# Temporal Variability of Car Usage as an Input to the Design of Before & After Surveys

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**Abstract**. Before & After surveys are a common method of measuring the effect of specific policies and projects designed to cause changes in travel behaviour. The purpose of this paper is to consider some issues involved in the design of Before & After surveys required for the evaluation of projects designed to change travel behaviour. To do this, it was important to obtain a quantitative understanding of the underlying variability of the parameters to be measured (in particular, the variation over time in travel by car). This was obtained by a detailed analysis of the MobiDrive data from Germany, and the estimation of Coefficients of Variation in key travel parameters for the Melbourne situation. Several features emerged from this analysis. Firstly, larger sample sizes are generally required to detect changes in either distance travelled or travel time than in trips undertaken. Secondly, larger sample sizes are required to detect changes from repeated cross-sectional surveys than from a panel survey. Thirdly, larger sample sizes are required to detect changes when using a daily travel diary compared to using a weekly travel diary (although this difference can be substantially reduced in a panel survey by maintaining the same day of the week for each household in later waves of the panel). Finally, larger sample sizes are required to detect changes from person travel data than from household travel data. Traded off against these sample size advantages, however, is the fact that some of the design parameters enabling smaller sample sizes also make the survey more difficult to conduct.

## BACKGROUND

Before & After surveys are a common method of measuring the effect of specific policies and projects designed to cause changes in travel behaviour (1). The Before survey establishes the situation before the change, while the After survey is designed to measure the situation after the policy or project has been implemented.

In 2001/2002, the Department of Infrastructure (DoI) in Victoria, Australia will be developing methodologies for a Victorian TravelSMART Program, and will be implementing pilot projects in 2002. Methodologies will be developed for working with schools, the community and workplaces.

The objective of the Victorian TravelSMART Program is:

> *"to reduce the negative impacts of car travel through a reduction in vehicle trips and kilometres travelled, achieved through voluntary changes by individuals, households and organisations towards more sustainable travel choices".*

The Victorian TravelSMART Program follows on from other such projects conducted in other states of Australia (2, 3) which have shown reductions in vehicle kilometres of travel of between 10% and 20%. To provide demonstrable proof of the effectiveness of such programs, the Department of Infrastructure has engaged a consultant to provide independent Evaluation Services to determine the impact of the Victorian TravelSMART Program. As part of the evaluation, the consultant is required to conduct Before & After surveys to measure the impact of the implementation of the Victorian TravelSMART Program**.** The objective of this paper is to address the issues that need to be considered in the design of such Before & After surveys. While this paper will use the evaluation of the TravelSMART Program as a case study example, the same issues need to be considered in any such evaluation, such as in the evaluation of the effects of new transit lines, new roads, new pricing policies or new land-use developments.

This paper covers the following topics:

- What data is to be collected?
- What type of survey will be used?
- From whom is the data to be collected?
- Over what period is the data to be collected?
- What magnitude of difference is to be detected in the "before" and "after" surveys?
- What is the inherent variability of the parameters to be measured?
- What levels of confidence are required in the results?

Specific comments on the Coefficient of Variation of vehicle kilometres travelled over different periods of time by different travel units (persons and households), based on data from the Mobidrive 6-week travel survey in Germany (4), and the implications for the TravelSMART Program Before & After survey sample size are identified. The results from the MobiDrive survey are expected to have wide applicability in a variety of other situations.

## SAMPLING ISSUES FOR TRAVELSMART PROGRAM EVALUATION

The design of a sample for evaluation of the TravelSMART Program, or any other program requiring Before & After surveys, needs to consider the following issues before a final sample design and sample size can be determined.

### What data is to be collected?

Clearly, the TravelSMART Program is multi-dimensional with potentially significant economic, environmental and social implications. However, it is unlikely that an effective and efficient evaluation would be able to evaluate the complete range of desired outcomes that are possible and measurable. The evaluation would therefore need to prioritise the desired outcomes, and specify performance measures that are practicably measurable. For the TravelSMART Program, the priority in the evaluation required specific quantified 'before' and 'after' measures of vehicle-kilometres of travel by household vehicles (VKT), greenhouse gas (GHG) emissions, and changes in modal split for trips and distances travelled.

It was therefore recommended that the proposed evaluation concentrate on quantified 'before' and 'after' measures of VKT. While not diminishing the value of the other Program Performance Measures, it was considered that unless significant and sustained reductions in VKT could clearly be demonstrated from the pilot studies, then precise measurement of the other performance measures would be futile. On the other hand, if this evaluation could demonstrate significant and sustained reductions in VKT, then future evaluations may be able to concentrate more fully on the other program performance measures.

It is also possible that a concentration on other performance measures could be misleading. For example, while mode shift is an important objective of the TravelSMART program, it should not be used as a primary measure of the success of the program. For example, by increasing the awareness of available public transport services, it may increase the usage of public transport without decreasing the usage of the private car. While this would result in an increase in modal share for public transport, it has done so by increasing total travel rather than by decreasing car usage.

