

METROPOLITAN MOBILITY SURVEYS: THE STATE OF PRACTICE

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ABSTRACT

The state-of-practice of metropolitan mobility surveys lies fairly behind the state-of-the art in most industrialised countries; needless to say the situation is not better in the developing world. It has been recognised that the state-of-the-art at present is a continuous survey with smaller than classical sample sizes in each year. This paper discusses the issues of sample size, data collection, and correction and weighting. We argue that sample sizes estimated on the basis of stratifications by income, car ownership and household size, allow to calculate trip rates, zone-level car ownership and mode choice models for different strata with a pre-specified error and level of significance. The consensus state-of-the-art and of practice considers collecting data for each day of the week during the whole year, and for all trips made by every household member. Data correction and weighting are fundamental steps in the survey procedure; we discuss also the need for independent data and validation strategies. The paper concludes with a brief report on the main results for the first wave of the 2001 Santiago mobility survey and the problems faced with its continuation (currently under way at least until 2007) that serve to illustrate the magnitude of the effort and to show that it is possible to do it in a developing country.

1. INTRODUCTION

In large metropolitan areas there is an important role for travel survey data. Sometimes data is used mainly for its richness in portraying an existing situation (e.g. the 1997-1998 New Zealand Travel Survey¹) helping the analyst to identify problems related to the transport system. However, the typical needs of a large-scale survey are to allow for the calibration of state-of-the art strategic transport-planning models. Thus, key data elements are trip rates, origin-destination trip matrices, mode choice data and information about network levels-of-service.

The state-of-practice in many advanced countries including the US (TMIP, 1996) lies far behind what could be labelled *state-of-the-art* (Stopher and Jones, 2003). Perhaps surprisingly, the current state-of-practice is found in two Southern countries: Australia, where the pioneering intellectual work of Richardson *et al* (1995), saw practical application in Melbourne² and several other places including Sydney³, New Zealand⁴ and most

¹ <http://www.ltsa.govt.nz/research/travel-survey/>

² <http://www.tuti.com.au/>

³ <http://www.transport.nsw.gov.au/factsheets/>

⁴ <http://www.ltsa.govt.nz/research/travel-survey/about-survey.html>

recently Perth⁵ and Chile, that today boasts probably the most advanced ongoing survey in the world⁶ to accompany its well-known strategic equilibrium transport modelling system ESTRAUS⁷ (De Cea *et al*, 2003).

Stopher and Jones (2003) provide a complete and useful guide of the elements a state-of-practice survey should consider. We concentrate here on certain key elements required to enhance the usefulness of the data as an aid to calibrating a complex supply-demand equilibration transport model. In that case, we argue that the survey should have the following features:

- consider stage-based trip information - ensuring that analyses can relate specific modes to specific locations/times of day/trip lengths, etc.,
- consider all modes of travel, including non-motorised trips,
- cover the broadest possible time period: e.g. 24 hours of the day, seven days of the week, and even possibly all seasons of the year (365 days),
- collect data from *all* members of all households in the study area,
- achieve high quality data (including low levels of response bias) which is robust enough to be used even at a disaggregate level, and
- consider an integrated data collection system incorporating household interviews as well as origin-destination data from other sources (i.e. screen line and cordon surveys).

Such a study comprises not only household interviews but also data from a variety of secondary sources, leading to the following data collection exercises:

- *Household surveys*: This data permits the estimation of trip generation and mode split models, and also provides information on the trip length distribution in the city, a key element in estimating trip distribution models.
- *Intercept surveys at external cordon points*: These are shorter surveys, carried out at points that intercept trips arriving and departing the study area.
- *Intercept surveys at internal cordon and screen line points*: These are also important inputs to trip generation and especially trip distribution models.
- *Traffic and person counts*: Provide information to validate the rest of the surveys. Note that integrating this data into the survey methodology is not straightforward.
- *Other related data*: Land-use data, including employment levels and composition, data about the transport network and the transport system (fares, frequency, etc.) and information from special surveys on individual preferences and attitudes, including data on elasticity of demand (e.g. stated preference methods).

Each component requires a detailed design together with a carefully selected sampling strategy. This paper focus on household surveys. For intercept surveys, sample size may be obtained using the method discussed in Ortúzar and Willumsen (2001, pp. 87-89).

