THE ROLE OF VALIDATION, WEIGHTING AND EXPANSION IN TRAVEL SURVEYS

E.A. Heathcote
Ministry of Transport, Victoria

ABSTRACT:

So that the large State transport budgets are spent efficiently and that appropriate transport services are provided, it is important that transport planners and decision makers are supplied with accurate descriptions of people's travel behaviour.

However, information on complex travel behaviour can only feasibly be collected using sample surveys and this approach may introduce errors, both sampling and systematic, into the travel descriptions. It is the survey manager's responsibility to ensure that currently available techniques for validating, weighting and expanding travel survey data are used to make the final survey results resemble the real world as closely as possible.

This paper investigates how and when validation, weighting and expansion should be considered in the survey process and also describes the three procedures as applied to the 1978/79 Melbourne Home Interview Travel Survey.

This paper expresses the views of the author and does not necessarily represent those of the Victorian Ministry of Transport

INTRODUCTION

Why Should Sample Surveys be Validated, Weighted and Expanded?

In 1978/79, the deficits of the Victorian Railways and the Melbourne and Metropolitan Tramways Board, together with the private bus fare subsidy, amounted to $231 m or 6.5% of total payments from the State Consolidated Fund. In this same year, approximately $330,000 was spent on direct data collection costs for the 1978/79 Melbourne Home Interview Travel Survey. Even allowing $0.5 m for the total cost of the survey, this amount was insignificant compared to the public transport deficits.

Travel survey data are used to monitor and evaluate aspects of a transport network which involves the expenditure of millions of dollars, even in public transport deficits. One thesis of this paper is that because of the monetary commitment in transport by the State, every effort should be made to provide survey data which reflect as accurately as possible people's travel movements. Bias in survey results may lead transport planners to incorrect conclusions about people's travel behaviour, thence to incorrect conclusions about the type of transport services required and finally to incorrect transport investment. Survey data can only be regarded as accurate when they have been:

- validated to check that the sample is representative of the target population and that the travel characteristics are consonant with administrative travel statistics;
- weighted, or multiplied by appropriate weighting factors, to correct for any biases which may exist in the sample;
- expanded, or multiplied by appropriate expansion factors, to represent the travel of the entire population using the best available reference frame.

These processes may appear obvious and simple. However, they are rarely carried out for Australian travel surveys (Dumble, 1979) and they need to be planned even before the survey is actually conducted.

The remainder of this paper examines when validation, weighting and expansion need to be considered in terms of the overall transport survey process and then looks at the techniques of validation, weighting and expansion applied to the 1978/79 Melbourne Home Interview Travel Survey and some results from this work.

The Revised Transport Survey Process

Richardson (1982) presented a systems-based approach to transport surveys, depicting forward, feed-back and backward linkups. This approach has been modified in Figure 1 to incorporate the validation, weighting and expansion tasks explicity:

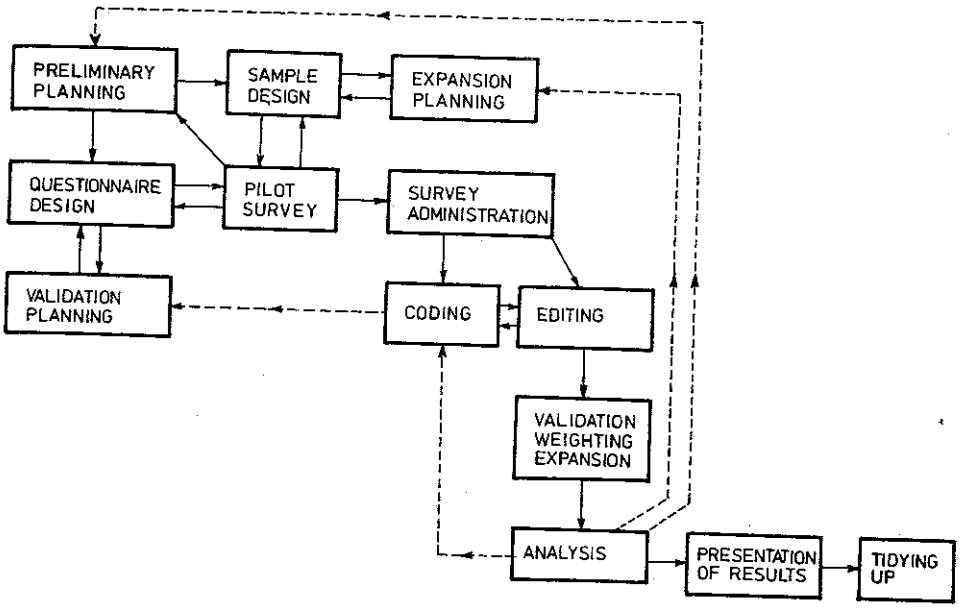

Figure 1 : THE REVISED TRANSPORT SURVEY PROCESS

"Expansion Planning" needs to be considered in conjunction with the sample design since, ideally, the sampling units should be expanded according to the inverse of the sample fraction, e.g., if 10% of the population had been surveyed by means of a simple random sample, then each survey result would be multiplied by 10 to estimate the result for the total population. This procedure is more complex when the sample is stratified by some variable, eg., Local Government Area (LGA), and it is possible that the actual sampling fraction is not known. In this situation, it is necessary to find secondary data with which the expanded survey data can be equated. For travel surveys, population and household figures produced by the Australian Bureau of Statistics (ABS) are often very useful but, again, their availability needs to be checked before the survey is conducted.

"Validation Planning" involves comparing the survey data with other data sets. This task should be associated with the questionnaire design since two data sets can only be compared when they collect information on similar topics and when the question wordings are similiar. The obvious secondary data source for checking socio-demographic characteristics from a travel survey is the Census of Population and Housing conducted by ABS. This census does have extensive geographic coverage but it also has some limitations. The Census is conducted once every five years and only estimates of population (by age and sex) and households are produced in inter-Censal years. Also, the Census is self-administered whereas most travel surveys have been conducted by personal interview. This presents a problem since Brög and Meyburg (1982) have shown that the method of collecting the data itself has a significant effect on the final survey results.

The actual processes of validation, weighting and expansion should be carried out after the data have been corrected for logical and coding errors but before the survey is analysed. In many Australian surveys, the processes of validation and weighting have been virtually ignored and the data have simply been expanded and analysed. The current disrespect for the traditional home interview travel survey and the associated modelling process may, in part, be associated with this lack of attention to the accuracy of the raw survey data.

The 1978/79 Melbourne Home Interview Travel Survey

During July 1978 - May 1979, a home interview travel survey was conducted in Melbourne. The survey was to provide for the city:

- a current inventory of person travel on a typical weekday;
- a data base for short-term planning;
- a means of validating the transportation models used for forecasting daily travel.

The survey was conducted according to the procedures of the traditional transportation survey developed in the United States during the 1960's and based on the home interview technique. The data were basically divided into four areas: household data, vehicle data, person data and travel data. Information was collected from 11,387 households spread across the 56 municipalities of the Melbourne Statistical Division (MSD). Personal characteristics were collected on 31,948 people and data on nearly 100,000 travel movements by these people were recorded. Overall, responses were recorded to approximately two million questions.

The target population for the survey was defined as all households (or occupied private dwellings) in the MSD. This meant that residents of non-private dwellings fell outside the scope of the survey even though they constitute 2.8% of Melbourne's population.

The sample frame actually used to select households was the list of addresses connected to the State Electricity Commission (SEC), on domestic tariff. This sample frame was not expected to produce any significant bias since most private households in Melbourne are connected to the SEC. The sample was selected on the basis of LGAs. The final quota size for each LGA was calculated as the mean of two quotas - one based on a sample size proportional to the size of the LGA (in terms of number of households), and the other based on a fixed sample size for each LGA. The sample was not proportionally stratified by LGA because only small numbers of trips would have been collected in the smaller LGAs. Addresses were then extracted using sequential random selection from electrical supply registers of the SEC's Metropolitan and Eastern Metropolitan Supply Districts, as well as from electrical departments of twelve municipalities bulk supplied by the SEC. An address master file describing 23,388 addresses was produced and 16,716 of these addresses were used during the survey. The final status of the 16,716 addresses is shown in Table 1 :

TABLE 1 FINAL STATUS OF ADDRESSES

Address Status	No.	%
Completed (for prescribed min. no. of people in household)	11,387	68.1
Refusals	2,588	15.5
Not at home	952	5.7
Vacant block/dwelling demolished	160	1.0
Unoccupied dwelling (inc. holiday homes)	484	2.9
Non residential	275	1.6
Foreign	251	1.5
Inconvenient at time	98	0.6
Not enough people present	29	0.2
Other reason (inc. cannot locate)	492	2.9
Total	16,716	100.0

Since 11,387 addresses were classified as completed interviews and 919 addresses were not occupied private dwellings, the effective response rate was 72.1%.