**What type of survey will be used?**

There are two types of survey that might be used in such an evaluation study: a repeated cross-sectional survey and a longitudinal panel survey. In identifying changes in behaviour, a longitudinal panel survey is clearly the preferred option since the between-sample variance is eliminated. This enables statistically significant changes to be identified with a smaller sample size in the Before & After surveys. It was therefore assumed that a panel survey design would be used in the TravelSMART evaluation surveys.

The major problem with a longitudinal panel survey, however, is the reduced response rate, especially in the "after" survey. This is compounded in the TravelSMART programs, where a 7-day recording period might be deemed to be necessary to pick up re-allocation of travel within a household between the days of the week. If this "attrition" between the Before & After surveys is a function of the parameters to be measured (e.g. do households who don't change their behaviour drop out of the "after" survey because they are not interested in the topic), then adjustments must be made for this "attrition bias" before conclusions can be drawn about the success of the TravelSMART program.

A more complete description of the biases that might occur in a panel survey of this nature is contained in a separate report (5).

**From whom is the data to be collected?**

The major decisions to be made here are, firstly, whether data is to be collected about people's travel patterns or about vehicle's travel patterns and, secondly, whether data is to be collected from all people (or vehicles) in a household or from only one person (or vehicle) in a household.

Collection of data about vehicle travel patterns is appropriate when the prime emphasis is on the measurement of VKT and vehicular use. Data on people's travel pattern is more appropriate when the emphasis is on the reasons for travelling and on the use of non-private-vehicle modes of transport.

Restriction of the survey to a single person or vehicle means that re-allocation of activities and travel between members of the household cannot be detected. Since one of the major objectives of TravelSMART is to encourage household members to devise more effective ways of undertaking the activities associated with their particular lifestyles, it might be expected that intra-household re-allocation of activities might be an option that needs to be monitored. Therefore, the travel patterns of the entire household need to be measured. In the context of a vehicle-monitoring survey, this means monitoring the usage of all vehicles in the household. For practical reasons, this means monitoring up to three vehicles per household (which will cover approximately 98% of all households in Melbourne).

In the discussion that follows, it is assumed that people are the focus of the measurement task but that sufficient detail will be obtained about the use of specific vehicles to enable the reconstruction of vehicle usage patterns.

**Over what period is the data to be collected?**

The major decision here is whether the survey should take place over one day or over a multi-day period. Statistically, the survey could be restricted to one day. However, because of the larger relative variability in daily travel, compared to say weekly travel, a much larger sample size of households would be needed in order to detect a specified difference in travel behaviour before and after the TravelSMART program implementation. For example, as will be described in more detail later in this paper, data from the MobiDrive surveys in Germany (a 6-week continuous panel survey of 150 households) showed that the Coefficient of Variation for daily household vehicle kilometres (within the same household) was two and a half times the Coefficient of Variation for weekly household vehicle kilometres (where the Coefficient of Variation is the Standard Deviation divided by the Mean). Since sample size is proportional to the square of the Coefficient of Variation, this would require about six times as many households doing 1-day travel surveys as would be required for households doing 7-day travel surveys. There is also a particular reason in TravelSMART why a 7-day survey would be more appropriate. Just as there may be re-allocation of activities and travel between household members, there may also be re-allocation of activities and travel across the days of the week in order to achieve a more efficient travel pattern (e.g. saving up several activities in one area and then doing them all on one day on a single trip). For this reason, there is an advantage to undertaking a 7-day survey that will capture these re-allocations across days of a complete week.

**What magnitude of difference is to be detected?**

Because of the nature of Before & After surveys, it is necessary to specify the size of the difference to be detected between the two surveys. Detection of a small difference will require a larger sample size compared to detection of a large difference. One might therefore be tempted to opt for detection of a large difference, if this can be done with a smaller sample size. However, if such a large difference does not in fact exist, then any smaller differences will not be detected (statistically). On the other hand, the collection of a large sample in order to detect a small difference may not be worthwhile if the effect of the difference detected is immaterial. Therefore, one needs to trade-off these two effects, and specify a difference which could reasonably be expected to occur, and, if it was detected, then the effect of this difference would be material. The client needs to specify a difference in the parameter(s) with which they would be satisfied if it was detected.

**What is the inherent variability of the parameters to be measured?**

In determining the required sample size, it is necessary to have an estimate of the inherent variability of the parameter to be measured. A parameter with high variability will require a larger sample size to detect a difference of a specified magnitude than a parameter with lower variability. In the context of a Before & After survey, repeated cross-sectional surveys will have greater variability than a panel survey because they include the variability between households as well as the variability within a household over time. A single person (or vehicle) will have greater variability than a household (or all vehicles in the household). Daily vehicle kilometres will have more relative variability than weekly vehicle kilometres. On this basis, a panel survey of weekly kilometres travelled by all household vehicles would have the lowest required sample size, while repeated cross-sectional surveys of daily kilometres travelled by a single vehicle would have the highest sample size.

