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Paper Abstract

Paper title: **Jumping at shadows: a review of methodological changes in the SMVU**

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Abstract (200 words):
The Survey of Motor Vehicle Use (SMVU) is the principal source of information on registered motor vehicle use in Australia. SMVU results are used to formulate transport policy and project future road transport activity. Changes to the survey methodology over time, however, mean that the raw survey results may not be directly comparable across surveys, obscuring trends in motor vehicle use. The methodological changes introduced in the 1998 survey are the most significant to date. Several Australian transport analysts and organisations adjust the SMVU results with the aim of producing consistent time series estimates of vehicle use. These efforts sometimes produce conflicting estimates, presenting a problem for uninformed practitioners who wish to quote measures of motor vehicle use. This paper provides an overview of major changes to the survey methodology between 1971 and 2002 and describes the results of several Monte Carlo simulations designed to assess the impact of some of these methodological changes. Based on our review of the methodology and the data quality information, we suggest that there are only a handful of factors that analysts need to adjust for in constructing consistent long-term time series estimates of vehicle use. The post-1998 survey results should be more reliable than the earlier results. Simulation results imply that the current survey design and other characteristics should produce reliable estimates of registered motor vehicle use.

Introduction

The Survey of Motor Vehicle Use (SMVU) (ABS 2003b, and earlier issues) is the only regular Australia-wide measure of registered motor vehicle use. The SMVU was first undertaken in 1963, with a second survey conducted in 1971. Between 1971 and 1995 the survey was undertaken more or less every three years, and since 1998 the survey has been undertaken annually.

The results of the SMVU are used by policy makers and transport agencies to inform decisions about road user charges, predict likely future road transport demand and assess future road infrastructure investment needs. For example, the National Transport Commission (NTC) and its predecessor, the National Road Transport Commission (NRTC), uses the SMVU estimates of heavy vehicle road use in the determination of heavy vehicle road use charges. The Bureau of Transport and Regional Economics (BTRE) uses the SMVU results for projecting future vehicle use and traffic growth on Australia's roads, and future greenhouse gas and noxious emissions from road transport.

The SMVU survey methodology has changed over time, quite significantly in some respects. Some of the more significant changes include a 75 per cent reduction in the total sample size since 1988, changes to the vehicle classification and variations to the set of characteristics used to stratify the sample. Perhaps the most significant changes occurred in 1998, when the survey collection method was altered from a 12-month recall-based survey instrument to quarterly pre-advice based survey.

The SMVU has also produced some anomalous results that appear inconsistent with other evidence. For example, the SMVU estimates of the total road freight task, illustrated in Figure 1, appear anomalously high in 1995 and low in 1998. Between 1991 and 1995 the SMVU results imply that total road freight, measured in tonne kilometres (TKM), grew by 7.8 per cent per annum, and between 1995 and 1998 the results imply total road freight declined absolutely. Neither of these results appears to be readily explainable by economic conditions or other data. Simple regressions of the pre-1998 SMVU freight task estimates against economic activity and road freight rates imply a higher level of road freight than indicated by recent SMVU results (see, for example, Cosgrove & Mitchell 2001). John Apelbaum (Apelbaum Consulting Group) has suggested that the recent SMVU results significantly underestimate total road freight activity (Stewart 2003). The Apelbaum Consulting Group (2001) estimates that the total road freight task in 1997–98 was 157.3 billion TKM, approximately 26 per cent higher than the raw SMVU estimate of 116.1 billion TKM.

Inexplicable results from the SMVU are not restricted to estimates of the freight task. Recent SMVU results significantly underestimate total automotive gasoline (petrol) sales, as Figure 2 illustrates. Up until 1988 the SMVU estimated total petrol consumption to within 5 per cent of actual petrol sales. Since 1988, however, the SMVU has underestimated total petrol sales by between 5 and 15 per cent in any single year. Yet the BTE (1995) has estimated that 97 per cent of total petrol sales are used in motor vehicles, with the residual used off-road in motor mowers, outboard motors and recreational vehicles. This result is particularly troubling for analysts, as petrol sales data is almost the only independent measure with which it had previously been possible to validate the SMVU results.