In the next section we present the principal components of the methodology proposed for Santiago, the capital city of Chile, which is applicable to other situations where a strategic transport planning model is the key use of the data. In Section 3 the sample size required to obtain specific objectives is examined; Section 4 discusses the issues of correction, weighting, expansion and validation of the data, and in Section 5 we provide a brief summary of the study currently ongoing in Santiago. This should make it possible to judge the magnitude of the effort and to get a feeling about its quality.

⁵ <http://www.daa.com.au/parts/>

⁶ <http://www.eod.cl>

⁷ <http://www.mctsoft.com>

2. STATE-OF-PRACTICE-METHODOLOGY FOR A CONTINUOUS SURVEY

2.1 An ongoing data collection process

Information should be gathered for each day of the week throughout the year over several years. This allows capturing seasonal variations as well as weekend-weekday differences. Advantages of this approach are that updated data is always available, so changes in demand over time can be measured and correlated to changes in the supply system. Also, the respondent task is easy and reliable, but still provides data over a longer period, and the process results in lower operational costs and allows for better quality control.

Although it may be necessary to wait for up to a year before there is sufficient data to calibrate a full-scale model, this can be seen as a set-up cost since the problem reduces in importance in the long run. If interviewers are used they need to be kept motivated over a longer period; it is also necessary to develop weighting processes which take account of seasonal variations, and to develop special methods for post-weighting annual data if it is combined with ongoing survey data.

Recommend best practice includes using a continuous survey approach where the survey is planned to run for 3-5 years at a minimum. Famous examples are the Victorian Activity and Travel Survey (VATS) in Melbourne, Australia which began in 1992 and lasted almost exactly a decade, and the Sydney Household Travel Survey (Batellino and Peachman, 2003) which began in 1997 and is planned to continue.

2.2 GIS basis of recording origin and destination data

Geocoding the origin and destination (O-D) information allows to use the data at any level of aggregation and liberates the modeller from the need to define a unique zoning system. This has become a standard in all major metropolitan surveys (NCHRP, 2002) and the future will probably see the application of more sophisticated tools like global positioning software (GPS) systems to aid this requirement (Wolf *et al*, 2003).

2.3 Periodic updating of matrices and models

Although it is possible to prepare partial trip matrices given specific requirements, trip tables for the whole area should be updated only every 12 to 18 months, depending on the type of city under study. Updating models periodically is advantageous (see Ortúzar and Willumsen, 2001, pp. 25-29), but is likely to have an effect on the data collected. In this context, elements worthy of periodical updating are trip generation models, O-D trip tables, modal split, and traffic levels in different parts of the network. Priorities will depend on the type of policies being considered, the need to monitor their performance, and the general modelling needs. They will also depend on expected rates of change and the cost of collecting data for updating - including the social cost of disturbing system users (DICTUC, 1998 gives a more detailed discussion).

Finally, it is necessary to mention that the availability of data collected on a continual basis allows for the implementation of a truly continuous planning approach (Ortúzar and Wilumsen, 2001, pp. 9-15), where user behaviour with respect to radical interventions in the transport system, as well as changes in petrol prices, bus fares or parking charges, may be monitored. The response to such policies should provide basic information about user behavioural thresholds and feed a temporal database that could facilitate the development of more sophisticated models.

3. SAMPLE SIZE

The essence of sample size calculations is one of trade-offs. Too large a sample means that the survey will be too costly for the stated objectives and the associated degree of precision required. The contrary will mean that results will be subject to a large degree of variability and so decisions may not reliably be based on the survey results. Somewhere between these two extremes there exists a sample size that is most cost-effective for the stated survey objectives. The client needs to decide on the acceptable standard error (i.e. how much the reported mean is likely to vary from the actual or population mean) of key variables and their acceptable level of confidence (i.e. how often the reported mean is likely to vary from the population mean).