A major problem in the TravelSMART study was obtaining any information on the variability of vehicle kilometres travelled within a household across an extended period of time. Most travel surveys (such as VATS - the Victorian Activity & Travel Survey) (6) record travel for any one household on only a single day. Therefore, it is impossible from such surveys to calculate the variability in travel across several days or weeks. One of the very few surveys to collect data from households across an extended period is the MobiDrive survey conducted recently in Germany (4). This survey collected data from about 150 households for every day over a period of six weeks. From this data, it is therefore possible to gain an idea of the relative variation in vehicle kilometres travelled (or other measures of travel behaviour) on a daily or weekly basis. While the absolute number of vehicle kilometres travelled in Melbourne might be different from the figures obtained for Germany, it is expected that the Coefficients of Variation will be of similar size.

Whether daily or weekly travel, or person or household travel, is used, the main point that emerges from the German MobiDrive surveys is that the natural variation in VKT is quite high (the details of this analysis are contained in the next section of this paper). Any Before & After surveys that attempt to detect differences in travel behaviour that have been caused by an external influence (such as the TravelSMART program) must therefore contend with the relatively high level of natural variability in the quantity being measured.

**What levels of confidence are required in the results?**

When testing hypotheses, such as occurs in Before & After surveys, there are four possible end-states of the hypothesis testing procedure. Two of these states signify that a correct decision has been made while the other two indicate that an error has been made.

If the true state is described by the null hypothesis $H_0$ and we accept $H_0$ as being a description of the true state, then we have made no error. Similarly, we will be equally correct if we reject $H_0$ when the true state is actually described by the alternative hypothesis $H_1$.

A Type I Error will have been committed if we reject the null hypothesis when it is in fact true. For example, we conclude that there has been no decrease in vehicle usage following the implementation of TravelSMART when, in fact, there has been a decrease in vehicle usage. A Type II Error will have been committed if we accept the null hypothesis when it is in fact false. For example, we conclude that there has been a decrease in vehicle usage following the implementation of TravelSMART when, in fact, it was simply chance variations in the two surveys that gave the appearance of a decrease in vehicle usage.

Obviously in testing hypotheses we would be interested in trying to minimise the chances of making either a Type I or Type II error. Which one we would be most interested in avoiding will depend on the relative costs associated with each type of error. The degree to which we wish to avoid each type of error is expressed in terms of the maximum probability that we will accept for making each type of error. The acceptable probability of committing a Type I error is called the level of significance of the test and is denoted by $\alpha$. The acceptable probability of committing a Type II error is denoted by $\beta$. The value $1-\beta$ is often called the power of the test.

**ANALYSIS OF THE MOBIDRIVE DATA**

As noted above, in determining the required sample size, it is necessary to have an estimate of the inherent variability of the parameter to be measured. One of the very few surveys to collect data from households across an extended period, from which longitudinal variability in travel behaviour can be estimated, is the MobiDrive survey conducted recently in Germany (4). The Mobidrive data contains information on 52,273 trips (from 334 people living in 146 households) over a period of 6 weeks in 1999. For each trip, the data contains (among other things) the date, mode, travel time and travel distance of each trip. Some summary statistics from MobiDrive, and the corresponding figures from VATS 95 are shown in Table 1.

It can be seen that, compared to VATS 95, the MobiDrive respondents make less car driver trips (about 70% of VATS 95), but more public transport trips (about 50% more trips and distance). The public transport minutes in MobiDrive are much higher than VATS 95 (over twice as large) because the speed of public transport in Germany (with its heavy reliance on trams and buses) is lower than in Melbourne (with its significant heavy rail system).

The MobiDrive data was extracted from the files to calculate the number of trips and the time and distance covered by each mode by each person on each of their 42 travel days in the reporting period. Thus the data was reduced to a 42 by 334 matrix of person travel per day, a 42 by 146 matrix of household travel per day, a 6 by 334 matrix of person travel per week, and a 6 by 146 matrix of household travel per week. For each person (or household), the average amount of travel (trips, distance or minutes) was calculated across all days (or weeks). The standard deviation of these amounts were also calculated, and thence the Coefficient of Variation. In addition to calculating the values across all 42 days, an additional analysis considered the values segmented by days of the week. Thus, for example, as well as calculating the average and standard deviation of distance travelled as a car driver across all 42 days, the average and standard deviation of distance travelled as a car driver on the 6 Mondays (and Tuesdays etc) was also calculated.

The results are presented below for travel as a car driver, using the three measures of travel given by number of trips, distance travelled and minutes spent travelling.

**Variability of Person Trips as a Car Driver**

*Panel Survey Weekly Trips per Person*

The average number of car driver trips per person per week was 8.37. The average standard deviation of the number of car driver trips per week, across the 6 weeks for one person, was 2.78. The average Coefficient of Variation (CoV) was 29% (note that this is not 2.78/8.37, but rather is the average CoV calculated across each of the respondents). However, as shown in Figure 1, the CoV is a function of the average number of trips per person per week. Apart from those who don't drive at all (whose CoV is obviously zero), the CoV is highest for the infrequent driver and falls as the average number of car driver trips increases. The CoV is related to the average number of car driver trips per person per week (T) by the equation: $CoV = 1.26\sqrt{T}$

Since people in Melbourne make more trips as a car driver than people in MobiDrive, it would be expected that the CoV of their weekly trip rate would be somewhat lower than in Mobidrive. Using the average weekly car driver trips per person in Melbourne (11.86) and MobiDrive (8.37) and the equation given above, the CoV of weekly car driver trips per person in Melbourne would be expected to be about 24% (i.e. 84% of 29%).