It was intended that the completed interviews within each LGA be spread uniformly over the survey period. However this target was not always achieved because:

- it was difficult to employ sufficient interviewers in the western and north-western areas of the MSD;
- in some areas there were lower refusal rates or fewer unoccupied dwellings;
- the interviewers varied in their productivity.

The final survey achieved the quota for each LGA and the distribution of day of household travel was approximately uniform over the weekdays Monday to Friday. However these results were not achieved simultaneously. Nor was the day of household travel uniformly spread over the 149 possible days during the survey period.

Before describing the validation of the sample and the weighting and expansion of the results, it is worthwhile commenting on the effort made to check and correct the survey data and the biases which were expected in the raw survey results.

Data editing

The raw survey data underwent a number of manual and computerised checks. For 10% of questionnaires, the responses to a set of 13 questions were checked again with the household. On the computer, the raw data were edited for range, questionnaire logic, suitable redundancy (e.g., if making a school trip, the traveller must be a full or part-time student) and reasonableness (e.g., a tertiary student must be at least 15 years old). If a particular interview failed an edit check, the questionnaire was inspected and, if necessary, the problem was referred to the interviewer. There were no "blanket" corrections made to the data. Approximately 10,000 errors were detected and corrected with the majority of these errors derived from the interviewing phase.

Expected biases

Even before the survey field work was completed, there were expectations of some biases in the survey results due to the particular survey design adopted.

A bias towards white collar, affluent, multiple-car households was expected because of the widely-held belief that this type of household is more willing to participate in home interview surveys. Also, only a small number of interviewers could speak foreign languages and these interviewers were not able to complete interviews at all the non-English speaking households. A bias towards English speaking households was therefore expected.

The definition of "completed interview" meant that it was quicker and simpler to achieve a completed interview in a smaller household. This fact, combined with the tendency for less mobile people to be contacted in home interview travel surveys was thought to bias the Melbourne survey towards small households with low mobility, e.g., elderly people living alone or as a couple.

Finally, on the basis of the earlier Melbourne surveys, it was expected that short private and public transport trips in the middle of the day would be under-reported. This expectation was based on the knowledge that some proxy respondents would not know the exact travel behaviour of all members in

their household and also the assumption that individuals themselves would forget to recount some of their short trips made during the day. This assumption was thought to be particularly relevant to CBD workers who made short trips at lunch-time and who perhaps used a tram.

VALIDATION

How Should Sample Surveys be Validated?

Ideally, travel sample surveys should be validated with respect to representativeness of the sample and reasonableness of the travel results. For the 1978/79 Melbourne survey, however, only the sample characteristics could be checked in any detail because of the lack of appropriate data sets for travel in Melbourne (Heathcote, 1983).

There are no prescriptions for validating samples from travel surveys but one obvious approach is to compare the raw socio-demographic characteristics of the sample with data from the Census of Population and Housing. However, even this approach may not be correct when the sample has not been drawn in a completely random fashion. If the sample has been drawn on a stratified basis, then the survey results need to be expanded by the appropriate factors before comparing with the Census data. If x_{ij} denotes the survey measurement of the ith individual in the jth stratum, n_j individuals are sampled in each stratum and there are N_j people in the jth stratum, then the best estimate of the value of x over the whole population is given by:

$$X = \sum_{j} \sum_{i=1}^{n_j} \left(\frac{N_j}{n_j}\right) x_{ij}$$

The expansion factor for each individual sampled depends on the stratum to which he/she belongs. If the individual belongs to the jth stratum, then the expansion factor is N_j/n_j. This approach is often required when validating at the widest geographic level, e.g., the Melbourne survey was stratified by LGA so it was necessary to expand the results before finally validating at the MSD level. Table 2 presents the MSD validation of household size for the Melbourne survey. Two sets of Census figures are given since the Melbourne survey was actually conducted between the two Censuses.

