Further Analysis of Variability of Travel over Multiple Days

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1 Introduction

In the last ATRF meeting, we reported on preliminary analysis of a 28-day GPS survey (Stopher et al., 2006). Since that meeting, we have collected a second and a third wave of data on the same panel, with panel participants providing 28 days of data in wave 2 and 15 days in wave 3. Compared to wave 1, where very few of the panel members provided a full 28 days of data or even 21 days of data, the panel members in wave 2 provided well over 21 days of data in most cases, and then provided 15 days of data in almost all cases in wave 3. This paper reports on further analysis of the variability of travel behaviour by day of week and among individual persons. It provides insights as to the potential benefits of multi-day data for modelling travel behaviour and opens up the potential to undertake a variety of analyses that are not currently possible with one-day data. In this paper, we again examine the effect of additional days of measurement on such measures as the number of daily trips, the travel time per trip and per day, and the travel distance per day and per trip. We analyse the change in the means of each of these values as additional days of data are considered, and also the changes in the estimates of the variances of each statistic. We also separate out the effects of weekdays and weekend days, and consider the implications of these data on sample sizes for modelling purposes, and the likely effects on the goodness of fit of models built on multi-day data versus the more traditional one day of data.

Evidence suggests that while much of what we do is based on routine, there is considerable variability in travel behaviour. For example, Pas (1986) and Pas and Sundar (1995) analysed the variability in trip rates, chaining, and daily travel times from a three-day data set collected in Seattle. They found that the intra-personal variability in trip rates is 38 percent, compared to 50 percent from a data set collected in Reading, England, something attributed to the longer reporting period (five days for the Reading data set). In a more recent study, Pendyala compared intra-personal variability in trip rates and travel times with these earlier studies using GPS data collected for the Lexington pilot study (Pendyala, 2003). He reports that intra-personal variability in trip rates for the three-day weekday sample was 49 percent, which is higher than the 38 percent reported by Pas and Sundar (1995). For the 3-5 day sample, this variability increased to 62 percent, which is higher than the directly comparable five-day Reading survey. The higher intra-person variability captured by GPS is attributed to the fact that it is able to measure infrequent and irregular behaviours that tend to be missed in self-reported diary surveys.

To our knowledge, the longest duration survey completed is the six week MobiDrive survey (Axhausen et al., 2002), which was completed in 1999 in the German cities of Halle and Karlsruhe. The extended nature of the survey enables unique analyses of variability in behaviour. For example, Richardson (2003) analyses the variability of a number of measures of travel behaviour, a summary of which is provided in Table 1. While this does not specifically show the impacts of extending the period to two, three, four, or more days, it is nevertheless interesting to note the reduction in variability that occurs from sampling people on the same day of the week for six weeks and sampling them for one week.

The only other analysis of this type we have found is from the five-week 1971 Uppsala survey, where Hanson and Huff (1988) found that the average number of home-to-home journeys and stops for one selected week were identical to those from the five week period.

Table 1: Day-to-Day Variability from the MobiDrive Data

Measure	*Daily*		*Stratified by Day of Week*		*Weekly*	
	Mean	*CV*[1]	*Mean*	*CV*	*Mean*	*CV*
Person Car Driver Trips	1.19	75%	1.19	56%	8.37	29%
Household Car Driver Trips	2.72	77%	2.72	67%	19.1	30%
Person car driver distance (km)	12.4	118%	12.4	63%	86.8	45%
Household car driver distance (km)	28.4	99%	28.4	79%	199	45%
Person car driver travel time	22.3	107%	22.3	59%	156	42%
Household car driver time	50.9	93%	50.9	72%	357	38%

[1] CV is the coefficient of variation, i.e., the standard deviation divided by the mean.

2 The Data

In September-December of 2005, we set up a panel of households in which household members were asked to take a GPS device and carry it with them for the following 28 days. The GPS device was a small personal device, about the size of a mobile telephone, and devices were provided to each household member over the age of 14. At the time of the original recruitment, households were told that there would be one or two additional waves of measurement that would take place at approximately 6-monthly intervals. Only those households that indicated agreement at that time to undertake the multiple waves of the survey were actually recruited for the panel. The second wave of the panel was conducted in March-April of 2006 and the third and final wave was conducted in September-November of 2006. The goal at the outset of this work was to set up and maintain a panel of 50 households. However, by the third wave, no additional recruitment was undertaken to make up for households lost to attrition, so the panel was allowed to decline in size. Table 2 shows the results of the recruitment of the panel members and the retention and make up for attrition that was experienced in this panel.