*Cross-Sectional Survey Weekly Trips per Person*

If we treat the MobiDrive data not as a panel survey, but as a series of repeated cross-sectional surveys, we can obtain an estimate of the likely variability in weekly trips per person across the population. The mean, standard deviation and CoV of weekly trips per person was obtained across all people in the survey for each of the six weeks of the survey. The average Coefficient of Variation (CoV) across the six weeks was 130%. This is far higher than the panel survey CoV of 29% for MobiDrive, and reflects the greater variability across people than within the same person over time. Using the same reduction factor to account for the higher trip rates in Melbourne, the cross-sectional CoV in weekly person trips is estimated to be about 109%.

*Panel Survey Daily Trips per Person*

The average number of car driver trips per person per day was 1.19. The average standard deviation in the number of car driver trips per day, across the 42 days for one person, was 1.00. The average Coefficient of Variation (CoV) was 75% (compared to a CoV of 29% for car driver trips per week). However, as with trips per week, the CoV is also a function of the average number of trips per person per day. The CoV is related to the average number of car driver trips per person per day (T) by the equation: $CoV = 1.63\sqrt{T}$

Since people in Melbourne make more trips as a car driver per day than people in MobiDrive, it would be expected that the CoV of their weekly trip rate would be somewhat lower than in Mobidrive. Using the average daily car driver trips per person in Melbourne (1.69) and MobiDrive (1.19) and the equation given above, the CoV of daily car driver trips per person in Melbourne would be expected to be about 63% (i.e. 84% of 75%).

*Cross-Sectional Survey Daily Trips per Person*

By treating the MobiDrive data as a series of repeated cross-sectional surveys, we can obtain an estimate of the variability in daily trips per person across the population. The average Coefficient of Variation (CoV) for daily trips between the 344 people across the 42 days was 168%. This is far higher than the panel survey CoV of 75% for MobiDrive, and reflects the greater variability across people than within the same person over time. Using the same reduction factor to account for the higher trip rates in Melbourne, the cross-sectional CoV in daily person trips is estimated to be about 141%. This estimate can be compared with a direct estimate using the VATS 95 data, since VATS 95 is indeed a cross-sectional survey of daily trips. The standard deviation of car driver trip per person per day in VATS 95 is 2.68, giving a CoV of 158% (compared to the 141% estimated from the adjusted MobiDrive data).

*Panel Survey Daily Trips per Person (stratified by day of the week)*

The preceding analysis of daily trip rates in a panel survey has made no distinction between the days of the week, i.e. it has simply calculated the variability across all 42 days making no distinction, for example, between weekdays and weekends. It is well-known however that there are significant variations in travel across the days of the week. In a panel survey, this variation can be removed from the design by ensuring that households are approached on the same day of the week in each wave of the panel, thereby ensuring that differences observed in the waves are not simply due to a change in day of week between the waves for that household. The variability in trip rates on the same day of the week across the 6 weeks of the MobiDrive data were therefore investigated.

The average number of car driver trips per person per day is still 1.19 (as observed earlier when all 42 days were considered together). However, the average standard deviation in the number of car driver trips per day, when each day of the week has been considered as a separate strata, is reduced to 0.81 (compared to 1.00 when all 42 days are considered together). The average Coefficient of Variation (CoV) was therefore 56% (compared to a CoV of 75% when all 42 days are considered together). However, as with trips per day across all 42 days, the CoV is also a function of the average number of trips per person per day. The CoV is related to the average number of car driver trips per person per day (T) by the equation: $CoV = 1.10\sqrt{T}$

Using the average daily car driver trips per person in Melbourne (1.69) and MobiDrive (1.19) and the equation given above, the CoV of daily car driver trips per person in Melbourne, after ensuring that the same day of the week is used in each wave of the panel survey, would be expected to be about 47% (i.e. 84% of 56%) (note that these calculations are not relevant to repeated cross-sectional surveys, since each household is only surveyed once in a repeated cross-sectional survey).

A summary of the Coefficients of Variation for Car Driver Trips per Person is given in Table 2.

### Variability of Household Trips as a Car Driver

The preceding section has considered the variability in the number of trips undertaken by a person on a daily or weekly basis. However, the Before & After surveys may be conducted on the basis of an entire household's travel patterns before and after the implementation of TravelSMART, in which case information is required about the variability in trip rates on a household basis. This section therefore repeats the previous analysis, but uses the household as the unit of analysis. Since the commentary would be very similar for this section as in the previous section, only the main results are presented in tabular format in Table 3.

### Variability of Person Distance Travelled as a Car Driver

The preceding sections have used car driver trips as one measure of travel as a car driver. This section will use the distance travelled as a car driver as another measure of travel as a car driver. As before, the analysis will be performed for persons and households, daily and weekly, and for panel and cross-sectional surveys. Once again, since the commentary would be very similar for this section as in the original section, only the main results are presented in tabular format in Table 4.