TABLE 2 MSD VALIDATION OF HOUSEHOLD SIZE

Number of Occupants	1976 Census No. of H/holds	%	Survey No. of H/holds	%	Expd. Survey No. of H/holds	%	1981 Census No. of H/holds	%
1	129,416	15.9	1,694	14.9	131,605	15.1	165,230	18.5
2	224,866	27.7	3,381	29.7	259,132	29.8	252,966	28.4
3	140,740	17.3	1,973	17.3	148,920	17.1	149,616	16.8
4	161,908	19.9	2,374	20.8	179,468	20.6	176,078	19.7
5	92,314	11.4	1,245	10.9	95,764	11.0	94,296	10.6
6	40,014	4.9	490	4.3	36,957	4.3	35,632	4.0
7	14,620	1.8	144	1.3	10,926	1.3	11,663	1.3
≥8	9,292	1.1	86	0.8	6,568	0.8	6,566	0.7
TOTAL	813,170	100.0	11,387	100.0	869,326	100.0	892,047	100.0

Sources: 1976 Census - special table from ABS showing the number of inmates in the household, by LGA.
1981 Census - LGA Summary File Table 35.

It is not obvious what statistical tests could be performed on this comparison since the large raw sample size would render the χ^2 test useless. An alternative test has been proposed by Gipps (1984).

At the LGA level, the Melbourne raw survey distributions were compared with the 1976 and 1981 LGA Census distributions. The results of this work were presented in the form of shaded maps showing how far LGA's deviated from the 1976-81 Census range for one value of the characteristic. Although these maps readily convey which LGAs were quite different from the Census data, they are limited to describing only one value of the characteristic, e.g., Figure 2 presents the differences between Census and survey data for one-person households in each LGA.