Table 2: Sample Disposition for the 50-Household Panel

Disposition	*Wave 1*	*Wave 2*	*Wave 3*
Initial Sample	288	90	-
Known Ineligible Households	81(28.1%)	27 (30.0%)	-
Unknown Disposition	0 (0%)	0 (0%)	-
Estimated Eligible Households	207[1]	63	46
Refusals	150 (72.5%)	46 (73.0%)	0
Recruited (New Recruits)	57 (27.5%)	17 (27.0%)	-
Completed (New Recruits)	50 (24.1%)	14 (22.2%)	-
Continuing Households Recruited	-	35 (70.0%)	44 (95.7%)
Continuing Households Completed	-	32 (64.0%)	36 (78.3%)
TOTAL Complete Households	50 (24.1%)	46 (40.7%)	36 (78.3%)
Households failing to comply	7 (3.4%)	3 (4.8%)	1 (2.8%)

As can be seen in Table 1, the initial wave had 50 completed households in it, as intended. In the second wave, the three households that did not comply were not identified as such until after all fieldwork was completed, so additional sampling to replace them was not possible within the time frame of the wave. Therefore, the sample dropped to 46 households. In wave 3, 44 of the 46 households were recontacted and agreed to participate in the third wave, although only 36 actually completed the GPS task in this wave. Table 2 shows the number of days of complete data obtained by person. It must be kept in mind that most people will stay at home all day on usually at least one day per week. Indeed, travel surveys in Australia generally report a non-mobility rate, i.e., a percentage of days on which people do not leave the home, of around 20 percent. This would mean that, for most people, if there are data for at least 5.6 days per week on average, then their data are likely to be complete. Further, for people who do not work, especially retired persons, the percentage of days with no travel is likely to be much higher. Table 3 shows the number of days for which people showed recorded travel. Based on a set of rules that we developed (Stopher et al., 2007), we then removed people from the data set where the number of days of travel that they reported were inconsistent with the expectation of taking the GPS device with them each day that they travelled. This reduced the samples to 75 persons in Wave 1, 79 persons in wave 2, and 53 persons in Wave 3. It is on these individuals that the remaining analysis is based.

Table 3: Days of GPS Data by Person

Number of Days	*Wave 1 (50 households)*	*Wave 2 (46 Households)*	*Wave 3 (36 Households)*
All Days	1 (1%)	39 (44%)	22 (31%)
6 to less than 7 days per week	13 (12%)	21 (24%)	20 (28%)
5 to less than 6 days per week	10 (10%)	7 (8%)	12 (17%)
3 to less than 5 days per week	27 (25%)	8 (9%)	10 (14%)
1 to less than 3 days per week	32 (30%)	9 (10%)	6 (8%)
More than 0 and less than 1	24 (22%)	5 (6%)	1 (1%)
Total	107 (100%)	89 (100%)	71 (100%)

A comparison of sociodemographic variables between the waves and also against the 2001 census (rather outdated for comparison with 2005-6 data, but the 2006 census statistics are not yet available for comparison) is shown in Table 4.

Table 4: Comparison of the Demographics for the Panel with 2001 Census Data for All Households*

Demographic (per household)	*Value*	*2001 Census*	*Wave 1*	*Wave 2*	*Wave 3*	*Wave 1 – Good GPS Data*	*Wave 2 – Good GPS Data*	*Wave 3 – Good GPS Data*
Number of Persons	1	33.70%	10.60%	13.00%	13.89%	10%	12.50%	11.76%
	2	34.20%	29.80%	45.70%	47.22%	32.50%	43.20%	50.00%
	3	14.00%	19.10%	13.00%	19.44%	17.50%	11.50%	17.65%
	4	12.10%	25.50%	23.90%	13.89%	27.50%	22.50%	14.71%
	5+	6.10%	14.90%	4.30%	5.56%	12.50%	4.10%	5.88%
Number of Vehicles	0	15.10%	4.30%	5.10%	2.78%	4.30%	4.90%	0.00%
	1	44.10%	29.80%	41.30%	41.67%	30.80%	39.80%	44.12%
	2	30.50%	46.80%	43.50%	33.33%	43.60%	41.40%	32.35%
	3+	10.20%	19.10%	10.90%	22.22%	20.50%	11.00%	23.53%
Average Number of Adults		1.9	2.11	2	2.08	2.08	1.8	2.03
Proportion of Population Adults		80.30%	71.30%	74.10%	82.42%	82.42%	73.90%	84.15%
Average Number of Children		0.47	0.85	0.7	0.44	0.44	0.68	0.382
Proportion of Population Children		19.70%	28.70%	25.90%	17.58%	17.58%	26.10%	51.85%
Average Number of Males		1.15	1.46	1.35	1.19	1.19	1.25	1.06
Average Number of Females		1.22	1.54	1.53	1.33	1.33	1.4	1.22
Average Number of Full-Time Workers		0.62	0.89	0.76	0.67	0.67	0.72	0.611
Average Number of Full-Time Students		0.4	1	0.74	0.44	0.44	0.73	0.388

* The South Australia census statistics are obtained by aggregating the Western Adelaide Statistical Subdivision (SSD 40510) with the Statistical Local Areas of Holdfast Bay North (SLA 405202601) and Holdfast Bay South (SLA 405202604) to approximate the evaluation zone.

The sample is clearly biased against one-person households and for 4-person households. In wave 1, households with 5 or more persons are also very much over-represented. Non-car owning households are underrepresented in each wave, while households with 2 cars are overrepresented. In waves 1 and 3, there is also an overrepresentation of households with 3 or more cars. Some of these differences may be attributable to changes in households between 2001 and 2005-6, but there is certain to remain a bias against one- person households and non-car owning households. The bias in household size leads to there being more children per household in the panel sample than in the census, and larger average household sizes. However, the number of adults per household is not much different in the sample than in the census. The proportion of males to females is about correct. The higher proportion of children per household also inflates the proportion of full time students in the sample. On the other hand, the number of workers per household may reflect more the differences in the economy between 2001 and 2006 than biases in the sample. Given the very small sample sizes used for the panel, however, most of the differences found here are not statistically significant. Only those differences in one-person households and non-car-owning households were found to be significant at 95 percent confidence. Other differences were not significant at this level.