### Variability of Household Distance Travelled as a Car Driver

The preceding section has considered the variability in the distance travelled as a car driver by a person on a daily or weekly basis. This section repeats the previous analysis, but uses the household as the unit of analysis. The main results are presented in tabular format in Table 5.

### Variability of Person Travel Time as a Car Driver

The preceding sections have used car driver trips and distances travelled as measures of travel as a car driver. This section will use the travel time as a car driver as another measure of travel as a car driver. As before, the analysis will be performed for persons and households, daily and weekly, and for panel and cross-sectional surveys. Once again, since the commentary would be very similar for this section as in the original section, only the main results are presented in tabular format in Table 6.

### Variability of Household Travel Time as a Car Driver

The preceding section has considered the variability in the travel time as a car driver by a person on a daily or weekly basis. This section repeats the previous analysis, but uses the household as the unit of analysis. The main results are presented in tabular format in Table 7.

## REQUIRED SAMPLE SIZE FOR BEFORE & AFTER SURVEYS

Given the estimates of variability described above, this section considers the required sample size for a survey that measures vehicle-kilometres before and after the implementation of TravelSMART. Assume, for the moment, that the survey will be a longitudinal panel survey with the primary objective of measuring total kilometres of vehicle travel undertaken by all vehicles in a household in a week. Assume that the intention of the Before & After surveys is to test whether there has been a reduction of total vehicle kilometres after implementation of the TravelSMART program. Assume that the required reduction is 10% of vehicle kilometres.

In order to calculate a sample size, it is necessary to estimate the variability of the parameter to be measured. Assuming a longitudinal panel survey, it is therefore necessary to estimate the variability of vehicle kilometres within a household from week to week. Based on the MobiDrive survey data, and adjusted for Melbourne conditions, the Coefficient of Variation of weekly household vehicle kilometres (over a 6-week period) has been estimated as 37%.

The required sample size for hypothesis testing in before and after surveys (Richardson, Ampt and Meyburg, 1995, pg 122) is given by:

$$n = \frac{2\left(z_{\alpha} + z_{\beta}\right)^2 \left(\sigma^2\right)}{\delta^2}$$

| | | | |
|---|---|---|---|
| where | n | = | required sample size |
| | $\alpha$ | = | the probability of making a Type I error |
| | $\beta$ | = | the probability of making a Type II error |
| | s | = | the standard deviation of the parameter to be tested |
| | $\delta$ | = | the required difference in the parameter to be tested |

Assuming that $\alpha$=$\beta$=5%, s = 37% (of the mean) and $\delta$ = 10% (of the mean), then the required sample size is about 290. This calculation assumes that the sample is being drawn from an infinite, or at least very large, population. However, in the TravelSMART project the size of the population of households in each of the study areas is relatively small (about 1500 households in each of three study areas). With such a small population (N), it is necessary to multiply the estimated sample size (n) by a Finite Population Correction Factor (FPCF), where:

$$\text{FPCF} = \frac{1}{1 + n/N}$$

With a population of only 1500 households, the required sample size is reduced to 242. That is, in order to measure a statistically significant reduction of 10% in weekly household vehicle kilometres in the after survey (when the inherent variability of weekly household vehicle kilometres is 37% of the mean), a sample size of 242 households would be required in both the before and after surveys.

The above calculation has been based on a number of specific assumptions, namely:

- Type of Survey: Panel
- Variable being Measured: Vehicle-kilometres
- Unit of Measurement: Households
- Period of Measurement: One week
- Coefficient of Variation of Parameter: 37%
- Detected Difference ($\delta$): 10% of mean
- Probability of making a Type I error ($\alpha$): 5%
- Probability of making a Type II error ($\beta$): 5%

By varying some of these parameters, we can see that, for a specific set of conditions, detecting a 10% change in travel with a confidence level of 95%, from a population of 1500 households in each study area, the sample sizes shown in Table 8 would be required as a function of the type of survey (panel or cross-sectional survey), the unit of measurement (person or household), the quantity being measured (trips, kilometres or minutes, and the time period of the survey (week, day or matched day-of-week).

Several features emerge from this comparison. Firstly, larger sample sizes are generally required to detect changes in either distance travelled or travel time than in trips undertaken. Secondly, larger sample sizes are required to detect changes from repeated cross-sectional surveys than from a panel survey. Thirdly, larger sample sizes are required to detect changes when using a daily travel diary compared to using a weekly travel diary (although this difference can be substantially reduced in a panel survey by maintaining the same day of the week for each household in later waves of the panel). Finally, larger sample sizes are required to detect changes from person travel data than from household travel data.

Traded off against these sample size advantages, however, is the fact that some of the parameters requiring smaller sample sizes are also more difficult to obtain. For example, panel survey data is more difficult to obtain (with full control of other biases) than repeated cross-sectional data. Weekly travel diaries are more burdensome than daily travel diaries. Getting travel data from all household members is more difficult than getting data from one member of the household.

## CONCLUSIONS

The purpose of this paper was to consider some issues involved in the design of Before & After surveys required for the evaluation of the impact of programs such as the TravelSMART program in Victoria, Australia. To do this, it was important to obtain a quantitative understanding of the underlying variability of the parameters to be measured (in particular, the variation over time in travel by car). This was obtained by a detailed analysis of the MobiDrive data from Germany, and the estimation of Coefficients of Variation in key travel parameters for the Melbourne situation.

