the respondent is in a hurry.

This paper builds on earlier work by Stopher and others to develop a passive GPS device, for which additional non-GPS data may be added either through inference or through a subsequent prompted recall survey. The paper describes the use of both in-vehicle and personal versions of a GPS device that logs position in one- or five-second intervals and has a number of other capabilities, such as turning off automatically when speed drops below 1 knot. Experiments have been performed in which the devices are tested for a range of different situations, including collecting data for one month, collecting data on trains, buses, and ferries, and experimenting with automatic on/off procedures.

The paper reports on a number of experiments, describes the procedures undertaken to download and analyse the data, and processing of the data for the prompted recall surveys. Initial results are included on experiments with the prompted recall, and options to develop this as an internet survey are explored.

In addition, analysis of the data is conducted to investigate congestion and the amount of time spent under congested travel conditions. Potential applications of this analysis to a variety of purposes is described in the paper.

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Introduction

A persistent problem in household travel surveys (HTS) is the inability of subjects to provide accurate geographic information about their origins and destinations, and accurate, objective data about trip times and distances. Most people know their home address. Many workers know their workplace address; few parents or children know their school addresses. Few, if any, can provide the street address of the places where they shop, and many will not know the street address of friends and relatives that they visit in the local area. Other addresses, e.g., for churches, restaurants, banks, etc. are not known. This results in a lengthy, costly geocoding effort that still leaves 10 to 20 percent of non-home, non-work locations uncoded, with a consequent loss of the data. Other addresses may be coded imprecisely, because it cannot be determined on which side of a street or intersection the visited location is sited.

People report perceived travel times and distances. The content of the time, e.g., travelling in heavily congested conditions, riding on an overcrowded bus, or travelling with a friend, will lead to major differences in perception and reporting of travel time. Negative content of time leads to overestimates of time and distance, while positive content leads to underestimates. In addition, depending on the nature of the survey, people may intentionally misreport times or distances to justify some perceived value judgement in the survey.

Most transport planners would like to collect route-choice data. However, those that have attempted this task have almost invariably failed. A few surveys have been able to determine freeway use on a trip. The lack of empirical data on route choice is one reason that most traffic commonly-used assignment procedures are based on minimising travel time, although it is widely recognised that this is not the correct paradigm.

Recently, GIS applications in transport have enabled attempts to deal with the problem of unknown trip-end addresses by equipping interviewers with computerised gazetteers. These allow them to probe subjects intelligently about the locations of trip starts and ends. However, the up-front costs of compiling such a gazetteer are large compared to the data-collection task. This method has had only limited success in dealing with the geographic location issue. It does not deal with the issues of accurate times, distances, or routes.

GPS As A Solution

Active GPS

In the past few years, GPS has been proposed and applied in several cases as a means to collect data on trip origins, destinations, travel times and distances as a supplement to household travel surveys (Wagner, 1997, Wagner *et al*., 1998, Guensler and Wolf, 1999, Draijer *et al*. 2000, Stopher and Wilmot, 2000). Initial tests have involved the use of a GPS receiver and antenna connected to a personal data assistant (PDA), where the respondent must perform the following functions:

- Turn on the GPS and PDA at the start of a trip.

- Respond to screen-displayed questions by entering data into the PDA prior to starting the trip.
- Turn off the GPS and PDA at the end of the trip.
- Enter corrected data, if an unplanned stop is made in the trip, other than for traffic.

Data such as the occupancy of the private vehicle, the trip purpose of each individual in the vehicle, the relationship of other occupants to the driver, and trip costs are also required. These data items cannot be collected by the GPS antenna alone, thereby necessitating coupling the GPS to a PDA and requiring data input by the subject. Recent work by Wolf *et al*. (2001) has shown that it may be possible to infer trip purpose accurately in a majority of cases, if one has parcel level land use data. This still leaves such items as occupancy, purposes of other occupants, and costs unanswered and will not provide a means to obtain needed public transport trip attributes, when the technology is extended beyond the car.