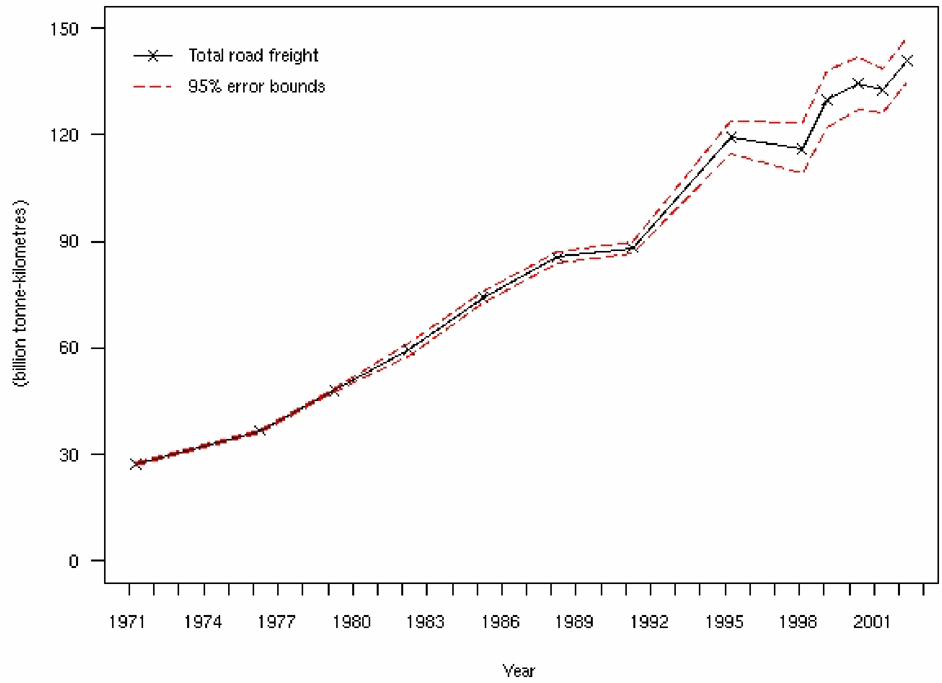

Figure 1 SMVU road freight task estimates

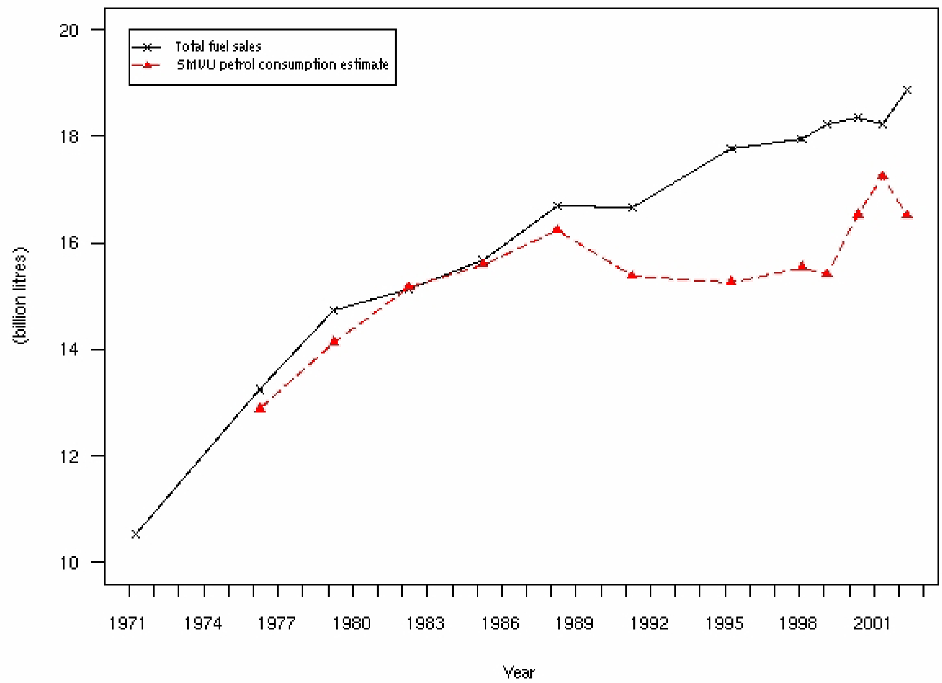

Figure 2 SMVU petrol consumption estimates and total petrol sales

The BTRE and other organisations, such as Apelbaum Consulting Group (ACG), have, from time-to-time produced adjusted estimates of motor vehicle use that correct for changes in the survey or apparently anomalous results. This has resulted in several, in some cases inconsistent, published estimates of total motor vehicle use. This can be confusing to the uninformed practitioner wanting consistent measures of motor vehicle use. It appeared to the author that a comprehensive review the changes in the survey methodology since 1971, and an assessment of the likely impact of these changes on the survey results, was warranted to reconcile some of these inconsistencies.

The full version of this paper provides a detailed review of changes in the survey characteristics. That review is based on published information, where available, about the quality of the SMVU results. Space constraints, however, necessarily restrict the amount of detail that we can provide in this version of the paper. Consequently, this version of the paper provides only a brief overview of the changes to the SMVU survey methodology between 1971 and 2002.

The methodological review is complemented by Monte Carlo simulations of the SMVU survey methods. These simulations provide quantitative measures of the impact of methodological changes and the reliability of the survey results. Separate simulations are conducted for passenger vehicles and articulated trucks—those vehicle classes responsible for approximately three-quarters of total vehicle kilometres travelled (VKT) and total TKM, respectively. The simulations are based on information from the 2001 SMVU.

Confidentiality restrictions prevent the Australian Bureau of Statistics (ABS) from releasing unit record data collected from the survey. In the absence of more detailed data, Monte Carlo simulations offer an instructive alternative means of thinking about results from the SMVU and assessing the impact of methodological changes.

Based on the methodological review we suggest that, outside of the usual variation associated with sampling from a population, there are only five reasons that would warrant amendments to the raw SMVU VKT and TKM estimates. The most significant of these is recall-bias and rounding measured in the 1988 and 1995 surveys, but the extent of recall-bias remains unclear.

The title of the paper, 'jumping at shadows', is meant to reflect our human tendency to prefer the familiar to the unfamiliar—in this case the older SMVU results to the newer results. We would argue that the most recent changes in the survey methodology, introduced in the 1998 SMVU, should have improved the reliability of the SMVU estimates of vehicle use, primarily because of the inclusion of odometer readings and the reduced incidence of rounding.[1] The simulation results described in this paper imply that most of the methodological changes introduced in 1998 should have had a negligible effect on estimates of vehicle use. The other notable finding from the simulations is that, based on the current sample size for passenger cars, stratifying passenger car use by vehicle age would not appear to significantly improve the reliability of the vehicle use estimates.

The structure of this paper is as follows. Section 2 provides a brief outline of the major methodological changes to the survey. The Monte Carlo simulations are described in section 3. The final section presents some concluding remarks.

[1] Roberts & Haines (1997) report that in a comparison of results from pilot surveys conducted using recall, pre-advice and log-book instruments the 3 month pre-advice based survey was the most reliable.

An overview of the SMVU methodology

Understanding the SMVU estimates of trends in vehicle use over time requires knowledge of the changes to the survey methodology and how these changes are likely to have affected the SMVU results.

There have been several significant changes to the SMVU sampling methodology over the course of the survey. These include:

- Variations to the total sample size—which increased from approximately 53 000 vehicles in 1971 to around 67 000 vehicles in 1988 and was then reduced to around 16 000 vehicles in 2000.
- Changes to the vehicle classification structure.
- Alterations to the sample stratification strategy.
- Adoption of a quarterly pre-advice based survey instrument in 1998, in place of an annual recall-based approach.
- Variations in the date of the sample frame and vehicle census.
- Changes in the measure of the vehicle population.
- Altered treatment of nil-use vehicles and use of vehicles de-registered during the survey period.
- Changes to the design of the survey form and the wording of particular survey questions.

Table 1 provides a summary of the major SMVU survey characteristics, and how they have changed over time. For the 1985, 1988 and 1995 surveys the ABS undertook additional survey work to verify the quality of the survey results. Summary information on these results is also included in Table 1. As mentioned in the introduction, space constraints necessarily restrict the amount of detail that we can provide in this version of the paper. The full paper provides a more detailed review of changes in the survey characteristics.

Despite all these changes, there are, in our view, only five changes for which adjustment to the raw SMVU estimates is warranted in order to derive a consistent time series measure of motor vehicle use (VKT or TKM). These are:

- The change, in 1998, to the measure of the vehicle stock from the number of vehicles on register as at the end of the survey period, in the pre-1998 surveys, to the number of vehicles registered for part or all of the 12 month survey period in the post-1998 surveys.
- The change, in 1991, in the treatment of vehicle deaths which, based on the ABS analysis, resulted in a reduction in estimated total VKT and TKM of 0.25 per cent and 1 per cent, respectively, relative to previous surveys.
- Measured recall bias and rounding in the 1988 and 1995 SMVUs. The ABS analysis suggests that recall bias and rounding may have led to an over-estimate of total VKT and TKM of approximately 5 per cent in these years. It is possible that the bias identified in these surveys may also have affected the earlier recall-based SMVU results, but without more substantive evidence, it is impossible to be conclusive about this.
- Changes to the vehicle classification structure, which affects estimates of vehicle use for different vehicle classes.
- Wording of the 1991 survey question asking respondents for an estimate of the average load carried by the vehicle.

Table 1 Summary of SMVU survey characteristics, 1971 to 2002

Date	*Fleet size* (*'000 vehicles*)	*Sample size* (*vehicles*)	*CV share* (*per cent*)	*Survey method*	*Fleet note*	*Sample strata*	*Vehicle class*	*Data quality* *Imputation rate* (*per cent*)	*Response rate* (*per cent*)	*Rounding / Bias* (*per cent*)	*Other notes*
30-Sep-71	5 106.8	53 000	80	Annual recall	Vehicles on register	X		NA	NA	NA	Pro-rating of results
30-Sep-76	6 556.9	51 000	80	–	–	X		NA	NA	NA	
30-Sep-79	7 285.3	57 000	75	–	–	–		NA	NA	NA	
30-Sep-82	8 132.6	60 000	80	–	–	–	X	NA	NA	NA	
30-Sep-85	8 865.2	60 000	77	–	–	–	–	NA	NA	No bias	No bias
30-Sep-88	9 356.4	67 000	75	–	–	–	X	NA	NA	Recall bias	Seasonal use vehicles
30-Sep-91	10 076.8	42 000	58	–	–	X	X	–	NA	50	Allowance for vehicle deaths
30-Sep-95	10 922.7	22 200	75	–	–	X	–	24	NA	23, Recall bias	Sample frame issues
31-Jul-98	11 863.0	20 000	61	Quarterly pre-advice	Registered during year	X	–	12	NA	6	
31-Jul-99	11 999.4	16 000	59	–	–	X	–	14	80	6	
31-Oct-00	12 228.0	16 000	58	–	–	–	–	14	80	4	
31-Oct-01	12 398.6	17 000	59	–	–	–	–	15		NA	
31-Oct-02	12 849.4	16 700	60	–	–	–	–	16	80	NA	

NA Not available
X Denotes change in survey method
– Unchanged
Sources ABS (2003b and earlier issues).