3 Analysis of the Data

Five principal variables were chosen for analysis, namely travel time per trip, travel distance per trip, number of trips per person per day, travel time per person per day, and travel distance per person per day or passenger kilometres of travel (PKT) per day. This produces a large number of graphs and analyses, so not all are shown in this paper. It also should be kept in mind that the first two waves are for 28 days of data, whilst the third wave was for only 15 days of data.

Our first analysis was to look at the means of each of the five variables by recording day. As examples of this, Figure 1 shows the means of number of trips per day by recording day and Figure 2 shows the means of the travel time per person per day by recording day. What can be seen in these figures is that there is a fairly random variation from day to day, more or less as one would expect. It is important to remember that each household would start recording on different days of the week, so that day 1 would be a mix of almost all days of the week. Because GPS devices were generally delivered on Monday through Friday, most households would start recording on Tuesday through Saturday. However, some delayed their start by a day or so from when the devices should have been put into use, so that there will also be some Sundays and Mondays for day 1. There is also no periodicity evident in Figures 1 and 2, relating to the length of the week. For example, in Figure 1, wave 3 shows the highest trips per day on days 4 and 12. In wave 1, the highest values are on day 1, day 17 and day 28, while in wave 2 they are on days 2, 14, and 16. In Figure 2, the peaks of travel time per person appear on days 1, 4, 6, and 17 for wave 1, days 14 and 15 for wave 2, and days 8 and 12 for wave 3. These variations underscore the random variations in the values. These results are, of course, quite different from what one would expect from self-report diaries, where one would expect to see a decline in the number of trips as the number of the recording day increases, due to fatigue and less accurate reporting as the time goes by. That this is not evident in these data is an important point to bear in mind in interpreting the remaining figures.

The next analysis was to cumulate the means and the variances over the days of the survey. Because wave 3 was only for 15 days, it makes the most sense to restrict the other two waves to 15 days for purposes of comparison, although we can also examine some comparisons between waves 1 and 2 only, to see what happens over a longer period of measurement. By cumulating the means and variances, we are able to compare the result of a one-day survey, for example, with the result of a two-day survey, where data are aggregated across the two days of the survey. Similarly, we can look at the results of what might have been a three-day survey, with data aggregated over the three days, and so forth up to 15 days, in the analysis for the three waves. One other point that should be kept in mind is the seasonal variability that may appear among these data waves. As noted earlier, the data for wave 1 and wave 3 were collected in the September-November period of 2005 and 2006 respectively, whilst wave 2 was collected in the March-April period of 2006. Therefore, we may see seasonal variations between wave 2 and the other two waves.