One of the greatest assets of GPS, besides the accurate reporting of trip geography is the capability of collecting data for several days at a time. Recent effort in HTSs has been devoted to extending the time period of collection beyond a single 24-hour weekday period (TMIP, 1996, NCHRP, 1996). In one recent survey (Axhausen, 2001) in Europe, the time was extended to six weeks, although it seems unlikely that this can be achieved as a general rule. Data tend to degrade after one or two days, response rates fall, and item nonresponse increases. In contrast, only its data storage capabilities limit the duration for which the GPS unit can be used. Depending on the accuracy of route data desired, it is possible to collect data for several days or even weeks with currently-available devices.

GPS has been restricted generally to collecting data for private car trips, where the GPS device and the associated PDA are installed in the car, and powered from the cigarette lighter/accessory outlet. Some trials have been attempted with personal GPS units. However, tests in the Netherlands (Draijer *et al*., 2000) found that people intentionally left the devices at home when making shopping trips, and certain social and recreational trips. They were also reluctant to use the devices when bicycling, mainly because of the weight. New, lighter, and less cumbersome units are under development and may solve this problem. However, for the moment, GPS applications are limited to use in the automobile.

A problem with the GPS-PDA is the opportunity for non-compliance. Subjects may forget to turn on the device, or may be too rushed to enter data before starting the trip. Correction for an intermediate stop is also onerous and may be skipped. Other problems with GPS-PDA devices are discussed by Stopher, Bullock and Greaves (2001), including cost, installation, programming, and assembly. However, the GPS-PDA has continued to be used in HTSs and has been deployed in subsequent surveys, e.g., Atlanta (Wolf *et al*., 2000).

Passive GPS

Passive GPS removes the PDA, and eliminates subject intervention. Using off-the-shelf GPS equipment, Bachu *et al*. (2001) performed a proof-of-concept experiment in which the PDA was eliminated and the respondent required only to turn on the GPS device before starting to travel. The remaining data were collected through a prompted recall survey, using the information about travel time and location to help subjects recall what they did.

The Survey Protocol

Each household in the sample is provided with a GPS unit for each vehicle owned or available for use by household members. The unit is to be placed in a vehicle for a pre-specified period of time, during which it will record the location of the vehicle and time of day, whenever the ignition is on. One of these units is shown in Figure 1.

Figure 1. An in-vehicle GeoLogger

During recruitment or when delivering the GPS units, household members are asked to provide addresses for home, the workplaces of each worker, the school name and address for each school child, and the name and location of two or three grocery stores frequently used by the household. If complete addresses are not known, data on the business name and approximate location are sought. These are then located by means of secondary sources to an exact address. In many areas, GIS maps are available that show and name schools, which can be used to help locate the schools of each recruited household.

After retrieving the GPS units, the data are downloaded, and the travel performed in each vehicle is reconstructed on a GIS, together with a tabulation of the locations of the origins, destinations, and the days and times when the travel took place. This is a non-trivial task, involving rules for identifying when there is a trip end, and removing poor quality data points that may hinder identification of the track, such as points interpolated by the receiver, and points that are recorded with insufficient satellites in view (Stopher and Bullock, forthcoming). The trips defined by the mechanistic rules are reviewed, to determine if the application of the rules appears to have produced plausible trips. There are potentials for any set of mechanistic rules to confuse traffic stops for destinations, and to miss actual destinations that have a very short duration, e.g., a pick up or drop off activity, and use of a drive-through facility.

Figure 2 shows a download of a day's worth of data from a GeoLogger. Each programme-defined trip is normally coded in a different colour, however labels are used to show the trip ends here. The figure shows the individual tracks as identified with the software procedure, ready for inspection, prior to formalising as plausible trips. There are three trips shown on the map. The prior information collected on locations used by the household is added to the map, and the track points are converted to a line for each trip. This is shown in Figure 3.