It is unclear what impact changes to the sample size, choice of sample strata and imputation have had on the survey results. We would expect that the first two should not have affected the estimate of total vehicle use, but will have increased the variation of the estimates. Similarly, the change from an annual to a quarterly survey instrument, and the application of post-stratification techniques to the 1998, 1999, 2000 and 2001 SMVUs should have had not affect estimated vehicle use. These issues are addressed further in the next section.

Monte Carlo simulations of the SMVU methodology

In this section, we describe and report results from Monte Carlo simulations of changes to the SMVU sampling methodology. Monte Carlo simulations are very useful for conducting repeated experiments of stochastic behaviour. The principal is straightforward—through repeated sampling from a given population it is possible to construct the profile of a distribution, which may otherwise be analytically intractable. For this paper, Monte Carlo simulations have been used to conduct counter-factual assessments of the quantitative impact on the SMVU results of changes to the survey methodology.

The simulations essentially mirror aspects of analysis that the ABS might undertake in designing the survey. For analysts, the Monte Carlo simulations offer an alternative way of thinking about the results from the SMVU and assessing the impact of methodological changes.

Section 2 suggested three areas where changes in survey methodology may have had an impact on the SMVU results and several changes that should not have affected the SMVU measure of vehicle use. We used Monte Carlo simulations to model the impact on the reported survey results of the following five aspects of the SMVU sampling method:

- changes in the survey methodology and seasonality
- rounding
- choice of sample size
- age-based sample stratification
- post-stratification.

Separate simulations were conducted for articulated trucks and passenger cars. Articulated trucks account for approximately 77 per cent of the total road freight (tonne-kilometre) task and passenger cars account over 75 per cent of total vehicle kilometres travelled (VKT) (ABS 2003a). Hence, focusing on these two vehicle classes provides a reasonable guide as to the impact on estimates of total TKM and VKT. All simulation results are based on average vehicle use information from the 2001 SMVU. All simulations were undertaken in R—the open-source software package for data analysis and graphical display.

Because they abstract from certain aspects of the SMVU sampling procedure, however, these simulations cannot provide incontrovertible evidence about the quality of the SMVU results. Additionally, the simulations cannot test the importance of non-sampling errors. However, given constancy in the methodology and design of the survey form, we might expect non-sampling errors to behave similarly across surveys.

Before considering the simulation results it is useful to briefly review some simple sampling theory.

Some sampling theory

Consider a population, such as the stock of vehicles on register, of size N. The corresponding values of some characteristic of the population, such as total VKT for each vehicle, are denoted by $Y_1, Y_2, \ldots, Y_N$. Fleet average VKT is equal to the sum of VKT by each vehicle divided by the total number of vehicles:

$$\bar{Y} = \frac{\sum_{i=1}^{N} Y_i}{N} \tag{1}$$

The variance of total population is:

$$S^2 = \frac{\sum_{i=1}^{N} \left(Y_i - \bar{Y}\right)^2}{N-1} \tag{2}$$

For a random sample of size n, drawn from a population of size N, the sample mean and variance of population characteristic Y are, respectively:

$$\bar{y} = \frac{\sum_{i=1}^{n} y_i}{n} \tag{3}$$

and

$$s^2 = \frac{\sum_{i=1}^{N} \left(y_i - \bar{y}\right)^2}{n-1} \tag{4}$$

Provided the sample is random, the sample mean and sample variance are unbiased estimates of the population mean and variance (Cochran 1977). The variance of the sample mean, y, is given by:

$$V(\bar{y}) = E\left(\bar{y} - \bar{Y}\right)^2 = \frac{S^2(N-n)}{nN} = \frac{S^2}{n}(1-f) \tag{5}$$

where $f = n/N$ is the sampling fraction. For large populations f is small and is often ignored. Across all vehicles in the 2001 SMVU, for example, $f = 0.0014$ sufficiently close to zero to be ignored. For articulated trucks in the same survey, however, $f = 0.041$, too large to be ignored.

Stratified sampling, where the total sample is split into two or more homogeneous groups, which are then sampled independently, may produce a gain in the precision of the estimates for a fixed total sample size. The separate sample estimates for each strata may be combined to derive an estimate for the whole population. The SMVU has always stratified the vehicle population, albeit using varying stratification strategies. The sample mean for a stratified random sample is:

$$\bar{y}_{st} = \frac{\sum_{h=1}^{H} N_h \bar{y}_h}{N} = \sum_{h=1}^{H} W_h \bar{y}_h \tag{6}$$

where y_h is the sample mean for strata h and $W_h = N_h/N$ is the stratum weight. The variance of the stratified sample mean is given by:

$$V(\bar{y}_{st}) = \sum_{h=1}^{H} W_h^2 \, V(\bar{y}_h) \qquad (7)$$

For the most recent surveys, quarterly survey estimates have to be aggregated into annual estimates. The annual estimate of fleet average VKT, for example, is equal to the sum of the quarterly estimates and, assuming the quarterly samples are independent, the variance in total annual VKT will be given by the sum of the quarterly variances.

Articulated truck simulation

As already mentioned, with the 1998 SMVU the survey changed from a 12 month recall-based survey instrument to a 3-month pre-advice based survey. Two results of this change in methodology have been an increase in the number of vehicles reporting nil-use and a reduction in the number rounded responses.

We simulated sampling from the articulated truck fleet to estimate the impact of the change to the quarterly survey methodology on:

1. the number of vehicles reporting nil-use and estimated total vehicle use; and
2. the impact of rounding on estimates of vehicle use.

Constructing a synthetic vehicle fleet: In order to compare the quarterly and annual simulation processes we used the 2001 SMVU results as the basis for constructing a synthetic articulated truck fleet, from which we then drew repeated samples using both annual and quarterly survey methods.

Table 2 shows the assumed characteristics of the articulated truck fleet, by age cohort, used to construct the simulated truck fleet. Based on the 2001 SMVU results, vehicles of 10 years or less (year of manufacture 1990 and after) averaged 135.7 thousand kilometers per annum and vehicles aged 21 years or more (year of manufacture 1979 and earlier) averaged 20.8 thousand kilometres per year. The assumed standard deviations in average VKT are based on the SMVU estimated standard errors and assumptions about the number of vehicles sampled.[2] For our simulation, we assumed that there were 407 vehicles sampled in the oldest cohort, 799 vehicles sampled from the 11 to 21 year age cohort and 1336 vehicles selected from the youngest cohort. For simplicity, we assumed VKT was log-normally distributed.[3] The standard deviation in VKT, based on these assumptions, was 43.1 thousand kilometres for vehicles of 10 years or less, 32 per cent of

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[2] The sample standard error is equal to $\sqrt{\sigma^2/n}$, where σ^2 is the population variance and n is the sample size. In practice, the population variance is not known and may be estimated by the sample variance $s^2 = \sum_{i=1}^{n}(X_i - \bar{X})^2 / (n-1)$. The sample standard error may be multiplied by the sample size to estimate the sample variance.

[3] The log-normal distribution is used for modelling many real-world phenomena and has the desirable property that the range of observations must be non-negative.

Table 2 Assumed articulated truck fleet characteristics

Year of manufacture	*No. vehicles*	*VKT*		*Vehicle load*	
		Mean	*Std. dev.*	*Mean*	*Std. dev.*
		(*kilometres*)		(*tonnes*)	
1979 and earlier	13 462	20 800	17 500	10.0	2.5
1980 to 1989	21 277	61 100	28 400	20.0	5.0
1990 and after	27 767	135 700	43 100	25.0	5.0

Source ABS (2003b).

average VKT, and 17.5 thousand kilometres for vehicles 21 years and older, 84 per cent of average VKT for those vehicles.