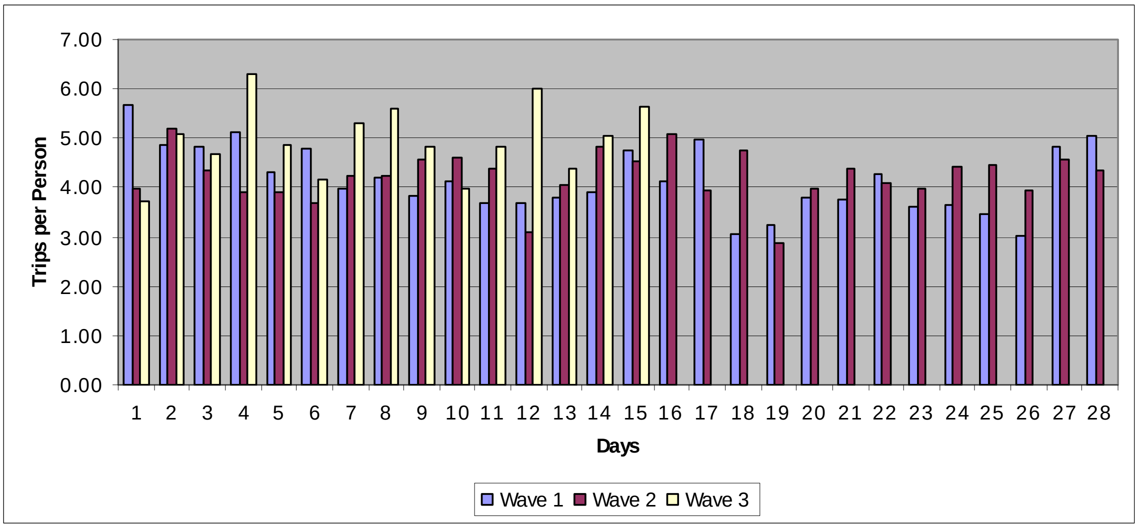


Figure 1: Mean Trips per Person by Recording Day

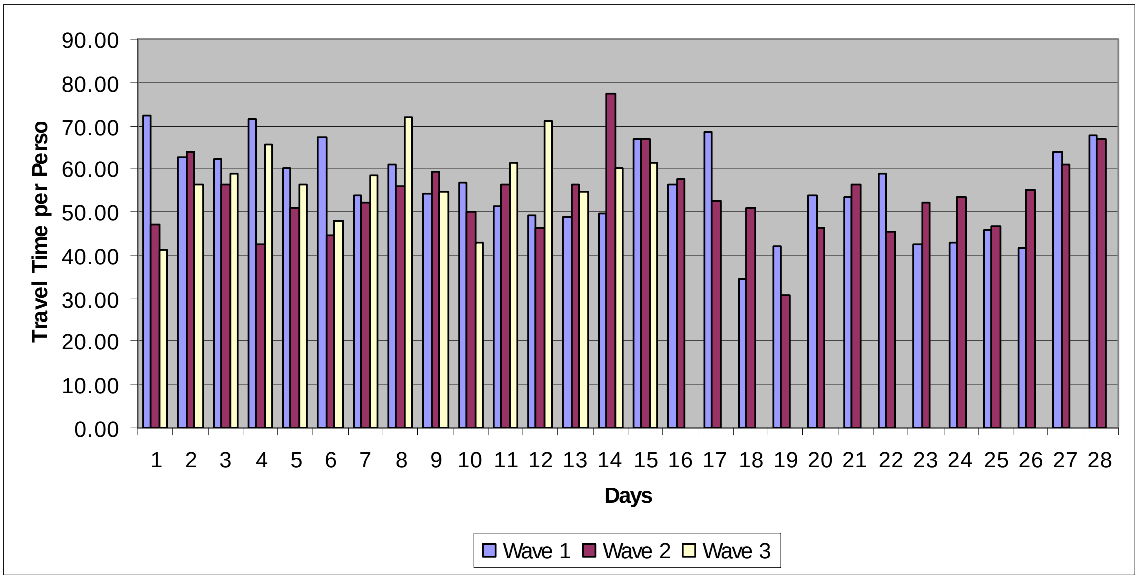


Figure 2: Travel Time per Person per Day by Recording Day

Figures 3, 4, and 5 show the results of cumulating the means over the first 15 days of the first two waves and all 15 days of the third wave for travel time per trip, trips per day, and PKT per day. In Figure 3, despite the expected variations in season, waves 2 and 3 show more similarity than wave 1. However, all three waves show instability in the values of the mean for the first 4 to 6 days, and then show a gradual trend to stable values, except for wave 2, where the cumulative mean continues to increase through the fifteenth day. Figure 4 shows trips per day, cumulated as means over the fifteen days. In this case, we see that the initial estimate on day 1 is lower than any other figure, and that the means increase significantly initially in waves 2 and 3, but much less in wave 1. All three waves then move towards a stable value, with waves 1 and 2 stabilising to a very similar value of around 3.8 to 3.9 trips per person per day, whilst wave 3 stabilises at about 4.6, probably due to the more biased nature of wave 3 than the other two waves. Figure 5 shows the cumulative means for PKT per person per day, and shows a generally more stable figure throughout the period of

15 days. Wave 2 is the only wave that shows a significantly different value at the outset, and all three waves stabilise towards quite similar values.