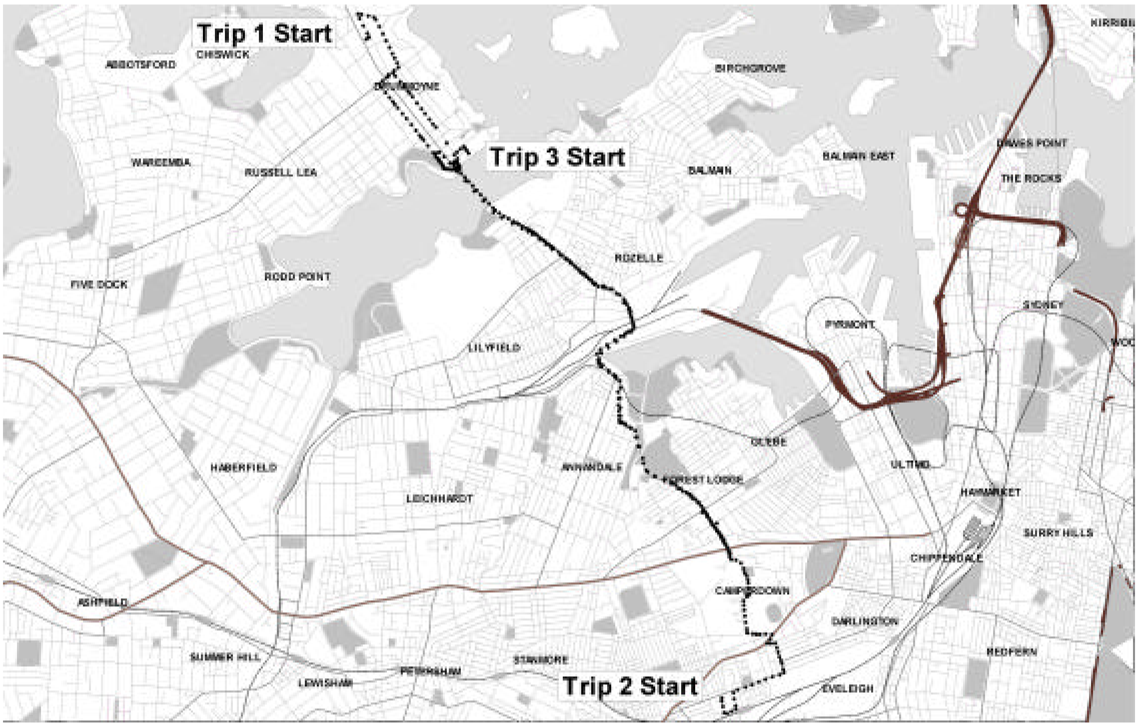

Figure 2. GPS tracks for one day

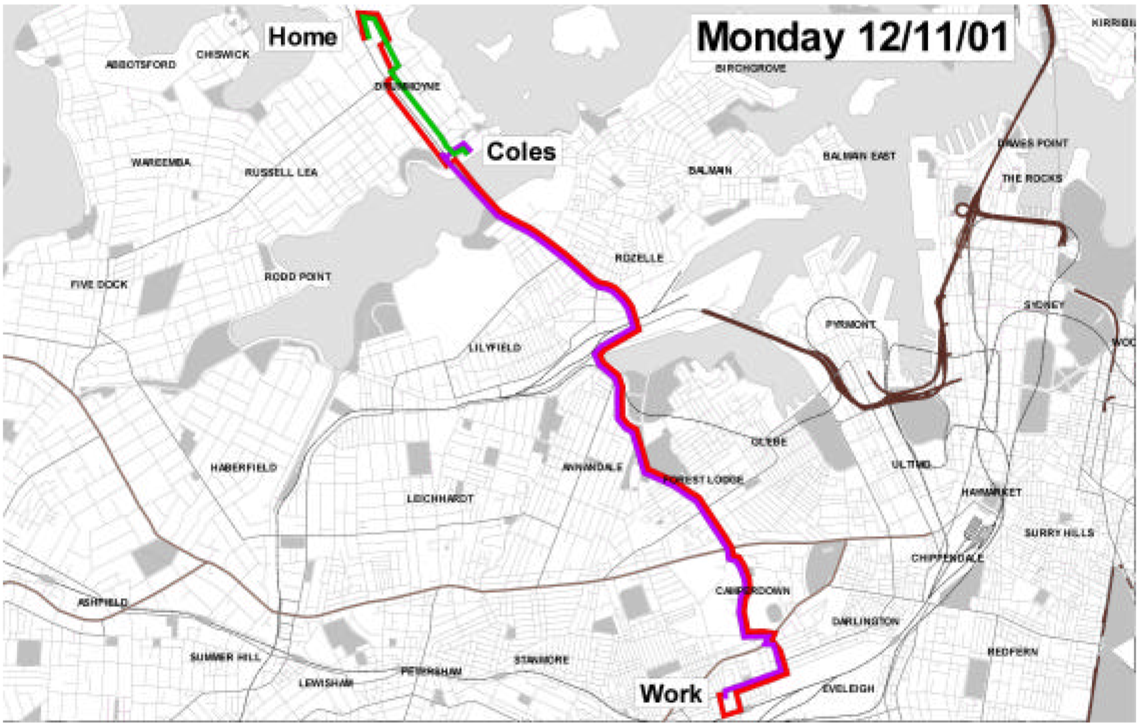

Figure 3. Line representation of tracks

A tabular representation is also produced, as shown in Figure 4. The origins and destinations that could be identified from the recruitment interview are included in the table and shown on the map. Those that cannot be identified are left blank. The table also shows the start and end times of the trips, the travel time, and the distance. Space is provided for entering the additional data on the driver, the driver's trip purpose, the number of occupants, and the trip cost. Additional questions are asked about the purposes of other occupants, besides the driver.

ROUTE ID	ROUTE NAME	TIME START	TIME END	ORIGIN	DESTINATION	TRAVEL TIME	DISTANCE
1	Trip 1 7 July	9:11:01	9:17:26	Home	Vumbaca's	6.42	3.18
2	Trip 2 7 July	9:34:03	9:35:53	Vumbaca's	Coles	1.83	0.76
3	Trip 3 7 July	10:15:50	10:21:42	Coles	Home	5.87	2.46
4	Trip 4 7 July	11:04:38	11:15:27	Home		10.82	5.54
5	Trip 5 7 July	12:34:26	12:49:06		Home	14.67	4.70

Figure 4. Tabular presentation of travel recorded by GPS

After the data have been compiled, the household is re-contacted and those members of the household that drove the car are interviewed. In the interview, the tabular presentation (Figure 4) of the travel performed is shown to each respondent, as well as the maps (Figure 3), if desired. These are used to prompt recall of the travel. For each trip identified, the additional desired data are requested, e.g., occupancy and identity of occupants, trip purposes, and parking costs. Respondents are also asked to identify any intermediate stops that were made that are not shown in the record, and also to confirm that all trips were to specific destinations, i.e., that the data processing has not identified a traffic stop or some other non-destination stop as a stop with a purpose for one or more of the vehicle occupants. The interview can be conducted in at least four ways:

- As a face-to-face interview;
- The maps and tables can be mailed to respondents and a telephone interview conducted;
- The maps and tables can be mailed out, with provision of places to fill in the information desired, and requesting respondents to mail the materials back; or
- The maps and tables can be provided on the Internet for an interactive web-based response.

Tests of the Protocol

Initial tests of a prompted recall protocol were designed and run at Louisiana State University in 2000 (Bachu *et al.*, 2001). At the time of writing, further tests were underway in Sydney, Australia. A pre-pilot survey was undertaken at ITS in Sydney in late 2001, in which several households of staff of the Institute were recruited and asked to place GPS units in all vehicles used by household members for one week. On the last full day that the GeoLoggers were in the vehicles, all household members were asked to complete a travel diary. In this case, the diary was a time-use diary, originally designed by Stopher and Wilmot (2001) and adapted for use in Australia. The purpose of this was to test the extent to which the data collected by the GPS are any less or more complete than from a time-use diary.

Preliminary Results from the Pre-Pilot

At the time of writing, results had been obtained from five households, consisting of one three person household, two two-person households, and two one-person households. For one of the two person households, no diary was obtained from the second person. In the other two-person household, one of the two adults travelled to work by train (as well as driving for part of the journey). That person was given a personal GeoLogger for seven days, rather than an in-vehicle one. The results of the personal GeoLogger have been combined with the vehicle GeoLogger results. The four subjects each kept the GeoLogger in their cars for between seven and eight days. Data were obtained on 236 trips, for which some summary data are provided in Table 1.