3.1 Choice of the sampling frame

Given the usual survey scope the sampling frame needs to be determined. This is a list providing information on all residents, visitors and people who pass through an area, and there are various options available. The household frame, while complex, is usually the most straightforward. If a national Census has been conducted recently and information on all dwellings is available, this can be ideal. Alternatively a block-list of the whole region could be used but it is important that it is up-to-date. In certain countries the government possesses a list of all dwellings officially registered for paying property taxes and this can be a useful starting point. If such lists are not available, other methods can be used, the most typical one in industrialised nations being telephone listings (Stopher and Metcalf, 1996), complemented by other methods if telephone ownership or listings are not universal. Finally, if no 'official' frame is available, it is always possible to sample blocks at random, enumerate the households in each, and randomly sample from these.

3.2 Sample size for household surveys

There are well-documented procedures for estimating the sample size of household surveys in order to satisfy different objectives; for example, estimation of trip rates, and trip generation by categories (Stopher, 1982). The plot thickens considerably if O-D matrices are needed. For example, Ortúzar *et al.* (1998) analysed the number of trips by O-D cell in Santiago for a group of only 34 zones (e.g. at the municipality level) using data from the 1991 O-D survey (Ortúzar *et al.*, 1993). They observed that only 58% of the cells contained more than 1000 trips. According to Smith (1979), in this case it would be necessary to postulate a sample size of 4% of all households to estimate an O-D matrix with a 25% standard error and 90% confidence limits. As there are some 1.4 million households in Santiago, this would imply a sample size of 56 000 households. Obviously such a large sample size is not justified to accomplish such a meagre objective.

So, clearly the driving force behind large sample sizes is the need to obtain trip matrices at the zonal level. Smith (1979) also shows that it is difficult to reduce the measurement error to an acceptable level in areas with more than, say, 100 zones, since the sample size required would be close to 100%. Hence, if the objective of the study includes estimating an O-D matrix, it is not only desirable but an absolute necessity to use a combination of survey methods – including both household and intercept surveys.

It is interesting to note that solving the following optimisation problem may help finding optimal sample sizes for certain predefined objectives:

To minimise

$$\sum_{i \in \{classes\}} \sum_{j \in \{zones\}} \alpha_j \eta_{ij}$$

$$0 \leq \alpha_j \leq 1$$

subject to

$$\sum_{j \in \{zones\}} \alpha_j \eta_{ij} \geq \mu_i$$

where α_j is the proportion of households to interview in zone j (e.g. a maximum of 5%), η_{ij} is the number of households of class i in zone j , and μ_i is the minimum acceptable sample size for each class i . This method permits segmentation other than by the socio-economic criteria. For example, if it is possible to identify spatial differences in terms of distance from the centre, say, and/or access to the public transport network, the number of classes considered for the optimisation may be increased. The design can also be improved by allowing for different response rates between different groups. In fact, in principle it is possible to estimate the number of households required in a gross sample (μ_i) to achieve a given minimum number of responses for each class, thereby ensuring a design that makes it possible to obtain even higher quality trip generation data.

Having done the above the designer must check if the sample size achieved in this form also allows the recovery of sufficient information to estimate other important variables, say, levels of car ownership per zone or mode choice models for different income strata. An exercise was undertaken in Santiago using data from the 1991 O-D survey. It was found that in all cases a maximum sample size of 15 000 households would be sufficient (Ortúzar *et al*, 1998). This is a much larger sample size than needed for most uses and it was recommended partly on political reasons⁸. Note that the critical figure arose from the need to estimate car ownership levels per zone, because a 500 zones system was being considered at the time and it is not recommended to compute mean values with less than 30 observations per class. So, if car ownership is only interesting at a district level (say 40 zones), the sample could be substantially reduced.

3.3 Challenges of a continuous survey

Assume, as in Santiago, that 15 000 households are to be interviewed in the first year of the continuous survey; however, much smaller numbers for updating purposes would be typically required in subsequent years, i.e. 5 000 as in Santiago.

This means that, in general, the approach can be seen to have further advantages as a small and well-trained field force and administrative procedures in years 2+ are likely to ensure high quality data with minimal effort. Also, a financial commitment for four years is made in Year 1, reducing the risk of difficulties of receiving repeat funding in, say, Year 4.

However, the method requires developing an easy-to-use, robust annual weighting and integration system to ensure that data is readily useable for modelling purposes (i.e. to ensure that *all* the data at the end of year 2 is representative of year 2, that *all* the data at the end of year 3 is representative of that year, and so on). In developing cities (i.e. where rapid changes occur in car ownership, land-use spread and distribution), this will mean a more accurate modelling capability than has ever been possible in the past. It would also provide a larger sample size for use in second and subsequent years.