Estimates of the average load by vehicle age are not available from the published SMVU results. We assumed the average load per vehicle kilometre travelled, including unladen vehicle use, is 25 tonnes for vehicles of 10 years or less, 20 tonnes for vehicles of between 11 and 21 years and 10 tonnes for vehicles 21 years and older. And the standard deviation in average load is assumed to be 2.5, 5.0 and 5.0 tonnes, respectively (see table 2).

Nil-use vehicles: To test the impact on reported nil-use of the change to a quarterly survey design we had to make some assumptions about the proportion of nil-use vehicles in each age cohort. We used a two stage process for determining nil-use in each quarter. In the first stage, we randomly selected the number of nil-use vehicles in the first quarter for each age cohort. We assumed that 20 per cent of vehicles aged 21 years and over remained unused in the first quarter, 5 per cent of vehicles aged between 11 and 21 years were unused and only 1 per cent of vehicles under 11 years of age were unused in the first quarter. In the second stage, we randomly assigned nil-use for each vehicle in each of the 2nd, 3rd and 4th quarters, conditional on how many previous quarters the vehicle had been unused. We assumed that if a vehicle had nil-use for one or two quarters it was more likely to be nil-use in the second and third quarters, respectively, reflecting the likelihood that a seasonal use vehicle is more likely to be nil-use for more than one quarter. However, if a vehicle was not used for three quarters it was unlikely to remain unused in the last quarter otherwise it would not be worth registering the vehicle. Table 3 shows the nil-use probability assumptions used to create the simulated articulated truck fleet.

We saved the synthetic articulated truck fleet to a Postgresql database. Storing the results in a database facilitated repeated sampling and enabled us to compare the results of quarterly and annual survey procedures drawn from the same population.

Table 3 Assumed probability of nil-use for the synthetic articulated truck fleet

Year of manufacture	*No. vehicles*	*Share of nil-use vehicles*				
		Qtr. 1	*No. quarters nil-use*			
			0	1	2	3
1979 and earlier	13 462	0.20	0.10	0.60	0.60	0.15
1980 to 1989	21 277	0.05	0.03	0.60	0.60	0.05
1990 and after	27 767	0.01	0.00	0.60	0.60	0.05

Source ABS (2003b).

Table 4 lists estimates of total VKT and total TKM for the synthetic articulated truck fleet. For comparison, the SMVU estimates for total VKT and TKM are included in the table. Total VKT for the synthetic fleet is 5.26 billion kilometres, within 2 per cent of SMVU estimate of total articulated truck VKT of 5.32 billion kilometres in 2001. Total TKM for the simulated fleet measures 106.4 billion tonne-kilometres, which is 4.5 per cent above the actual SMVU estimate of 101.9 billion tonne-kilometres in 2001—implying that our assumed average loads are probably a little higher than actual average loads. The synthetic fleet includes a significant number of high utilisation vehicles—324 articulated trucks in the synthetic fleet travelled more than 500 000 kilometres per annum and 833 vehicles travelled more than 250 000 kilometres per annum.

Figure 3 illustrates the frequency distribution of VKT for the 2001 SMVU and synthetic articulated truck fleet. The figure shows that the assumptions used to generate the simulated articulated truck fleet result in slightly different shaped VKT distribution compared to the SMVU results. A Chi-square test rejects the null hypothesis of no difference.[4] However, it should be noted that the VKT distribution from the SMVU is based on a quarterly survey and the simulated distribution is based on annual vehicle usage. This is an area where the simulations could be improved by access to more detailed data from the ABS with respect to the age cohort sample sizes and the population or sample variances. For this paper, we overlooked the differences between the synthetic and sampled distributions, using the synthetic distribution in the simulations reported below.

Simulation results: Consider now a simulation of the alternative SMVU survey methodologies: the quarterly pre-advice and annual recall-based approaches. For the quarterly simulation, we divide the survey frame into four (approximately) equal quarterly survey frames. Sampling is undertaken without replacement in each of the four quarters. For the annual simulation, the same total number of vehicles are selected and sampled on an annual basis. The assumed quarterly and annual sample sizes, by vehicle cohort, are listed in table 5. For this simulation we have assumed equi-proportionate sampling across vehicle cohorts. The sampling process was repeated 100 times for both the quarterly and annual approaches in order to measure the spread of the sample results.

Table 4 Synthetic articulated truck use

Year of manufacture	*No. vehicles*	*VKT*		*TKM*	
		Total (million km)	*Average ('000 km)*	*Total (billion tkm)*	*Average ('000 tkm)*
1979 and earlier	9 852	146.0	14.8	1.2	118.3
1980 to 1989	19 325	1 115.2	57.7	17.9	925.7
1990 and after	32 325	4 364.4	135.0	87.40	2 702.3
All vintages	61 502	5 625.6	91.5	106.4	1 730.1
SMVU	62 506	5 321	86.5	101.9	1 804.4

[4] The test statistic was 24 789, well above the critical value $\chi^2_{df=21} = 32.7$.

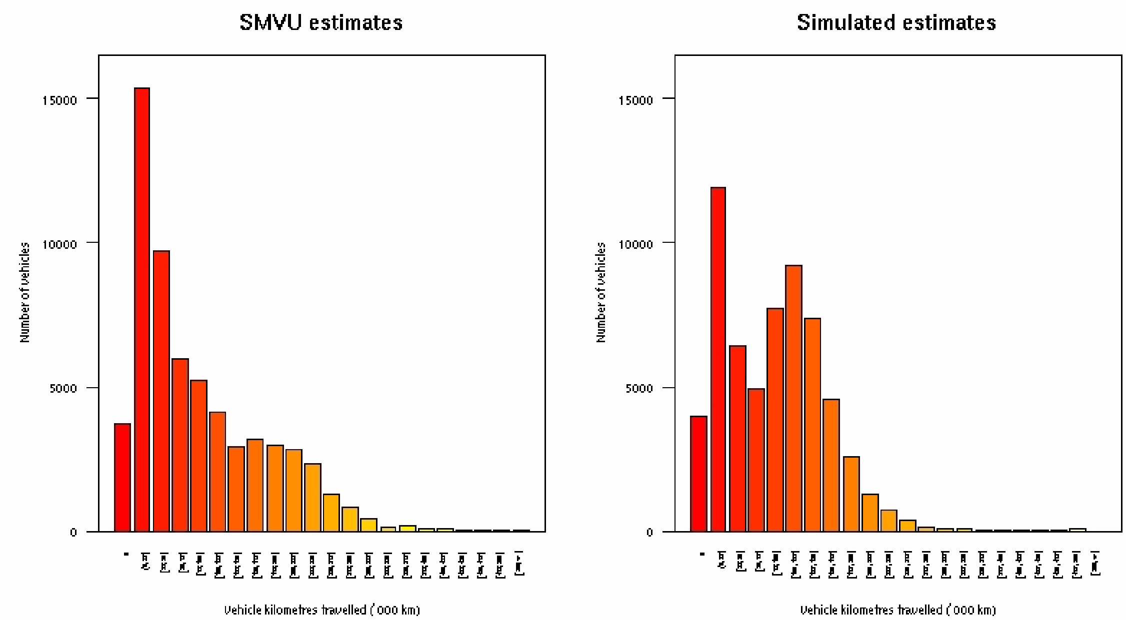

Figure 3 Comparison of actual and simulated articulated truck VKT distribution

Table 5 Articulated truck sample size, by quarter

	Quarter				
Vintage	*First*	*Second*	*Third*	*Fourth*	*Total*
1979 and earlier	102	102	102	101	407
1980 to 1989	200	200	200	199	799
1990 and after	334	334	334	334	1336
All vehicles	636	636	636	634	2542

Table 6 Comparison – quarterly and annual sample survey results

Simulation	*Nil-use*		*VKT*		*Avg. VKT*		*TKM*	
	Mean	*S.E.*	*Mean*	*S.E.*	*Mean*	*S.E.*	*Mean*	*S.E.*
	(per cent)		*('000 km)*		*('000 km)*		*(billion tkm)*	
Synthetic fleet	0.00	NA	5 626	NA	91.5	NA	106.4	NA
Quarterly	5.22	0.43	5 623	128	91.0	2.08	106.3	2.45
Annual	0.03	0.03	5 620	65	91.0	1.06	106.3	1.26
Z-statistic			–0.059		–0.059		–0.045	

Impact of nil-use vehicles: We first considered the impact of the change from annual to quarterly on the proportion of nil-use vehicles and estimated total VKT and TKM. The results are listed in Table 6.