Table 1. Statistics from the GPS data collection

Statistic	Minimum	Maximum	Mean	Standard Deviation
Number of Trips	15	43	4.00/day	-
Number of Weekday Trips	11	41	4.17/day	-
Number of Weekend Trips	2	14	3.69/day	-
Trip Length (minutes)	0.53	157.17	21.17	29.47
Trip Length (kms)	0.13	106.02	11.65	15.85
Average Speed (kph)	3.25	62.85	30.00	12.24
Average HDOP value	1.21	5.46	1.93	0.48
Average number of satellites	2.63	9.99	6.67	1.50

Table 1 shows person trip rates of four trips per day per person which is close to what is usually found in diary surveys. The data recorded are generally of high quality, as shown by an average of more than six satellites in view and an average HDOP of just under 2. The prompted recall surveys were conducted between two and 20 days after GPS device retrieval. There was a slight problem in recollection of trip details in the case of the 20-day time lapse, but none with the others. Among the shorter time lengths (2-14 days), there was no detectable difference in the ability of subjects to recall the additional data about their trips. The algorithm for detecting trip ends worked well. There were five superfluous trip ends, of which three were extended traffic stops, one was a search for parking and one was a case of listening to the radio for a time before turning off the ignition. There were four missed trip ends, which were pick up and drop off activities.

For the activity diary day, the five households reported making 25 trips, while the GPS devices recorded 28 trips. This is a 12 percent increase in trips recorded by the GPS compared to the diary and is consistent with results found in California. Respondents were asked to indicate the start and end time of each activity and also to estimate the distance travelled. The results are shown in Table 2. The double lines set off divisions between persons.

As shown in Table 2, four trips were incompletely recorded by the GPS devices, because of problems with building canyons. Three trips that were recorded by the GPS devices were not recorded in the diaries. While the sample is very small, this rate of under-reporting is consistent with other results obtained from recent surveys. There is strong evidence in Table 2 of the rounding of reported start and end times, which leads to most reported travel times being a multiple of 5 or 10. This also leads to overestimates of travel time in all but one case, which is where two trips were reported as one in the diary. Given the missing trips, there is an overall over-reporting of travel time of 12.8 percent. However, if the comparison is made to only those trips recorded by both the GPS and the diary, the travel-time discrepancy rises to 22.4 percent. In terms of vehicle kilometres, the results are somewhat similar. In only five cases did respondents underestimate distance. Overall, there was an 8 percent error in the reported vehicle kilometres, with respondents estimating approximately 25 VKT more than was recorded on the GPS devices. Comparing only the trips that appear in both the GPS and diary records, the under-reporting of distance decreases to 15 kilometres, or 5 percent.

Table 2. Comparison of diary and GPS results for 4 households

Trip	Travel Time			Travel Distance		
	Diary	GPS	Percent Difference	Diary	GPS	Percent Difference
1	30	29	4.2	9	7.92	14
2	10	6	54.6	3	1.66	81
3	20	8*	*	10	6.96*	*
4	60	59	1.5	33	32.39	2
5	12	10	23.3	5	3.89	29
6	15	13	18.9	5	3.98	26
7	75	68	10.3	33	32.21	2
8	20	16	26.8	10	6.81	47
9	15	5*	*	6	1.66*	*
10	-†	18	-	15	9.30	61
11	-	1	-	-	0.28	-
12	10	7	45.6	5	5.38	-7
13	20	18	-10.2	6	15.20	-65
14		4			1.79	
15	70	64	9.3	98	87.38	12
16	-	3	-	-	2.29	-
17	73	65	12.7	27	31.4	-14
18	5	1**	**	3	0.30*	*
19	-	1**	**	3	0.18*	*
20	40	46	-12.6	28	32.6	-14
21	-	5	-	4	2.29	75
22	-	4	-	4	2.73	46
23	15	6	171.1	7	2.48	182
24	30	7	330.6	4	3.52	14
25	45	11	305.6	4	4.91	-19
26	-	6	-	3	2.75	9
27	-	9	-	8	7.41	8
28	-	11	-	8	6.33	26
ALL	565	501	12.77	341	316.00	7.91