Following this analysis, the paper estimated the required sample size for a survey that measures trips, vehicle-kilometres and travel time for car travel before and after the implementation of TravelSmart. Sample sizes were calculated for different Types of Survey, Units of Measurement, Periods of Measurement, Coefficients of Variation of the Parameters of Interest, the desirable Detectable Difference in the before and after surveys, the Probability of making a Type I error ($\alpha$) and the Probability of making a Type II error ($\beta$).

Several features emerged from this analysis. Firstly, larger sample sizes are generally required to detect changes in either distance travelled or travel time than in trips undertaken. Secondly, larger sample sizes are required to detect changes from repeated cross-sectional surveys than from a panel survey. Thirdly, larger sample sizes are required to detect changes when using a daily travel diary compared to using a weekly travel diary (although this difference can be substantially reduced in a panel survey by maintaining the same day of the week for each household in later waves of the panel). Finally, larger sample sizes are required to detect changes from person travel data than from household travel data.

Traded off against these sample size advantages, however, is the fact that some of the design parameters enabling smaller sample sizes also make the survey more difficult to conduct. For example, panel survey data is more difficult to obtain (with full control of other biases) than repeated cross-sectional data. Weekly travel diaries are more burdensome than daily travel diaries. Getting travel data from all household members is more difficult than getting data from one member of the household.

As always, the actual sample size chosen will depend on discussions between the client and the consultant, taking account of the available budget for the survey and the required quantity and quality of data collectable within that budget.

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**LIST OF FIGURES**

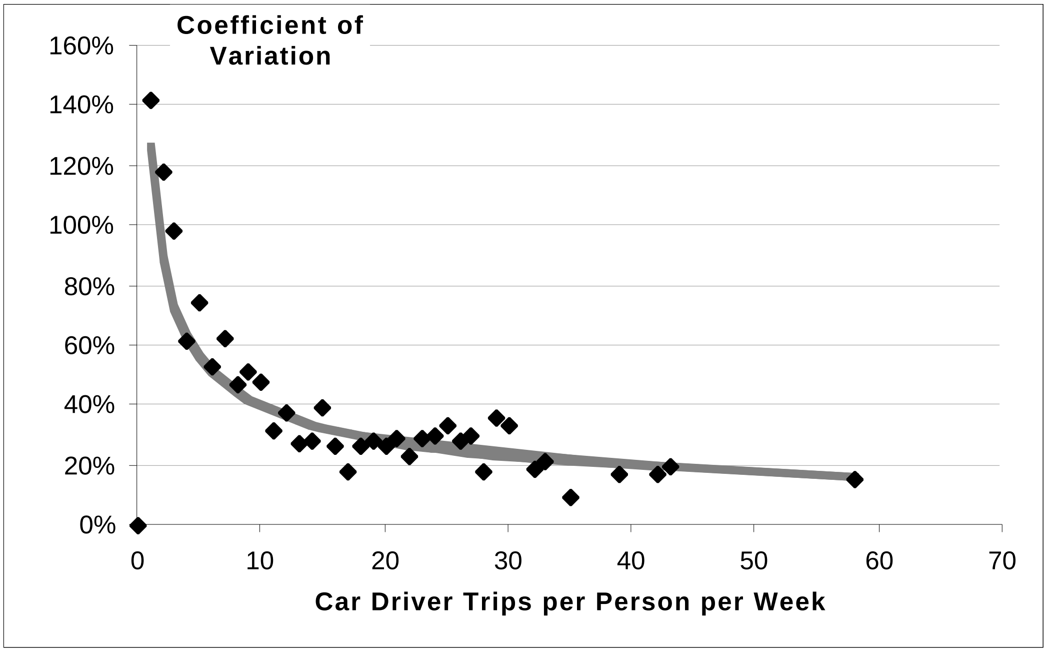


**FIGURE 1 Coefficient of Variation of Car Driver Trips per Person per Week as a Function of Average Car Driver Trips per Person per Week**

**LIST OF TABLES**

**TABLE 1 Comparison of Travel Behaviour in Germany and Melbourne**

| **MobiDrive** | Daily Car Driver Travel | | | Daily Public Transport Travel | | |
|---|---|---|---|---|---|---|
| | Trips | Distance | Minutes | Trips | Distance | Minutes |
| Household | 2.7 | 28.4 | 50.9 | 1.2 | 9.7 | 32.3 |
| Person | 1.2 | 12.4 | 22.3 | 0.5 | 4.2 | 14.1 |

| **VATS 95** | Daily Car Driver Travel | | | Daily Public Transport Travel | | |
|---|---|---|---|---|---|---|
| | Trips | Distance | Minutes | Trips | Distance | Minutes |
| Household | 4.5 | 43.1 | 83.4 | 0.7 | 7.4 | 16.0 |
| Person | 1.7 | 16.1 | 31.1 | 0.3 | 2.8 | 6.0 |