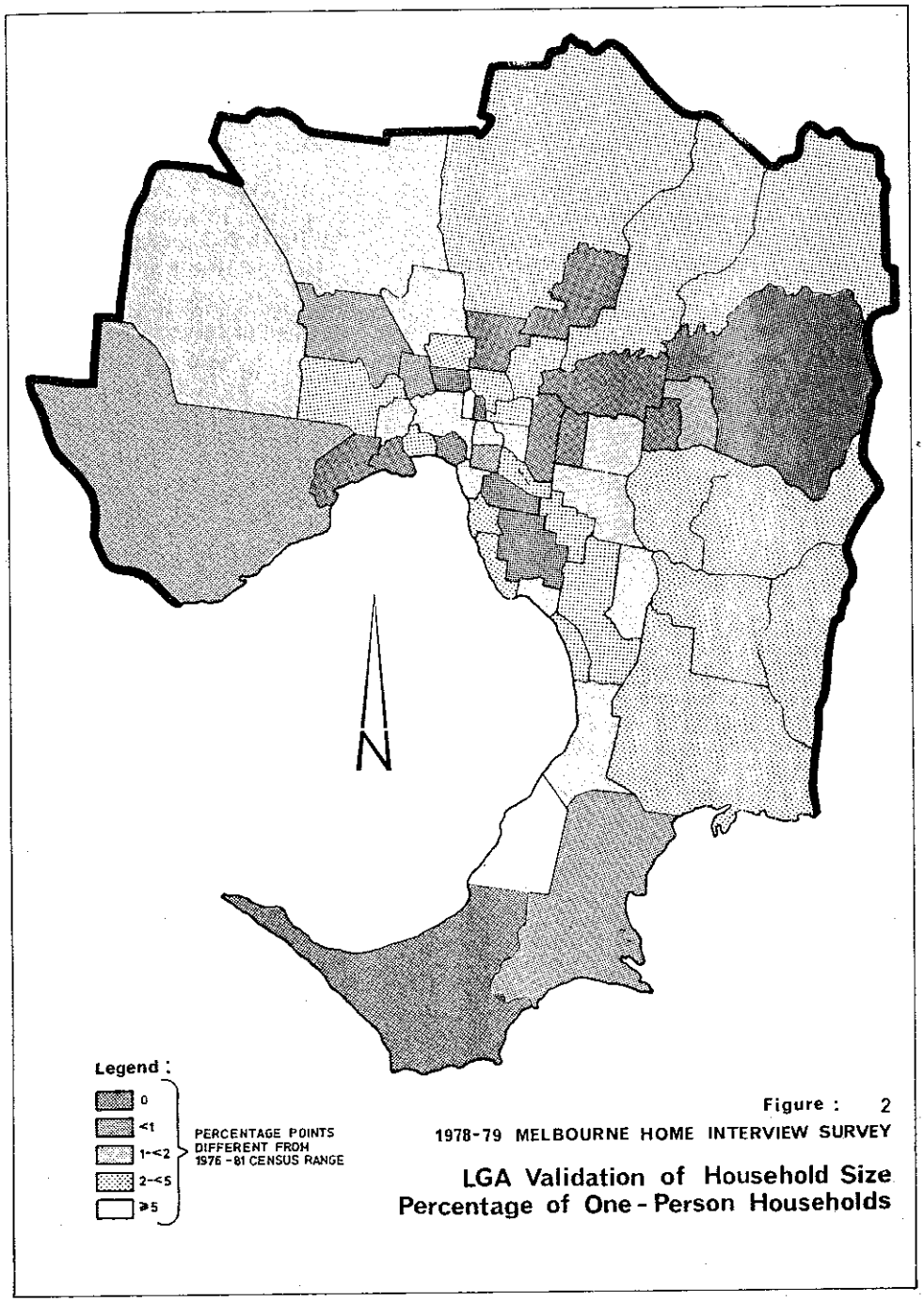

Figure : 2
1978-79 MELBOURNE HOME INTERVIEW SURVEY

LGA Validation of Household Size Percentage of One - Person Households

Validation of Household Characteristics

It is important that the sample households be representative of all households because household characteristics, as well as personal characteristics, affect travel behaviour, e.g., if larger households are over-represented in the sample, the number of people will also be over-represented and the number of trips will also probably be over-represented; if households with high motor vehicle availability are over-represented in the sample, then the number of motor vehicle trips and the private motor vehicle mode share will probably be over-represented. Both these instances could result in misleading information being given to the transport planner who may then propose inappropriate transport policies.

Three household characteristics were compared for the Melbourne survey: dwelling structure, motor vehicle availability and household size.

Results of the Melbourne survey

- **Separate houses** were well represented at the MSD level. Considering the percentage of separate houses, three in five LGAs fell within two percentage points of the 1976-81 Census range. At the LGA level, the survey bias was towards over-representation of separate houses. This probably reflects the relative ease of contacting people living in separate houses who are in a more settled life - cycle stage and who probably do not go out as often as flat-dwellers.

- Survey and Census frequency distributions for **"number of motor vehicles garaged"** compared reasonably well at the MSD level. Considering only the percentage of travel impeded households - the "zero-car" households - three out of four LGAs fell within two percentage points of the Census range. The survey bias was towards under-representation of "zero-car" households. This bias reflects the traditionally held belief that the more affluent households respond to home interview surveys and implies an over-representation of motor vehicle trips in the raw survey results.

- The survey was under-represented with respect to **"one-person households"**, both at the MSD and LGA levels. However, three in five LGAs still fell within two percentage points of the Census range (for the percentage of "one-person households"). This bias with respect to very small households may be due to the difficulty in contacting such households (either because the person is not at home or because he/she will not answer the door) and it may result in total trips being over-estimated.

Validation of Personal Characteristics

Personal characteristics of the sample will clearly affect the description of travel behaviour given to the transport planner or decision maker. If young and elderly people are under-represented in the sample, then the number of trips will probably be over-represented since these two sectors

of the population are not very mobile and are often dependent on others for their transport. Incorrect representation of white and blue-collar workers will also affect the survey results since blue-collar workers tend to work earlier shifts and thereby influence the description of travel by time of day. Licence holdership is another variable which clearly affects people's ability to travel (especially by car). Over-representation of people with drivers licences will probably mean over-representation of car driver trips in the raw survey data.

Nine personal characteristics were compared for the Melbourne survey: sex, age, country of birth, employment status, industry of employment, occupation of employment, income, study status and motor vehicle licences.