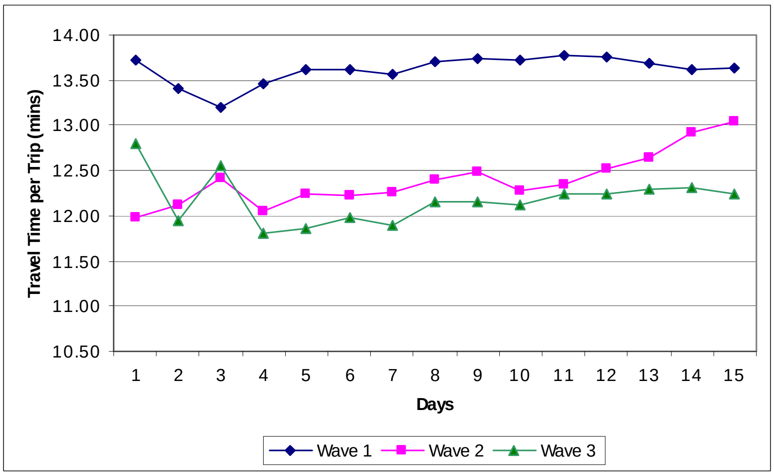


Figure 3: Cumulative Mean Travel Time Per Trip

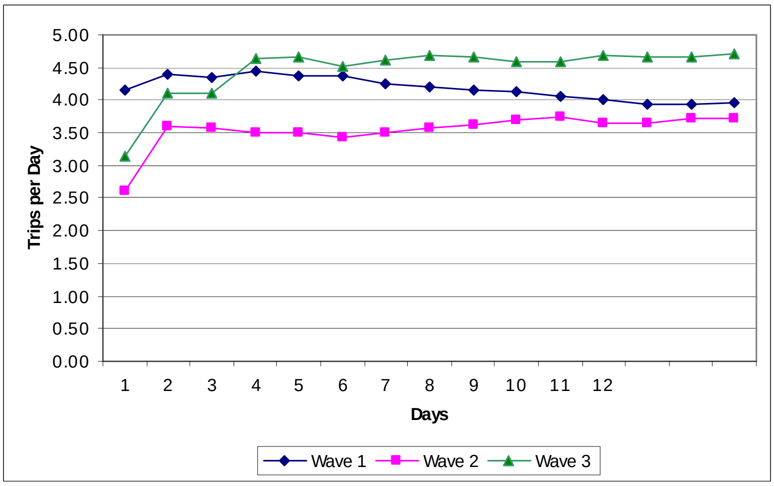


Figure 4: Cumulative Mean Trips Per Day

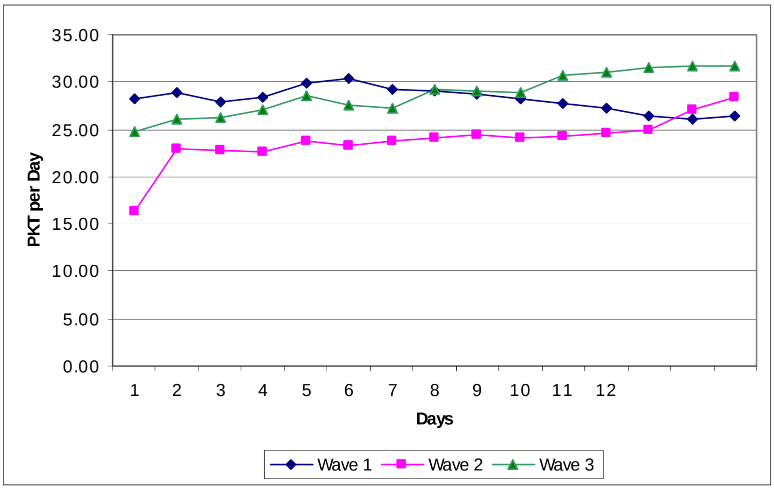


Figure 5: Cumulative Mean PKT per Person Per Day

The cumulative values of variance behave somewhat differently to the cumulative means. Figures 6, 7, and 8 show the variances for the same variables as are shown in Figures 3, 4, and 5. In Figure 6, we see the cumulative values of the variance of travel time per trip. From Waves 1 and 3, there is some instability in the first few days, and then the values converge to a stable value that is somewhat lower than the initial values. Wave 2 exhibits increasing variance, probably as a result of the wave running into the Easter holiday period at the latter end of the 28 days for most households.