**TABLE 2 Variability in Person Car Driver Trips in Germany and Melbourne**

| ***Weekly Trips per Person*** | Panel Survey | | Cross-sectional Survey | |
|---|---|---|---|---|
| | MobiDrive | Melbourne | MobiDrive | Melbourne |
| Average | 8.37 | --- | 8.4 | 11.86 |
| Standard Deviation | 2.78 | --- | 10.79 | --- |
| Coefficient of Variation | 29% | --- | 130% | --- |
| Adjustment Factor | 84% | --- | 84% | --- |
| Adjusted CoV | --- | 24% | --- | 109% |
| ***Daily Trips per Person*** | Panel Survey | | Cross-sectional Survey | |
| | MobiDrive | Melbourne | MobiDrive | Melbourne |
| Average | 1.19 | --- | 1.19 | 1.69 |
| Standard Deviation | 1.00 | --- | 1.97 | 2.68 |
| Coefficient of Variation | 75% | --- | 168% | 158% |
| Adjustment Factor | 84% | --- | 84% | --- |
| Adjusted CoV | --- | 63% | --- | 141% |
| ***Daily Trips per Person (stratified by day of week)*** | Panel Survey | | Cross-sectional Survey | |
| | MobiDrive | Melbourne | MobiDrive | Melbourne |
| Average | 1.19 | --- | --- | --- |
| Standard Deviation | 0.81 | --- | --- | --- |
| Coefficient of Variation | 56% | --- | --- | --- |
| Adjustment Factor | 84% | --- | --- | --- |
| Adjusted CoV | --- | 47% | --- | --- |

**TABLE 3 Variability in Household Car Driver Trips in Germany and Melbourne**

| ***Weekly Trips per Household*** | Panel Survey | | Cross-sectional Survey | |
|---|---|---|---|---|
| | MobiDrive | Melbourne | MobiDrive | Melbourne |
| Average | 19.1 | --- | 19.1 | 31.7 |
| Standard Deviation | 5.0 | --- | 16.3 | --- |
| Coefficient of Variation | 30% | --- | 85% | --- |
| Adjustment Factor | 78% | --- | 78% | --- |
| Adjusted CoV | --- | 23% | | 66% |
| ***Daily Trips per Household*** | Panel Survey | | Cross-sectional Survey | |
| | MobiDrive | Melbourne | MobiDrive | Melbourne |
| Average | 2.72 | --- | 2.72 | 4.53 |
| Standard Deviation | 1.79 | --- | 2.92 | 4.66 |
| Coefficient of Variation | 77% | --- | 109% | 103% |
| Adjustment Factor | 77% | --- | 77% | --- |
| Adjusted CoV | --- | 60% | | 85% |
| ***Daily Trips per Household (stratified by day of week)*** | Panel Survey | | Cross-sectional Survey | |
| | MobiDrive | Melbourne | MobiDrive | Melbourne |
| Average | 2.72 | 4.53 | --- | --- |
| Standard Deviation | 1.48 | --- | --- | --- |
| Coefficient of Variation | 67% | --- | --- | --- |
| Adjustment Factor | 78% | --- | --- | --- |
| Adjusted CoV | --- | 52% | --- | --- |

**TABLE 4 Variability in Person Car Driver Distance in Germany and Melbourne**

| ***Weekly Kilometres per Person*** | Panel Survey | | Cross-sectional Survey | |
|---|---|---|---|---|
| | MobiDrive | Melbourne | MobiDrive | Melbourne |
| Average | 86.8 | --- | 86.8 | 112.9 |
| Standard Deviation | 35.5 | --- | 142.1 | --- |
| Coefficient of Variation | 45% | --- | 164% | --- |
| Adjustment Factor | 88% | --- | 88% | --- |
| Adjusted CoV | --- | 40% | --- | 144% |
| ***Daily Kilometres per Person*** | Panel Survey | | Cross-sectional Survey | |
| | MobiDrive | Melbourne | MobiDrive | Melbourne |
| Average | 12.4 | --- | 12.4 | 16.1 |
| Standard Deviation | 13.2 | --- | 27.3 | 36.7 |
| Coefficient of Variation | 118% | --- | 223% | 228% |
| Adjustment Factor | 88% | --- | 88% | --- |
| Adjusted CoV | --- | 103% | --- | 196% |
| ***Daily Kilometres per Person (stratified by day of week)*** | Panel Survey | | Cross-sectional Survey | |
| | MobiDrive | Melbourne | MobiDrive | Melbourne |
| Average | 12.4 | --- | --- | --- |
| Standard Deviation | 9.8 | --- | --- | --- |
| Coefficient of Variation | 63% | --- | --- | --- |
| Adjustment Factor | 88% | --- | --- | --- |
| Adjusted CoV | --- | 55% | --- | --- |