The results show that there is very little difference between the mean VKT and TKM estimates obtained from the annual and quarterly based approaches. Yet there is a significant difference between the annual and quarterly survey estimates of the proportion of nil-use vehicles. Repeated sampling of the fleet allows us to test the significance of any differences in the annual and quarterly survey methodologies. We use a simple *Z*-test to compare the difference of the results. The test statistics, listed in the last row in table 6, are all less than the critical value, $Z_{0.975} = 1.96$, and hence are not statistically significant. In other words, as might be expected, the choice of annual or quarterly survey instruments should have no impact on the average and aggregate vehicle use estimates.

Impact of rounding: The ABS reported a significant reduction in the proportion of rounded responses following the change to the quarterly survey approach. We also undertook to estimate the impact of rounding on the survey results. We conducted two simulations that involved rounding. In the first case, 'fair rounding' was assumed—that is, it was assumed there was an equal chance that the respondent would round their estimate up or down to the nearest 1000 or 5000 kilometres in the case of the quarterly survey and 1000 or 10 000 kilometres in the annual survey. In the second case, we assumed 'skewed rounding'—with 80 per cent of rounded responses assumed to be rounded up and 20 per cent rounded down. For both cases we assumed that 25 per cent of all sample responses were rounded.

The results for these two simulations are displayed in tables 7 and 8. In the case of fair rounding, one would expect that any rounding-up would be offset by rounding-down. The simulation results, reported in table 7, bear this out—fair rounding has no noticeable affect on estimated total VKT or TKM. The Z-test statistics, listed in the last row in table 7, are all less than the critical value, $Z_{0.975} = 1.96$, and hence are not statistically significant.

In the skewed rounding case, the impact on estimated VKT and TKM while more noticeable remains relatively small—estimated total VKT is only 0.15 per cent above actual VKT. These results imply that, by itself, the level of rounding reported by the ABS in the 1995 SMVU should not have had a significant effect on the estimates of vehicle use. Rather, to produce the magnitude of over-estimation reported by the ABS (1998, 1996, 1990) the measured rounding must have included a significant amount of skewed recall-bias.[5] Richardson (2000), for example, notes that in recall-based surveys of cumulative travel over an extended period, survey respondents may over-estimate their total travel by including trips that may have been made before the start of the survey period. The phenomenon is known as 'telescoping'.

[5] Although not reported here, we also conducted a simulation in which half of all responses were rounded, 80 per cent of them rounded up by 3000 or 30 000 to simulate bias and test the rounding algorithm. This simulation produced an estimate of total VKT = 7474 million kilometres and TKM = 143.5 billion tonne kilometres—33 per cent and 35 per cent higher than the comparable synthetic fleet measures.

Table 7 Comparison – quarterly and annual sample survey results with even rounding

Simulation	*Nil-use (per cent)*	*VKT ('000 km)*	*Avg. VKT (km)*	*TKM (billion tkm)*
Base	0.00	5 626	91 471	106.4
Quarterly	5.22	5 623	91 426	106.3
Annual	0.03	5 620	91 381	106.3
Z-statistic		0.402	0.402	0.006

Table 8 Comparison–quarterly and annual sample survey results with skewed rounding

Simulation	*Nil-use (per cent)*	*VKT ('000 km)*	*Avg. VKT (km)*	*TKM (billion tkm)*
Base	0.00	5 625.6	91 471	106.4
Quarterly	5.22	5 635.2	91 627	106.6
Annual	0.03	5 632.1	91 576	106.6
Z-statistic		0.449	0.449	–0.063

Sample variation: Having constructed a synthetic articulated truck fleet it is possible to investigate how much variation there is in the survey results from year-to-year. Year-to-year variation in the survey estimates may mask trends in vehicle use. We considered how likely is it that the survey estimates will over- or under-shoot the total task by more than 5 per cent in any one year. Of the 100 repeated draws using the quarterly sampling procedure, only 3 samples produced an estimate of total VKT outside of the 5 per cent of the actual fleet value. For TKM, only 5 samples produced an estimate of total TKM outside of the actual fleet total. The distribution of estimated total VKT and TKM is illustrated in figure 4. In other words, the chances of the survey result over- or under-estimating the total articulated truck VKT and TKM by 5 per cent or more is 3 per cent and 5 per cent, respectively. These estimates are only approximate, as the strata sample sizes have not been chosen to minimise sampling error of the survey estimates and these estimates are based on only a small number of replications. Nonetheless, they suggest that, with current sample sizes, the chances of over- or under-estimating total freight vehicle use are relatively small.

These estimates do not really tell us anything not already reported in the SMVU. They are in effect equivalent to the estimated standard errors for the SMVU. They are, however, useful in illustrating the accuracy of the SMVU and suggest that analysts should have strong evidence before adjusting the survey results.

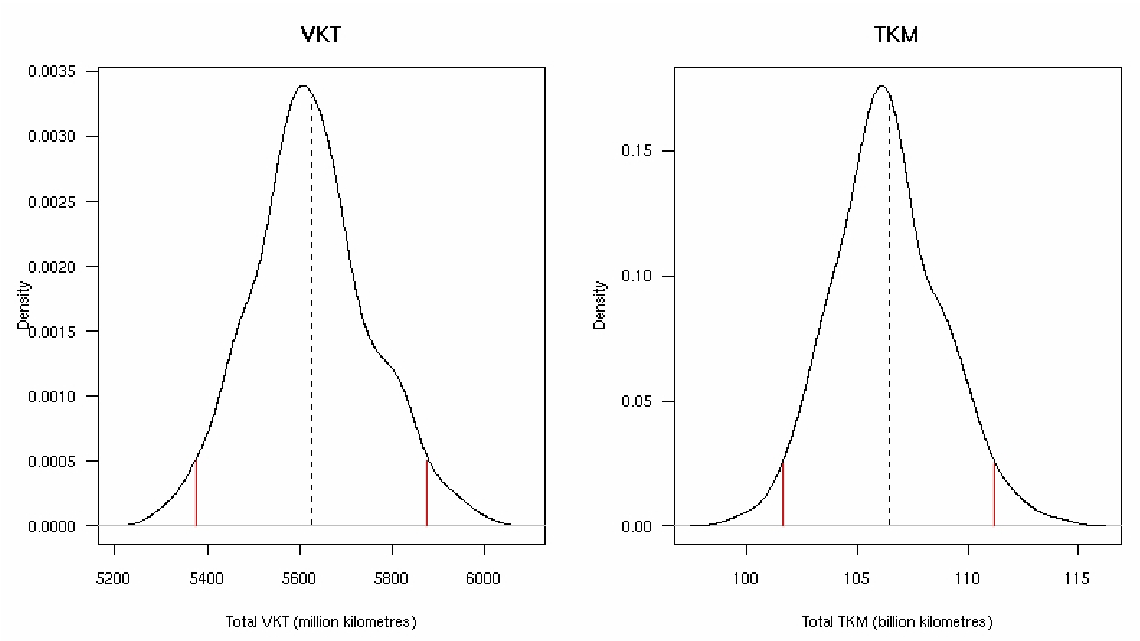

Figure 4 Distribution of estimated articulated truck VKT and TKM

Passenger car simulation

As previously mentioned, passenger cars are the largest motor vehicle class—responsible for approximately 75 per cent of total road vehicle kilometres travelled and 85 per cent of total road sector petrol consumption (ABS 2003*b*). As illustrated in figure 2, recent SMVU estimates of passenger vehicle fuel consumption underestimates total petrol sales, quite significantly in some years. This discrepancy between the SMVU petrol consumption estimate and total petrol sales has been used to suggest that the SMVU also under-estimates total passenger car VKT.