** For these trips, the first almost 2 kms was not recorded on the GPS because of canyon effects*
*** Little data was recorded for these short trips dues to canyon effects.*
† For these trips, no arrival time was entered in the diary

These results are again consistent with what has been observed in both Texas and California, where the under-reporting of travel time and distance was closer to 5-10 percent, while actual trip numbers were about 25 percent different. As found in those cases, it is short trips that are most likely to be omitted. This also means that average trip lengths, in both time and distance, are shorter from the GPS (17.89 minutes and 11.29 kilometres) than from the diary (31.39 minutes and 13.64 kilometres). These averages are also inflated from the normal, because of one long trip by the fourth respondent, for a distance of 87 kilometres. Examining the detailed records, most of the reported start and end times are within a few minutes of the times recorded by the GPS device, with the expected rounding errors. There is one case only where the discrepancy is a little more, with the diary showing a trip from 7:00 a.m. to 7:10 a.m. that actually took place from 6:44 to 6:51 a.m. according to the GPS. Several respondents did not provide any start or end times.

Following the pre-pilot survey, a full pilot survey will be conducted on a number of households drawn from the Transport Data Centre of the Department of Transport of New South Wales, and also the Institute for International Health at the University of Sydney. It is anticipated that this pilot survey will permit refining the protocols and instruments to be used, and will also provide some additional data with which to begin testing some alternative methods of analysis and factoring.

Investigating Congestion

Traffic congestion causes major levels of pollution in most cities around the world and represents an obvious challenge for transport planners. Traditionally, congestion has been measured using several methods, most of which rely on probe vehicles or static instrumentation. Some of these methods are labour intensive and costly and none are truly accurate. Passive GPS technology represents a more cost effective and accurate method for collecting data about travel activity in congested conditions. Unlike traditional methods for measuring congestion, GPS devices can capture second by second information on vehicle speed, location and time of day while measuring personal travel activity at the same time. To reduce the quantity of data, tracks from the preceding experiment were analysed to show the occurrence of congestion and to estimate the proportion of time spent in congested conditions.

Figure 5 shows a segment of freeway, with grey to black dots showing the GPS track points, coded according to speed (the darker the colour, the slower the speed). Three main areas of congestion are shown along the mainline of the freeway. This segment of freeway is posted at 90 kph maximum speed. The speed profile in Figure 6 shows more clearly what has been happening along this segment. The maximum speed along this segment is 94 kph, while the mean speed is 29.9 kph, and there are several segments where the vehicle was stationary. The speed representing congested conditions could be selected, and the amount of time spent at such speeds can be determined readily from Figure 6. For example, if one were to set 35 kph and below as representing congested conditions, then approximately 8 minutes of the 16 minutes spent on the freeway are under congested conditions.

Other useful data could be obtained from this information, such as acceleration and deceleration rates and periods, which would provide additional data relating to emissions. Space does not permit further investigation in this paper.