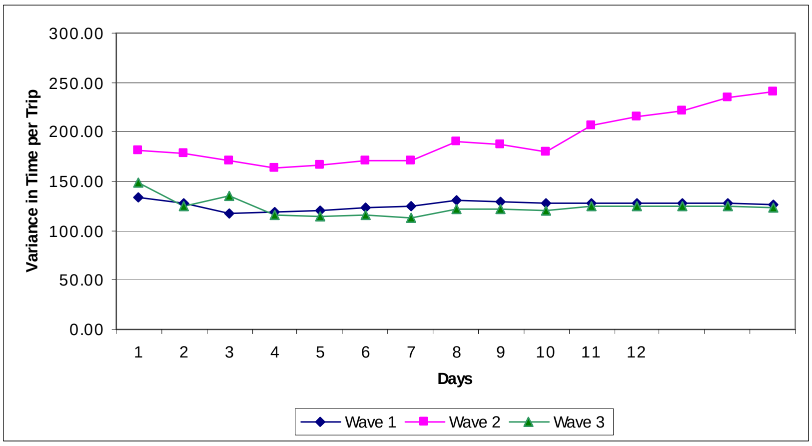


Figure 6: Cumulative Variance of Time per Trip

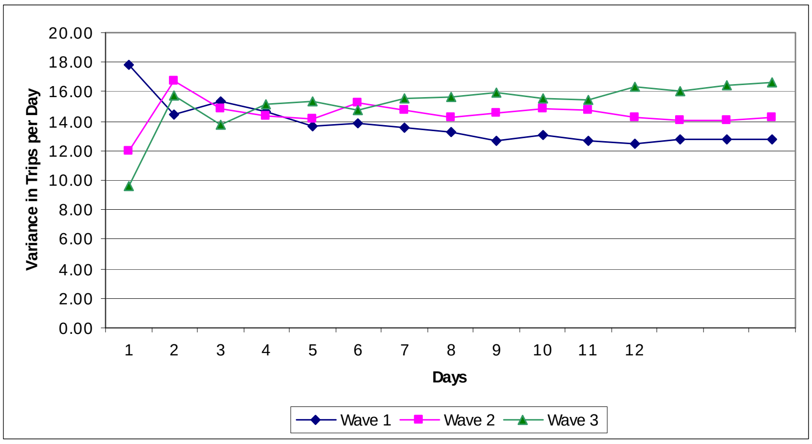


Figure 7: Cumulative Variance of Trips per Day

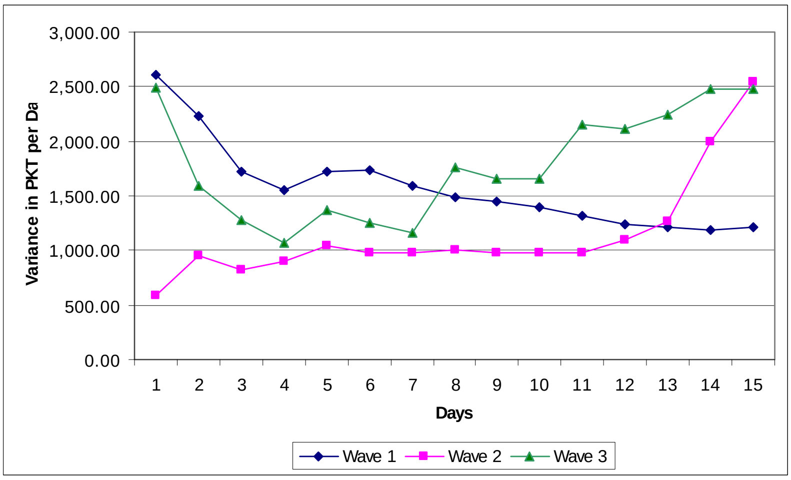


Figure 8: Cumulative Variance of PKT per Day

Figure 7 shows the cumulative variance of trips per person per day, and again shows instability at the outset, and converges to fairly similar stable values for all three waves. Interestingly, wave 1 began with a much higher variance for the first day, whilst waves 2 and 3 began much lower. Variance in PKT, as shown in Figure 8, is the least stable from these small panels. Wave 1 and wave 2 are almost mirror images of each other, with wave 1 declining and wave 2 increasing in value as more days are added. Wave 3 initially declines and then climbs again to an even higher value than starting. It is unclear what can be concluded from the behaviour of this variance. As a consequence, it is worth looking at what happens to this variance over a longer period of time. Figure 9 shows the results over 21 days, with wave 3 still shown here for reference purposes.

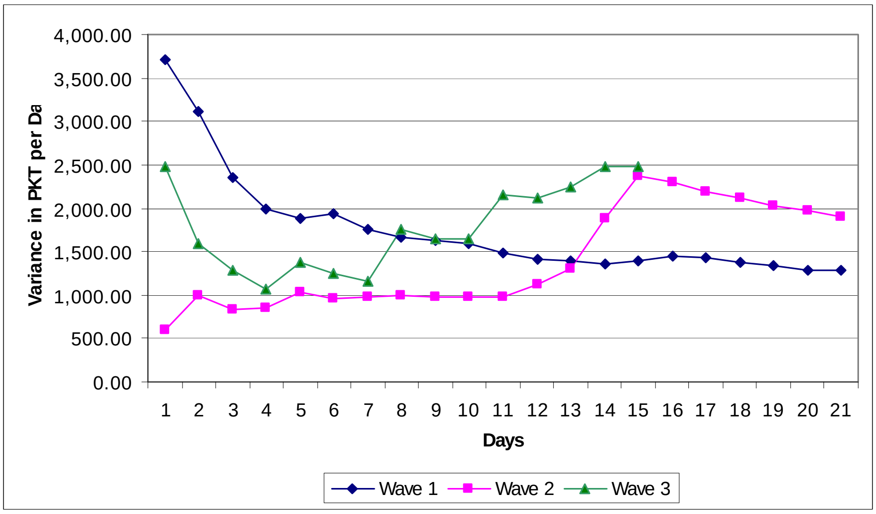


Figure 9: Cumulative Variance for PKT per Day over 21 Days

As can be seen, there is now a more interesting trend showing. The wave 2 results are now declining steadily after 15 days, and paralleling the results from wave 1, but with a value that is about 500 squared kilometres higher. It also appears as though the wave 3 results may have been starting to follow those of wave 2. This would suggest that this value may not stabilities until about 20 or more days of data are collected, or the sample size is increased.

For the other variables, the extension to 21 days is not particularly interesting, because the additional six days shows generally a continuation of the stability already observed in the latter part of the 15-day data. Figure 10 illustrates this by looking at the cumulative mean of travel time per trip, while Figure 11 shows the results for cumulative variance of trips per day. In both cases, the additional six days confirm the previously observed stability in values.

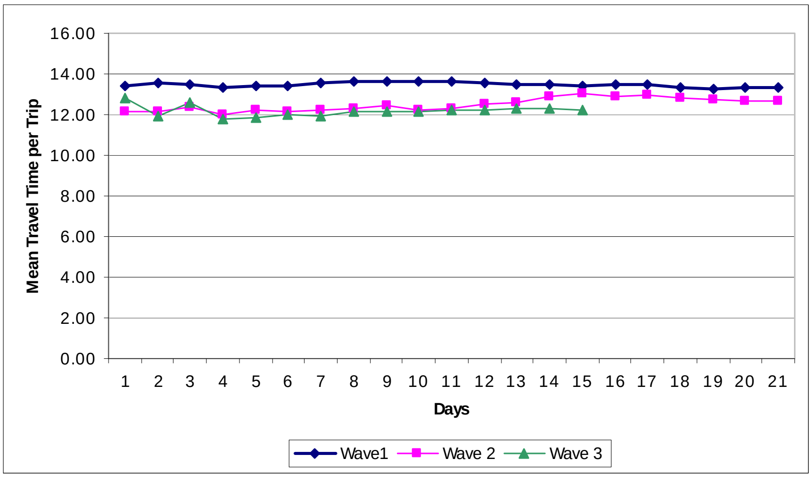


Figure 10: Cumulative Mean Travel Time per Trip over 21 Days

In each of the figures provided so far, each day in the graph includes a mix of weekdays and weekend days. Therefore, we also undertook an analysis in which we separated weekdays from all days. Analysing wave 1 data, we found that the biggest effect that this had was to show an increased instability in the first few days, and then a convergence to very similar values as were found in the data for all days of the week. Two examples of this are provided in Figures 12 and 13.