Results of the Melbourne survey

The **sex** distribution in the survey was very similar to the Census. The percentage of males in the survey fell within 0.6 of one percentage point of the Census figures. At the LGA level, more than 4 in 5 LGAs fell within two percentage points of the Census range for percentage of males, and there was no strong survey bias to males or females. This lack of bias should avoid survey bias towards male or female oriented trips, e.g., work, shopping.

With respect to **people's age**, five-year age cohorts were reasonably well represented in the survey, but people 75 and over were slightly under-represented.

For the percentage of dependent children aged 5-14, four in five LGAs fell within two percentage points of the Census range, with some bias towards over-representation of this age group. Dependent children may be slightly over-represented again because of the relative ease of contacting households in more settled life-cycle stages, e.g., households with young children.

Such a sample bias could result in a bias towards school trips in the raw survey results.

At the other end of the age scale, 7 in 10 LGAs fell within two percentage points of the Census range for the percentage of people 65 and over. The survey was biased towards under-representation of these people. This bias is probably due to the difficulty in contacting such people. In certain areas of Melbourne, e.g., St. Kilda, people living alone were loathe to answer the door to the interviewer.

The under-representation of elderly people implies an over-representation of total trips since, on average, people 65 and over make fewer trips than younger adults (from 1978/79 unpublished raw data, people 65 and over made 1.67 unlinked trips/weekday while people 18 to 64 made 3.44 unlinked trips/weekday).

For the MSD, the survey was probably well-represented with respect to **country of birth.** Considering the percentage of Australian-born people, more than 6 in 10 LGAs fell within two percentage points of the Census range with some bias towards over-representation of Australian-born people. Such a bias would be due to the difficulties in completing interviews in non-English speaking households and may result in some geographical bias in the raw trip destinations because of the geographical concentrations of some ethnic groups.

The survey indicated a lower percentage **employed** than the Censuses, but there were obvious differences in the collections of the two data sets which would have affected this comparison. If there is a sample bias towards those not working, then work trips may be under-represented in the raw survey results.

Comparison of **industry** figures for the survey and the Censuses implied that the two different coding procedures had led to different results.

Bearing in mind that people described their own occupation in both the survey and the Censuses, and the resulting problems, the survey was over-representative of **white-collar workers** at both MSD and LGA levels. This bias was expected before the survey was conducted and may result in over-representation of work trips in the later times in the morning and evening peaks.

The survey described a higher percentage of **zero-income** earners than the Censuses. However, this comparison was difficult, given the sensitivity of the question and the high non-response in the survey. This variable would probably be the least reliable in the survey data.

There was a higher percentage **studying** in the survey than in the Censuses. Survey bias towards more educated people or problems with the Census questions could have been the cause. If the sample is biased towards people studying, then school trips may be over-represented.

On the basis of a weak comparison with the 1976 Census, the survey may have been over-representative of **motor vehicle licence** holders and under-representative of **motor-bike licence** holders. If more motor-vehicle licence holders have been interviewed because they are more likely to be members of more affluent white collar households, then car driver trips may be over-represented in the raw survey results.

LGA Validation

Survey results for the eastern and outer western LGAs most closely resembled the Census data in terms of the percentages of separate houses, zero-vehicle households, 1-person households, males, 5-14 and

over 65 year olds and Australian born people. For these characteristics, the survey results for Camberwell and Ringwood most closely resembled the Census data, while Malvern's results were the most distant.

A summary of the LGA validation for ten variables is presented in Table 3.

TABLE 3 : SUMMARY OF LGA VALIDATION

Characteristic	% LGAs Within Census Range	Within 1 Percentage Point of Range	Within 2 Percentage Points of Range	Within 5 Percentage Points of Range
Dwelling Structure				
% Separate Houses	20	39	59	93
Motor Vehicle Availability				
% 0-Vehicle Households	25	52	75	98
Number of Occupants				
% 1-Person Households	27	38	61	98
Sex				
% Male Persons	11	45	84	100
Age				
% Persons 5-14 Years	43	64	82	100
% Persons ≥ 65 Years	20	55	71	100
Country of Birth				
% Persons Born in Australia	29	46	66	91
Employment Status				
% Persons Employed	11	34	52	89
Industry of Employment				
% Persons in Manufacturing	25	43	59	85
% Persons in Wholesale and Retail Trade	25	36	52	86
% Persons in Community Services	0	9	16	50
Occupation of Employment				
% White-Collar Workers	21	32	41	79
Study Status				
% Persons Studying	18	39	54	96

WEIGHTING

Why Does Sample Bias Arise?