⁸ The first wave of the survey was to take place in 2001, 10 years after the previous O-D survey (as is usual practice, Stopher and Metcalf, 1998), and the government officials behind the project required a 'sensible' sample size to start with (note that the 1991 survey comprised 33 000 households, Ortúzar *et al*, 1993).

4. CORRECTION, EXPANSION AND VALIDATION OF THE DATA

4.1 Corrections by household size and socio-demographic characteristics

To make corrections that guarantee that the household size, age and sex, housing type and vehicle ownership distributions of the sampled data represent that in the population (based on Census data), an iterative approach is needed, as more simplistic methods do not guarantee correct results. Multi-proportional fitting (Ortúzar and Willumsen, 2001, pp. 168-170; 185-186) is probably the best approach as it guarantees convergence in very few iterations. Furthermore, the application of this method has the additional advantage of not requiring the subsequent calculation of expansion factors. Stopher and Stecher (1993) give an almost pedagogical example of this approach.

To avoid bias in the multi-proportional correction (i.e. we are correcting by items as diverse as household size on the one hand, and personal characteristics on the other), it is better to define unique categories avoiding classes that consider - for example - two to four persons, six or more persons. Nevertheless, it is easy to imagine occasions on which it would be necessary to group because a certain class is not represented in the sample for a given zone. In that case, it is convenient to check if it is possible to group similar zones instead of making the correction at such a disaggregate level (Stopher and Stecher, 1993).

4.2 Additional corrections in household surveys

In addition to correcting by household size, vehicle ownership and socio demographics, there are two other correction procedures necessary – depending on whether it is a personal interview or self-completion survey (Richardson *et. al.*, 1995):

1. *Corrections for non-reported data*: These are needed when certain elements of the survey have not been answered (*item non-response*). In self-completion surveys, interviewing a validation sample using personal interviews and then weighting the data accordingly (Richardson *et. al.*, 1995) is used to address this. This correction is not usually needed when personal interviews are used because interviewers must be well trained and supervised thereby decreasing the incidence of item non-response (but see the discussion in Stopher and Jones, 2003).
2. *Corrections for non-response*: These are needed when a household or individual does not respond, i.e. does not return the survey instrument or refuses verbally or by mail to respond to the survey (Zimowski *et al*, 1998). It is important to differentiate between genuine non-response or sample loss (e.g. vacant dwellings which do not generate travel should be ineligible), and refusals (where the person could be travelling but not responding, clearly eligible). For personal interviews, it has been recommended that corrections should be based on the number of visits necessary to achieve a response, as this is associated with strong differences in travel behaviour (Keeter *et al*, 2000). In self-completion surveys, on the other hand, it was originally believed that corrections could be done based on the number of follow-up reminders needed to generate a household response (Richardson *et. al.*, 1995), but the problem is likely to be more complex than for personal interviews (Richardson and Meyburg, 2003).

A final related point is how to decide when a household is complete. The US National Travel Survey uses the 'fifty-percent' rule (at least 50% of adults over 18 years of age completed the survey), after arguments that excluding households where not everybody responded may exaggerate bias, and data are weighted to mitigate the person-level non-response in sampled households.

4.3 Integration weighting for a continuous survey

Finally, it is most important to consider the weighting procedures required to integrate the continuous data set. This should be done on an annual basis to unite each wave of the survey, proceeding as follows:

1. *Household weighting* should take place for each 'important' variable (chosen in prior consultation). In table 1 we make an example of how it would occur for household size; this should be done in a similar way for car ownership or household income. In the example, if we consider households of size 1 say, we can see that they constitute 13.33% of the sample in year 1 (i.e. 2000/15 000), 17% of the sample of year 2, and if added without reweighting, 14.25% of the sample for both years. However, this would be akin to the proverbial mixing of apples and pears. To integrate the data properly we need first to calculate (appropriate) weights for year 1 to ensure that both sets have the same proportions as measured in the latest year (based on the assumption that the new sample drawn each year represents the real characteristics of the population better). These weights are equal to the ratio between the percentages (for each strata) of years 2 and 1 (i.e. $24/20 = 1.2$ in the case of households of size 2). The third part of the table shows the result of adding the weighted year-1 data to the year-2 data, to achieve a final sample of 20 000 households that has the same distribution according to household size as it occurs in year 2.