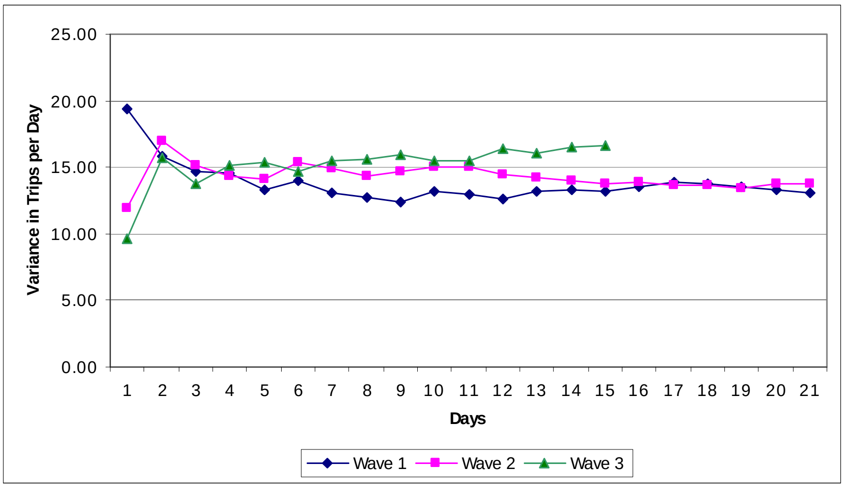
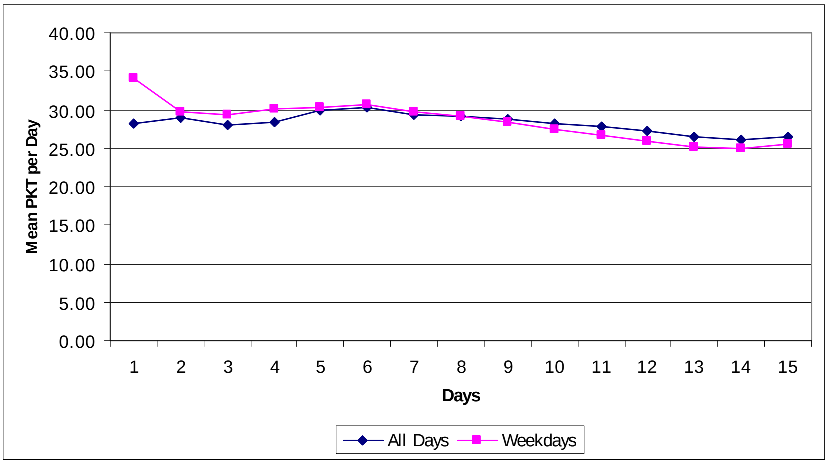


Figure 11: Cumulative Variance for Trips per Day over 21 Days



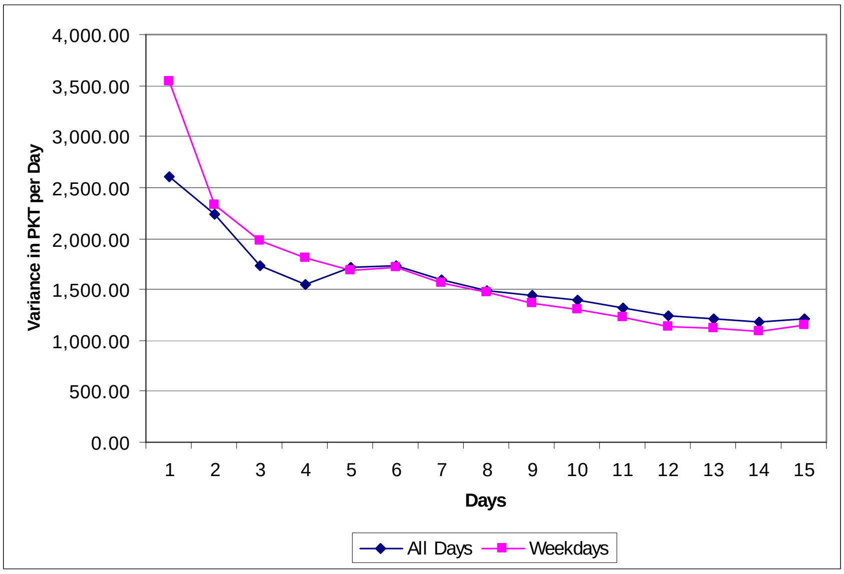


Figure 13: Cumulative Variance for PKT per Day by Weekday and All Days

Figure 12: Cumulative Mean PKT per Day by Weekdays and All Days

Figure 12 shows that the cumulative mean for PKT per day for weekdays begins higher than that for all days, but then declines to a stable value that is approximately the same as that found over the longer period for all days together. Similarly, Figure 13 shows that the cumulative variance for PKT per day for weekdays only also starts substantially higher than that for all days together, and then declines and maintains a value that is approximately the same as that for all days. These two figures suggest that the effect of differences between weekdays and weekend days is quite pronounced when looking at less than about five days of data, but then the differences largely disappear as more days are averaged together.