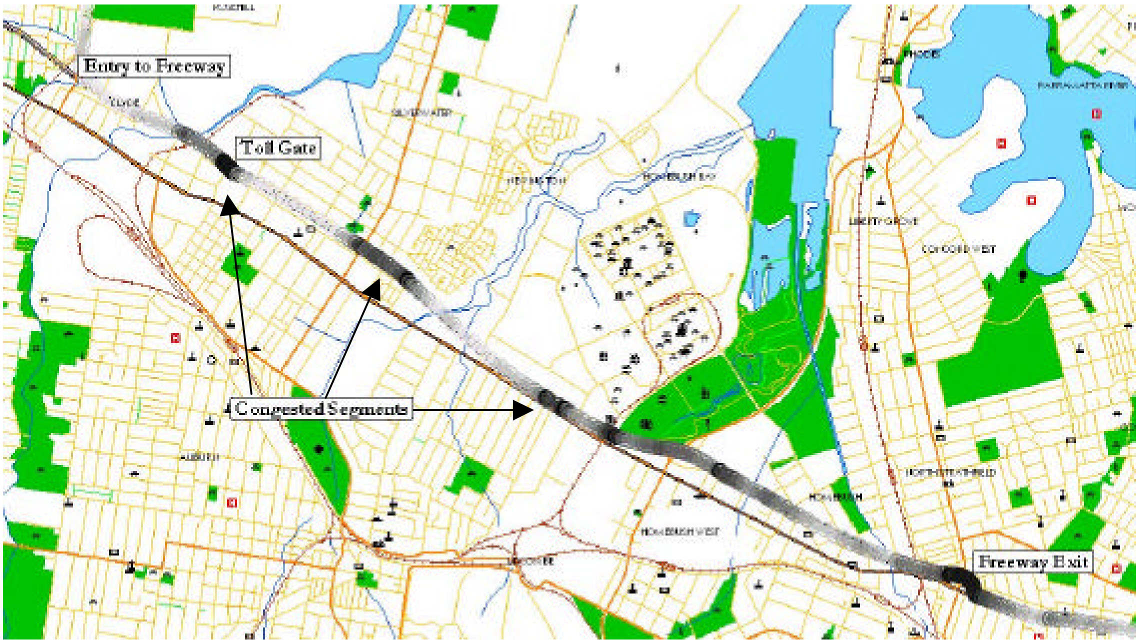

Figure 5. Trace along freeway segment

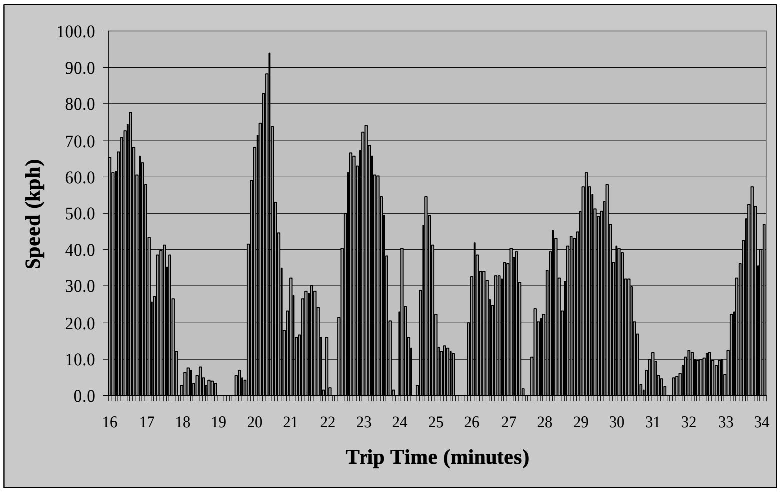

Figure 6. Speed profile along selected freeway segment

Conclusions

The high completion obtained by the prompted recall method with route maps suggest that this technique is successful and can be used for future surveys. The accuracy of the travel time and distance data is clearly demonstrated in the pre-pilot survey, as well as data on routing, origin and destination. The prompted recall was able to complete all of the desired data with ease, even after a lapse of up to 14 days from when the travel was undertaken.

It is not expected that this type of survey would be conducted on several thousand households in a metropolitan area. It holds out promise as a means of correcting data obtained from a standard household survey. While no research has been done on this aspect, it appears likely that further research would produce methods whereby travel times and distances could be corrected, and better imputation could be performed for the origins and destinations that people are unable to identify sufficiently for geocoding in conventional surveys. In addition, there are clear potentials to analyse route choices, congestion, speed profiles, and emissions-related statistics.

The GPS protocol holds out considerable promise of providing a relatively inexpensive and easily-conducted survey that can provide accurate geographic and time data on household members' travel. A high level of accuracy in the data collection is achievable and the device is simple and easy for subjects to use. The prompted recall survey appears to hold considerable promise, and it appears to be worthwhile to examine its sensitivity to elapsed time between the travel and the interview.

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