Table 1: Weighting Procedures for Integration

		Household Size										
		1		2		3		4		5		Total
Year 1		2000	13,33%	3000	20,00%	4000	26,67%	5000	33,33%	1000	6,67%	15000
Year 2		850	17,00%	1200	24,00%	1000	20,00%	1500	30,00%	450	9,00%	5000
Total		2850	14,25%	4200	21,00%	5000	25,00%	6500	32,50%	1450	7,25%	20000

Weighting Values for Year 1

		1		2		3		4		5	
Year 1		17,00/13,33	1,275	1,200	0,750	0,900	1,350				

Reweighting Procedure

		1		2		3		4		5		Total
Year 1		2550		3600		3000		4500		1350		15000
Year 2		850		1200		1000		1500		450		5000
Total		3400	17%	4800	24%	4000	20%	6000	30%	1805	9%	20000

2. *Vehicle weighting*. A variable of particular importance in this case is vehicle age, since without correct weighting it could appear as if the fleet was ageing faster than normal.
3. *Person weighting*. Factors of importance are likely to be income and education.
4. *Trip weighting*. Number of trips and mode are likely to be the key variables in this case - all done according to the same general principles described above.

In this way the data will be representative of the population in every year of the survey. Of course this is not perfect, but with a good sampling scheme it should be very robust.

4.4 Recommendations for validation

In a mobility study, the most important validation is done within the survey data itself, not with secondary data, since each method has its own particular biases that may confound this task. Gross comparisons (number of trips crossing a cordon, number of trips by mode)

often give relatively poor comparisons. State-of-practice survey techniques minimise these problems, but use of independent data to check figures from all elements of a metropolitan O-D travel survey is still recommended (Stopher and Jones, 2003). Objective comparisons of these figures, taking into account the strengths and weaknesses of each survey method, make it possible to detect potential biases and to take steps to amend them.

5. SOME RESULTS FROM THE 2001 SANTIAGO MOBILITY SURVEY

As maybe typical of a developing country, although originally planned as a continuous survey, the study had a one-year pilot⁹ and then ran for less than a year (a mixture of delayed start and data required with urgency), stopped for more than a year, but started again in 2004 for a further four years.

5.1 Pilot study

During this stage five survey methods were tested: two for mail back questionnaires (delivered and collected by hand, and delivered and returned by mail), two for personal interviews (on paper and on laptop computers) and one mixed-mode method where part of the interview was carried out by an interviewer (typically collecting household data) and the remainder was completed by the respondent and returned by mail. In all cases the survey forms were carefully designed (employing the services of both an editor and a graphic designer), printed in attractive colours and tested in several focus groups. The results led to abandoning the laptop computer interviews, the full mail-back method and to concentrate on personal interviews (with the possibility of mail-back for those preferring to fill in their own diaries), and mail-back forms delivered and collected by hand for those houses/flats where it was too difficult or impossible to get eye-contact with the dwellers.

During this preliminary study a heuristic was designed to obtain the minimum set of intercept stations in the strategic network that would allow the detection of a given number of trips between O-D pairs in the area (say 100 per time period), while being less than a maximum allowed error level between the observed and estimated O-D matrix. This was done for car and public transport trips yielding 100 stations (in the car case) and less than 50 (for public transport) for the whole of Santiago. Special software was also designed to aid survey coding and validation. Among its many features were the automatic production of a validated list of streets and places in the city, in order to minimise digitising errors of this sort. The software also detects missing data and does on-line validation using more than 300 checks and reports.

5.2 First wave of the final survey¹⁰

The study area was divided into five districts. Offices were located at their centres - each housing a professional in charge, a supervisor, two coders/validators and up to 15 interviewers. The personnel was coordinated from headquarters at the university.