**TABLE 5 Variability in Household Car Driver Distance in Germany and Melbourne**

| ***Weekly Kilometres per Household*** | Panel Survey | | Cross-sectional Survey | |
|---|---|---|---|---|
| | MobiDrive | Melbourne | MobiDrive | Melbourne |
| Average | 199 | --- | 199 | 302 |
| Standard Deviation | 68 | --- | 206 | --- |
| Coefficient of Variation | 45% | --- | 104% | --- |
| Adjustment Factor | 81% | --- | 81% | --- |
| Adjusted CoV | --- | 37% | | 84% |
| ***Daily Kilometres per Household*** | Panel Survey | | Cross-sectional Survey | |
| | MobiDrive | Melbourne | MobiDrive | Melbourne |
| Average | 28.4 | --- | 28.4 | 43.1 |
| Standard Deviation | 25.2 | --- | 40.3 | 64.0 |
| Coefficient of Variation | 99% | --- | 145% | 148% |
| Adjustment Factor | 81% | --- | 81% | --- |
| Adjusted CoV | --- | 81% | | 117% |
| ***Daily Kilometres per Household (stratified by day of week)*** | Panel Survey | | Cross-sectional Survey | |
| | MobiDrive | Melbourne | MobiDrive | Melbourne |
| Average | 28.4 | 43.1 | --- | --- |
| Standard Deviation | 19.3 | --- | --- | --- |
| Coefficient of Variation | 79% | --- | --- | --- |
| Adjustment Factor | 81% | --- | --- | --- |
| Adjusted CoV | --- | 64% | --- | --- |

**TABLE 6 Variability in Person Car Driver Travel Time in Germany and Melbourne**

| ***Weekly Minutes*** | Panel Survey | | Cross-sectional Survey | |
|---|---|---|---|---|
| ***per Person*** | MobiDrive | Melbourne | MobiDrive | Melbourne |
| Average | 156 | --- | 156 | 219 |
| Standard Deviation | 58 | --- | 214 | --- |
| Coefficient of Variation | 42% | --- | 137% | --- |
| Adjustment Factor | 84% | --- | 84% | --- |
| Adjusted CoV | --- | 36% | --- | 116% |
| ***Daily Minutes*** | Panel Survey | | Cross-sectional Survey | |
| ***per Person*** | MobiDrive | Melbourne | MobiDrive | Melbourne |
| Average | 22.3 | --- | 22.3 | 31.2 |
| Standard Deviation | 20.7 | --- | 40.0 | 52.6 |
| Coefficient of Variation | 107% | --- | 184% | 169% |
| Adjustment Factor | 84% | --- | 84% | --- |
| Adjusted CoV | --- | 90% | --- | 155% |
| ***Daily Minutes per Person*** | Panel Survey | | Cross-sectional Survey | |
| ***(stratified by day of week)*** | MobiDrive | Melbourne | MobiDrive | Melbourne |
| Average | 22.3 | --- | --- | --- |
| Standard Deviation | 16.4 | --- | --- | --- |
| Coefficient of Variation | 59% | --- | --- | --- |
| Adjustment Factor | 84% | --- | --- | --- |
| Adjusted CoV | --- | 50% | --- | --- |

**TABLE 7 Variability in Household Car Driver Travel Time in Germany and Melbourne**

| ***Weekly Minutes per Household*** | Panel Survey | | Cross-sectional Survey | |
|---|---|---|---|---|
| | MobiDrive | Melbourne | MobiDrive | Melbourne |
| Average | 357 | --- | 357 | 584 |
| Standard Deviation | 107 | --- | 309 | --- |
| Coefficient of Variation | 38% | --- | 87% | --- |
| Adjustment Factor | 78% | --- | 78% | --- |
| Adjusted CoV | --- | 30% | | 68% |
| ***Daily Minutes per Household*** | Panel Survey | | Cross-sectional Survey | |
| | MobiDrive | Melbourne | MobiDrive | Melbourne |
| Average | 50.9 | --- | 50.9 | 83.4 |
| Standard Deviation | 38.2 | --- | 58.6 | 91.6 |
| Coefficient of Variation | 93% | --- | 118% | 110% |
| Adjustment Factor | 78% | --- | 78% | --- |
| Adjusted CoV | --- | 73% | | 92% |
| ***Daily Minutes per Household (stratified by day of week)*** | Panel Survey | | Cross-sectional Survey | |
| | MobiDrive | Melbourne | MobiDrive | Melbourne |
| Average | 50.9 | 83.4 | --- | --- |
| Standard Deviation | 31.1 | --- | --- | --- |
| Coefficient of Variation | 72% | --- | --- | --- |
| Adjustment Factor | 78% | --- | --- | --- |
| Adjusted CoV | --- | 57% | --- | --- |

**TABLE 8 Sample Sizes Required for Various Before & After Survey Designs**

| | Trips | Kilometres | Minutes |
|---|---|---|---|
| Panel Survey | | | |
| Person | | | |
| Week | 119 | 279 | 234 |
| Day | 547 | 909 | 810 |
| Matched Day-of-Week | 359 | 460 | 399 |
| Household | | | |
| Week | 110 | 242 | 168 |
| Day | 510 | 726 | 648 |
| Matched Day-of-Week | 417 | 562 | 473 |
| Repeated Cross-Sectional Survey | | | |
| Person | | | |
| Week | 947 | 1123 | 990 |
| Day | 1112 | 1270 | 1165 |
| Household | | | |
| Week | 582 | 758 | 597 |
| Day | 762 | 998 | 825 |