There may of course be other explanations for this discrepancy between the SMVU fuel consumption estimate and actual fuel sales. For example, the ABS reports that the fuel consumption question on the survey consistently requires the highest rate of imputation (around 25 per cent) due to non-response. Also the lack of stratification by vehicle age, for passenger cars, may reduce the accuracy of the SMVU fuel consumption estimates. Interestingly, the divergence between actual fuel sales and the SMVU fuel consumption estimates occurred around the time of the reduction in the passenger car sample size in 1991 and 1995, possibly implicating the passenger car sample size as a factor in the reduction in the reliability of the fuel consumption estimate. Of course, any drop in sample size should affect the reliability of the estimate and not the expected value of the point estimate. That is, if the sample size was the problem, estimated fuel consumption should vary around the level of actual fuel sales rather than lying consistently below it.

This section then considers the impact of variations to the sample size, sample strata and the use of post-stratification techniques on estimates of passenger car use. Unlike the articulated truck simulation, tests of the sample size and stratification strategy do not require construction of a synthetic vehicle fleet. Rather, it is possible to repeatedly select from a specified distribution and compare the simulation results. This is fortunate, as with almost 10 million registered passenger cars, constructing and sampling from a synthetic vehicle fleet would have been computationally prohibitive.

Passenger car use assumptions: Rather than using the SMVU survey results as a base, as was done for articulated trucks, we use the average vehicle use assumptions used in the BTRE CARMOD model of passenger vehicle use. CARMOD has been used by the BTRE to project future passenger car use, fuel consumption, and greenhouse and noxious emissions. It is based on the actual historical data from the pre-1998 SMVUs and more recent SMVU data adjusted to meet total fuel sales. Of particular use for this analysis, CARMOD includes adjusted estimates of the vehicle stock, average vehicle utilisation and average fuel consumption for each of 22 separate age-based vehicle cohorts—separate cohorts for each vehicle age between 0 and 20 years and a single class for all vehicles aged over 20 years. Table 9 lists the estimated number of vehicles and the assumed average VKT in 2001, by age cohort, in CARMOD. Table 9 also includes an assumed standard deviation for average VKT for each cohort, used in the simulations described below. Based on the 2001 SMVU results from the ABS Data Cubes (ABS 2003*c*), the standard deviation for the most recent vehicle cohorts were assumed to be between 1 and 1.25 times average VKT for those classes. For vehicles aged 7 years and over, the standard deviation was assumed to be between 1.5 and 2.5 times average VKT for these vehicle classes. These assumptions imply a fleet wide standard deviation in VKT of 24 893 kilometres. This is close to the estimate implied by the relative standard error published in the SMVU Data Cubes.[6]

Figure 5 illustrates the assumed annual VKT distribution for each of the 24 separate vehicle classes. Again, we assume a log-normal distribution for average VKT within each age cohort. For the simulations, we used quarterly survey periods. For simplicity, we assumed that travel was independently and evenly distributed across each quarter and that the size of the vehicle stock remained fixed over a full 12 month period. These assumptions imply that average VKT in each quarter is 0.25 times annual average VKT and the standard deviation in VKT in each quarter is half the annual standard deviation in VKT.

[6] The 2001 SMVU Data Cube reports a standard error of 2.99 per cent (ABS 2003*c*, Table 12) for fleet average passenger car VKT. Multiplying by the assumed sample size—3200 vehicles—implies a fleet-wide standard deviation of 24 694 kilometres. The published SMVU results appear to provide conflicting estimates of the standard error associated with the estimates of fleet average VKT for passenger cars. In contrast to the Data Cubes, the formal SMVU publication (ABS 2003*b*, p. 33) reports a standard error for passenger car VKT of 2 per cent.

Table 9 Passenger car simulation assumptions

Age	*No. vehicles*	*VKT*	
		Mean	*Std dev.*
	('000 vehicles)	*(kilometres)*	
0	644.6	12 556	15 695.0
1	590.8	23 488	28 185.6
2	665.3	20 769	23 884.3
3	645.4	19 917	21 908.7
4	537.8	19 066	20 019.3
5	517.5	18 393	18 393.0
6	504.3	17 768	26 652.0
7	453.1	17 141	26 854.2
8	421.1	16 355	26 713.2
9	408.0	15 734	26 747.8
10	394.2	15 257	26 954.0
11	443.0	14 779	27 094.8
12	431.0	14 304	27 177.6
13	350.2	13 829	27 197.0
14	322.4	13 352	27 149.1
15	360.9	12 678	26 623.8
16	369.2	12 001	26 002.2
17	321.7	11 330	25 303.7
18	297.7	10 864	24 987.2
19	262.2	10 659	25 226.3
20	223.7	10 149	24 695.9
Over 20	804.6	9 000	22 500.0
Total	9 968.7	15 500	24 896.3

Source ABS (2003*b*, and earlier issues) and BTRE CARMOD.

The 2001 SMVU surveyed approximately 4000 passenger car and motor cycles. Assuming that around 800 of these were motor cycles, leaves a total sample of 3200 passenger cars. For the simulation, we assumed the total sample was evenly distributed over the year, implying a sample of 800 vehicles each quarter. For each simulation, we repeated the sampling process 500 times to estimate the variation in the sampling process.

Simulation results: We ran the simulation and produced estimates of passenger vehicle use using four different sampling approaches:

- simple random sample
- skewed random sample
- stratified random sample
- post-stratification techniques