A large marketing campaign was designed by a specialist firm and launched just prior to the start of the survey. It involved newspapers, radio, road and bus signs, and leaflets that were distributed to houses, malls and at special events. It included a monthly raffle of US\$ 200 for surveyed households that returned complete forms for all members. The campaign continued, although at a decreasing level, for the whole year, and special focus groups

⁹ http://www.sectra.cl/productos_servicios/biblioteca/Documentos/Mespivu_A2.PDF

¹⁰ http://www.sectra.cl/transporte/transporte_urbano_eod_frm.html

conducted during and after the survey suggested that it had been an important element in the success of the data collection exercise.

Personnel selection and training was a complex task; a specialist consulting firm was hired and given appropriate specifications to find and recruit the staff needed. More than 750 people were interviewed to fill the approximately 80 initial interviewer positions. The training activities take a whole week and involve tests on the comprehension of the survey forms, role playing, tests on detecting faulty or missing data, work with psychologists on how to handle rejection, discussions on innovative ways to contact people, supervised work in the field, etc. Personnel loss was around 20% during the first two months of the survey but it stabilised after that.

Every week a set of addresses was generated for each office (i.e. a random process in space and time); the interviewers would visit these addresses, collect the general information, assign a travel day and leave a 'memory jogger' for each household member. Then came back the day after the travel day (or at most, two days later), filled in the travel information for each respondent and returned the survey forms to the office (two days later at the most). Here the data was given a preliminary check by hand by the supervisor and all obvious errors and missing data were detected. These were corrected immediately either by phone or by a special visit to the household. The apparently complete data was then sent to headquarters to be digitised. Here the special software allowed the validators to do their work more efficiently by activating special fields to fill-in the data. This process ended with a final report on the status of the household; if some information was missing or was apparently faulty, the survey forms were returned to the local office for correction. After this step, the new data (if it was obtained) was entered into the database and a final summary made of the status of each survey form (i.e. complete, incomplete and in this case grouped in one of several categories). The data was physically archived (there was a librarian in charge) in such a way as to assist speedy retrieval. The database was backed up twice a day on two computer servers and also copied onto a CD once per week, thus ensuring a secure system.

In parallel to the data collection process, a validation system consisting in a visit to approximately 10% of the households interviewed was implemented (the figure was higher in the case of interviewers with unusually high efficiency, or with unusually low household sizes or trip rates by household). The process used a especially designed form that enquired, first, if the interviewer had really visited the home; after that, a check was made on the veracity of the information registered in the survey instrument, and finally questions were made about the interviewer behaviour (i.e. serious, helpful/respectful) and survey process (i.e. how many days before the 'travel day' was the survey material received?).

The data collection stage for a first set of 15 000 households began in August 2001. Data was collected for the 'normal period' (August-December 2001; March-April 2002) and for the 'summer' period (January-February 2002). By May 2002 the process was completed with the following totals achieved:

	Normal Period	Summer Period	Total
Weekday	9048	2290	11 338
Saturday	1575	432	2007
Sunday	1723	469	2192
Total	12 346	3191	15 537

The overwhelming majority of households (96.8%) was contacted using the personal interview-based system. In only 490 cases were self-completion forms eventually needed (i.e. when it was not possible to contact the household personally).

The response rates (around 70%) were very high, suggesting that the careful methodology presented in the paper can work properly even in a non industrialised country. Further, of the 15 537 'complete' households, 14 383 (i.e. 92.6%) are absolutely complete; 606 have one or more items missing from the household (e.g.. income, vehicle data or information about mortgage or rent paid; only in 10 cases was data missing about a complete household member), 509 have one or more items of trip data missing (e.g. trip time, fare paid, incomplete destination), and 39 have items missing in both categories. Finally, it is worth noting that only 543 (3.5%) of all complete households lacked income information.

During the study more than 475 000 valid intercept surveys were conducted on buses and shared taxis, and by intercepting cars, taxis, lorries, bicycles and pedestrians in some 150 intercept stations distributed throughout the city. The stations were selected in order to maximise the likelihood of observing numbers of trips greater than 100 between all O-D pairs in the city, for the 775 final zone system.

In conclusion, the early results from the Santiago 2001 continuous survey suggest that the methodology described in this paper is capable of giving high response rates and hence valid data for its purpose of providing adequate information for estimation of state-of-the-art strategic transport planning models.

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