4 Implications for Modelling and Household Travel Surveys

Clearly, at this point, one must be cautious in deducing implications because the panel consisted of only 50 or fewer households, and there are probably some important seasonal effects that have occurred in the data, especially for wave 2. However, the overall impression created by examining these results is that one day data are highly unstable. Even data from a two-day survey would appear to contain significant instabilities, although these could be reduced if results were averaged across the two days, rather than treating the data as providing twice as many observations on trips as one-day data. The high instability is even more evident in comparing between waves, where frequently there are large differences between the different waves for the first two or three days of data, with these differences gradually moderating as the period of observation becomes longer.

Table 5 shows the differences in means and variances in the key variables from the three waves between the values obtained from the first day of data and the value obtained from 15 or 21 days of data. As Table 5 shows, both the means and variances for each of the five key measures selected change from day 1 to day 15, but generally change much less from day 15 to day 21. In cases where the mean changes very little, the variance still changes quite a bit, as for example with the travel time per trip, where the values of the mean change relatively little across the days, but the variance changes by up to 20 percent.

Table 5: Comparative Values of Cumulative Means and Variances at Days 1, 15, and 21

Measure – Mean (Variance)	*Wave 1*			*Wave 2*			*Wave 3*	
	First Day	*15th Day*	*21st Day*	*First Day*	*15th Day*	*21st Day*	*First Day*	*15th Day*
Travel Time per Trip	13.44 (120.26)	13.44 (122.45)	13.35 (124.57)	12.15 (182.97)	12.87 (225.15)	12.70 (207.52)	12.80 (148.93)	12.23 (122.96)
Travel Distance per Trip	8.00 (393.48)	6.54 (97.45)	6.49 (93.82)	5.35 (55.37)	6.77 (157.52)	6.65 (147.88)	7.93 (194.22)	6.74 (161.91)
Trips per Person per Day	4.15 (19.36)	4.10 (13.25)	3.98 (13.12)	2.64 (11.93)	3.72 (14.01)	3.71 (13.79)	3.13 (9.58)	4.72 (16.64)
Travel Time per Person per Day	56.53 (3605)	57.45 (2890)	55.77 (2827)	37.74 (2801)	51.47 (3208)	50.74 (3038)	39.88 (2157)	57.65 (2644)
Travel Distance per Person per Day	33.17 (3706)	28.13 (1355)	27.24 (1284)	16.63 (592.84)	27.07 (1881)	26.55 (1905)	24.71 (2487)	31.78 (2473)

As we have discussed in another paper at this conference (Stopher et al., 2007b), GPS is now becoming a feasible method for surveys and the sample sizes required are significantly lower than those required for normal modelling activities. Because of the high level of intra-personal variability, the sample sizes required are only about 35 percent of those required for a one-day diary survey, to achieve similar statistical significance in the results. From the data presented in this paper, it appears that the ideal length of a GPS survey is about 15 to 20 days, from the point of view of achieving stable values of means and variances, on which modelling is usually based. There does not appear to be a compelling reason to extend the length of the survey beyond about 20 days, because the values appear very stable from somewhere around the 14th to the 18th day. Generally, the 15-day long wave 3 which we have analysed in this paper shows fairly good agreement on most variables, although care will need to be taken with the timing of such a survey, relative to holidays and other times of unusual travel. If such periods are to be included, it would tend to argue for longer periods of data collection. An alternative method of scheduling the survey which was not part of this experiment, but which may offer some significant advantages is to conduct the survey over much of the year, rather than being concentrated into a short period of time such as a month or two.

One of the most important implications of the results shown in this paper is that the variances that are required to be explained by models may not be the variances that are measured in a one-day survey. Rather, in most cases, it would appear that the variances to be modelled are not as large as those that would be measured from a one-day survey. Further, even the mean values that will affect the modelling results may be different from a one-day survey than from a longer period survey.

5 Conclusions

With the advent of improving technology for personal GPS devices, in terms of battery life, sensitivity and accuracy, and ease of being carried around, the use of GPS as an alternative method for collecting travel data has become much more feasible. Sampling issues for such surveys appear to be very similar to those met with in most diary-based surveys, such as a bias against non-car owning households and one-person households, but appears to be less of an issue with large households, which often see the task of completing 5 or more diaries to be much more of an issue than having three or more people carrying a passive GPS device for a couple of weeks. Further, it is clear that the GPS makes the collection of multi-day data very feasible and there is, as expected, no evidence of a drop off in reporting with longer periods of GPS data collection. In the figures analysed early in this paper, the variability in trip attributes (numbers of trips, time spent travelling, etc.) exhibit no time dependent properties.

On the other hand, the need for multi-day data seems rather evident when looking at the cumulative values of means and variances, where the values obtained from a one-day survey are quite different from those obtained at the end of, say, a 15-day period. While no modelling has yet been attempted with the multi-day data, and there is little information in the international literature on the effects of using multi-day data in modelling, the implications would be that the variances will be different and the mean values also will be different. While it is not certain from such a small sample at this stage, there is certainly some reason to speculate that modelling may be influenced positively by the use of multi-day data.

6 References

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