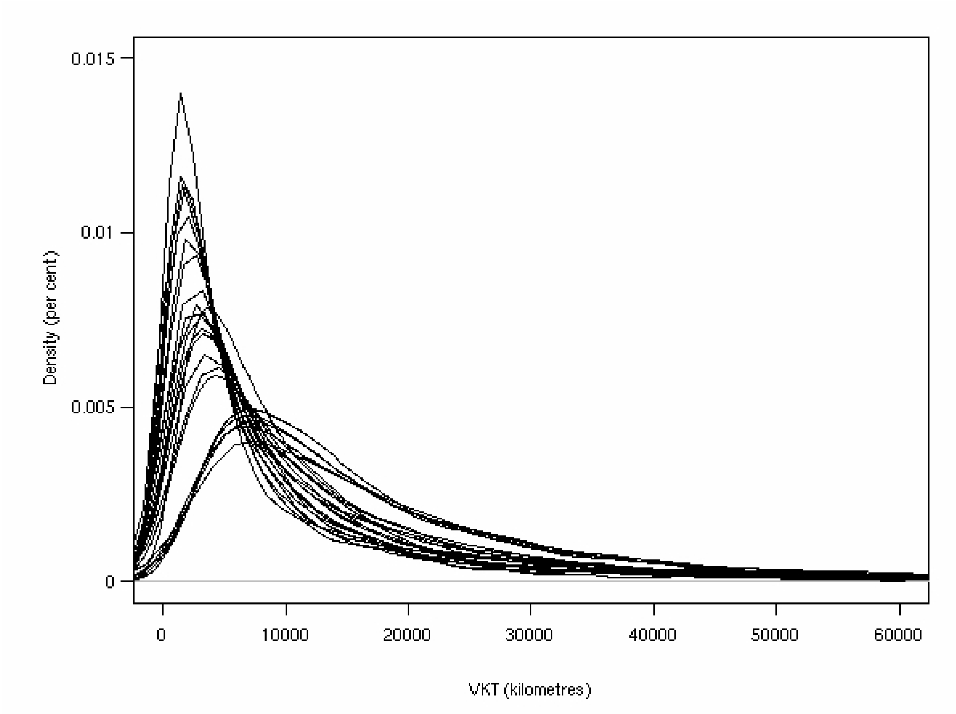

Figure 5 Assumed VKT distribution – Passenger vehicles

For the stratified random sample we used two different sets of age-based strata, one with 22 strata—one for each vehicle age cohort in CARMOD—and the other with six strata—new vehicles, vehicles aged 1 to 5 years, 6–10 years, 11–15 years, 16–20 years and vehicles over 20 years. Post-stratification was applied to the simple random sample results and the skewed random sample results. In the skewed random sample simulation, we sampled disproportionately fewer new vehicles and more older vehicles than would be obtained from repeated simple random sampling. Table 10 lists the mean of estimated total and average VKT across the 500 samples and the mean standard error of estimated average VKT. The results show that for all but the skewed simple random sample, the mean sample results are all within 0.5 per cent of actual VKT implied by our fleet assumptions.

Sample stratification and post-stratification: Figure 6 shows the distribution of estimated average VKT for the simple random sample and the two age-based stratified sampling procedures. It can be observed from the figure that the distributions are very similar for the three different sampling strategies. The stratified sample mean standard errors for fleet average VKT straddle the mean standard errors for the simple random sample—the mean standard error is slightly higher for the 22 strata case and slightly lower for the 6 strata case than is the case for the simple random sample—but the results are almost indistinguishable. These results imply that there is very little gain from stratifying passenger vehicles by vehicle age. Interestingly, the mean standard errors from the simulation are around 70 to 75 per cent higher than the mean standard errors reported in the SMVU, which implies that the variation in actual vehicle use may be even smaller than that assumed here.

Using the repeated simulation results, we can estimate the likelihood of obtaining an estimate of the sample mean lying above or below the actual average. For the random and stratified sample estimates drawn from the simulated fleet VKT distributions, the probability of obtaining a sample mean 10 per cent above or below the actual mean is 5.2 per cent for the simple random sample, and 5.8 per cent and 5.0 per cent, respectively, for the 22 strata and 6 strata simulations.

We also considered the impact on the survey estimates of using post-stratification techniques. The ABS (2003*a*,*b*) used post-stratification to re-estimate the results for the 1998, 1999, 2000 and 2001 SMVUs. Table 10 showed that the skewed sample produced vehicle use estimates well below the population values. Table 10 includes vehicle use estimates derived using post-stratification applied to the simple random sample and the skewed random sample results. Post-stratification applied to the skewed sample results produces estimates in line with those of the simple random sample and do not significantly change the random sample results. This simulation confirms that post-stratification can improve estimates from an unrepresentative sample and will not alter results obtained from a reliable sample. Figure 7 illustrates the impact of post-stratification on the distribution of estimated average VKT for the simple random and skewed samples.

Table 10 Passenger car use simulation mean estimates

Simulation	*Total VKT*	*Average VKT*	*SE(Avg. VKT)*
	(million km)	*(kilometres)*	
Actual	154.5	15 500.0	NA
Random sample	155.2	15 564.9	794.7
Skewed sample	141.6	14 199.7	768.8
Stratified sample			
22 strata	155.3	15 574.3	812.1
6 strata	154.5	15 496.9	767.7
Post-stratified sample			
Random	155.1	15 563.5	798.8
Skewed	153.7	15 419.9	776.2

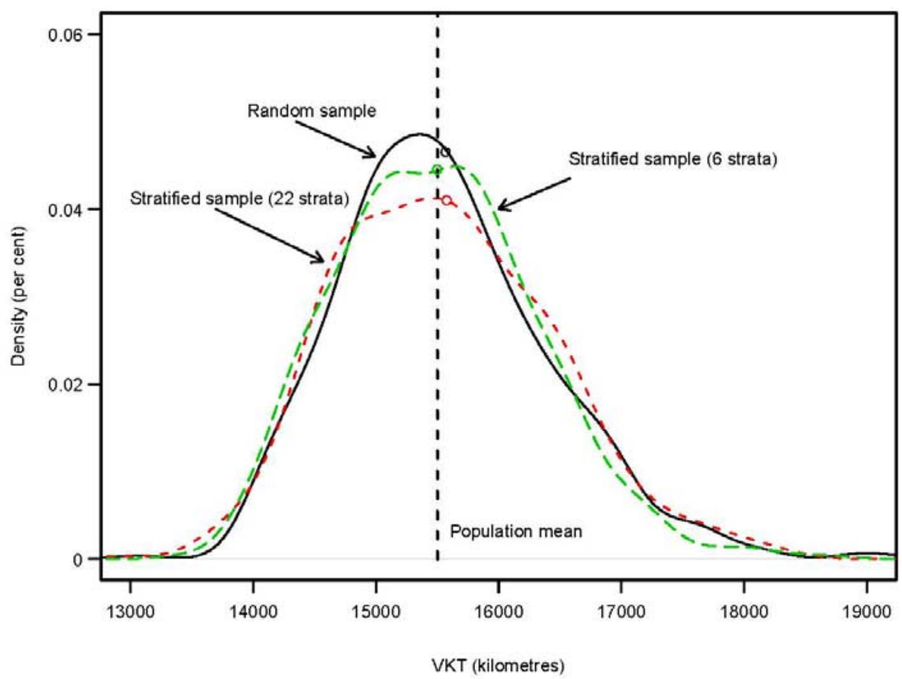

Figure 6 Simulated sampling average passenger vehicle VKT

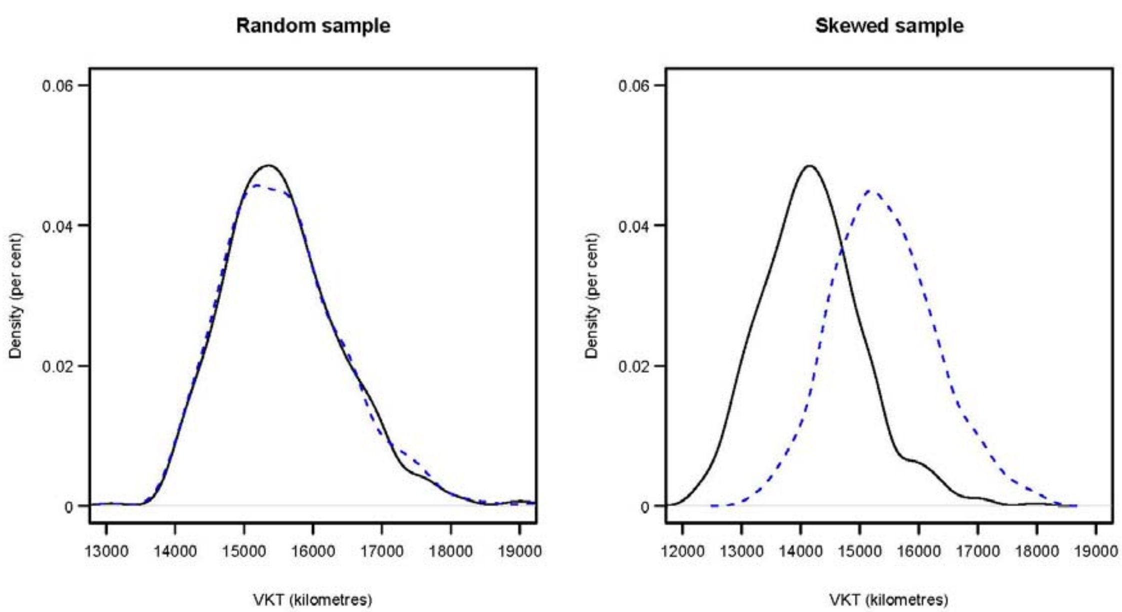

Figure 7 Impact of post-stratification on estimated average VKT

Sample size: Of interest to analysts is whether the size of the passenger car sample is sufficient to produce reliable results and by how much increases in the sample size will improve the reliability of the survey results. Figure 8 shows the estimated impact on the reliability of VKT by varying the sample size from 1800 vehicles up to 6400 vehicles. The figure contains two panels. The left panel shows the mean standard error associated with the estimated average VKT. The right panel shows the estimated proportion of simulations for which average VKT is more than 10 per cent above or below the fleet average VKT. One can see that the mean standard error declines as the sample size increases—a 50 per cent increase in the sample size, to 4800 vehicles, reduces the expected standard error from around 5 per cent to 4.1 per cent, and a doubling of the sample size reduces the expected standard error to 3.5 per cent. However, the proportion of sample results for which it the expected estimated average VKT lies 10 per cent above or below the population average falls from approximately 5.8 per cent to around 3.4 per cent for a 50 per cent increase in the sample size, and to around 1.0 per cent for a doubling in the sample size.

These results suggest that we could expect only modest improvements in the reliability of survey results for registered vehicle use even from a doubling in the passenger vehicle sample size.

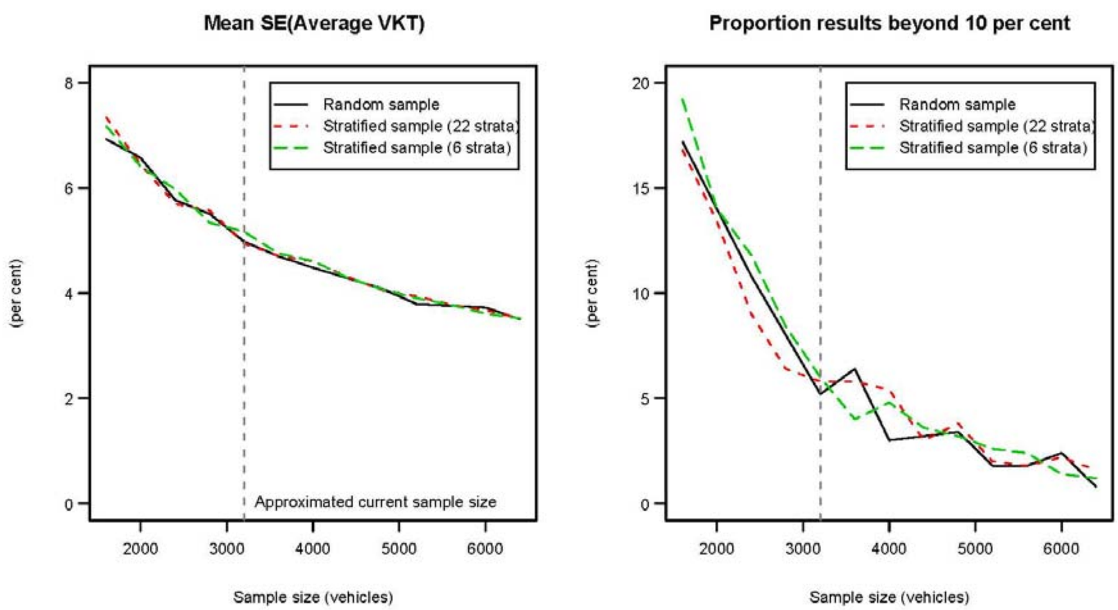

Figure 8 Sample size and survey reliability

Concluding remarks

The SMVU is one of the few surveys of vehicle use in the world and is a relatively cheap way of collecting information about vehicle use in Australia. The results are used by transport analysts to draw conclusions about trends in vehicle use and road freight movements.

Because a sample survey collects information from only a fraction of the population, the sample results necessarily include a degree of imprecision—due to both sampling and non-sampling errors. The degree of imprecision in any sample is affected by many factors, such as sample size, heterogeneity of the population, respondent error and non-response bias. In using the SMVU results to draw inferences about trends and make predictions about the future activity, analysts' need to be mindful of the uncertainty associated with the survey.

Changes to the SMVU survey methodology also affect the comparability of the survey results. This paper has outlined the major changes to the SMVU survey methodology between 1971 and 2002. Those changes include variations in the sample size, changes to the way the vehicle population is measured, adoption of a quarterly pre-advice instrument in place of an annual recall-based survey instrument, changes to the treatment of vehicle deaths and changes in vehicle classification and sample strata. Among these changes, we argue that there are only five changes that warrant adjustment of the raw SMVU estimates to produce consistent time series estimates. These were listed in section 2.

All other changes to the survey methodology should have had either no substantive impact on the survey results or else only affected the variability of the results.

This paper also reports the results of simulations of the SMVU sampling procedure. These simulations were designed to estimate the impact on the survey results of:

- changing from an annual to a quarterly survey instrument
- rounding
- sample stratification
- sample size

The simulations imply that the move from an annual recall-based survey approach to a quarterly pre-advice based survey should have had no substantive effect on the estimates of total vehicle use. Certainly, the use of quarterly survey instrument is likely to result in a larger number of nil-use vehicles, but this should have no effect on the estimates of total vehicle use. With regard to rounding, the simulation results suggest that rounding should have no effect on the survey results if rounding up and rounding down are equally likely. Even where rounding is skewed, the simulations imply that it has a small impact on the survey estimates. The effect of any response bias is likely to be much more significant than simple rounding.

Simulations of the impact on passenger vehicle use of alternative age-based strata imply that stratifying by vehicle age would not significantly improve the survey results with respect to vehicle use. And simulations of different sample sizes suggest that increasing the sample size would not have much impact on the reliability of the survey results.

The simulation results suggest that the present design of the SMVU should produce reliable estimates of registered vehicle use. But they are by no means conclusive evidence. However, arguments that the SMVU under-estimates freight because the SMVU is out of date (Stewart 2003, p. 34) do not seem plausible. As the SMVU uses a vehicle-based stratified random sample of the vehicle fleet, we would not expect it to systematically underestimate vehicle use for any reason other than non-sampling error. The available evidence suggests, if anything, that the shift to a pre-advice methodology in 1998 should have reduced respondent error and improved the quality of the SMVU estimates. Equally, the SMVU should provide an accurate measure of total passenger car VKT. However, the recent gap between the SMVU estimate of total petrol consumption and total petrol sales (figure 2) remain puzzling. We do know from the ABS (2003c) that the average rate of fuel consumption remains the item on the survey requiring the greatest rate of imputation by the ABS, suggestive that this item is the most unreliable measure in the survey. This issue will probably only be resolved through more detailed analysis of respondent behaviour.

Ultimately, the SMVU results will remain open to interpretation. Sampling error and response bias will be ever present in the survey inviting comparisons between the SMVU results and other data sets. Analysts producing alternative estimates of vehicle use should be clear, however, about what they are adjusting for and why. Efforts in this area would be helped by access to more detailed data from the SMVU.

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