Simply because the population is sampled and not enumerated introduces sampling errors into the data. These sampling errors depend on the size of the sample and the variability in the data being collected. Larger sample sizes lead to smaller sampling errors. This source of error has been acknowledged since the introduction of sample surveys and it is usually treated by quoting confidence intervals for population estimates from sample surveys.

More recently, however, greater attention has been paid to non-sampling, or systematic, errors associated with survey measurement (e.g., Brög and Meyburg 1980, Brög and Ampt 1983).

Systematic errors can arise for a number of reasons, principally:

- failure to obtain information from some people in the chosen sample; some people cannot be contacted while others simply refuse to participate in the survey;
- failure to measure some variables accurately; this problem may be due to the survey instrument or to people's inability to recall and record information accurately;
- failure to edit, code, tabulate and interpret the results accurately.

At the conceptual level, these errors can now be corrected by the introduction of various weights on the raw survey data (Brög and Meyburg, 1981). Each survey record is assigned a series of weights, or factors, which are then multiplied to give one final weight for the record. This approach attempts to correct for the following types of bias:

- socio - demographic
- temporal - day of week
  - date
- non-response - people
  - trips

Weighting factors for each of these types of bias will now be discussed in turn.

Socio-demographic Weighting

Socio-demographic weighting relies on the existence of secondary data sets which describe the entire population and which are comparable with the data collected in the sample survey.

For the Melbourne survey, strong comparisons could be made between the survey data and the Census data for the following six variables:

- dwelling structure
- motor vehicle availability (exclusive of motor bikes)
- number of household occupants
- sex
- age
- country of birth

Weights were applied to each household and person record in the survey so that the survey distributions coincided with the interpolated Census distribution (midway between 1976 and 1981) for these six variables. Weights were defined for each LGA.

There were no Census tables describing the distribution of the six variables simultaneously for each LGA. When this is the case, the survey data is weighted by multiplying them by the ratio of the percentage of people recorded in a particular cell of the six-dimensional Census matrix to the percentage of survey respondents in the same cell. However, when only the marginal totals of the matrix are available, it is necessary to use an iterative procedure, fitting the survey data to the Census data one variable at a time. The basic fitting procedure is to divide the Census percentage distribution for a particular variable by the corresponding survey percentages to produce a set of weights.

For the Melbourne survey, weights were first applied to the household file so that the survey distribution for dwelling structure coincided with the interpolated Census distribution. The weighted results were then modified by a second weight so that the weighted "motor vehicle availability" distribution was coincident. Survey records expanded by the product of the two weights were then modified by a third weight, so that the weighted "number of occupants" distribution was coincident. This process was continued until all three weighted survey distributions coincided with the interpolated Census distributions simultaneously (i.e., until the ratio of the Census percentage to the weighted survey percentage equalled 1.00 for each value in each distribution). The weights were always applied in a cumulative manner. The product of the three final weights for each household was then transferred to the corresponding records on the person file; e.g., a person living alone, in a house, with no car, was assigned the product of the final weights for "separate house", "zero motor vehicles" and "1 occupant".

A similar process was repeated on the person file for the three variables sex, age, and country of birth, except that the household socio-demographic weight was also included in calculating the weighted survey distributions for the

person variables. Finally, the appropriate household and person weights, and their products, were transferred to the trip file.

A final household weight for each household record was computed as the product of the marginal weights for the appropriate values of "dwelling structure", "motor vehicle availability" and "number of occupants". The actual household weights on the file ranged between 0.00 and 8.08 but 80% of them fell within the much narrower range 0.73 - 1.27, i.e., no element of household survey data was weighted by more than ±27%.

Similarly, a final person weight for each person record was computed as the product of the marginal weights for the appropriate values of "sex", "age" and "country of birth". These weights ranged between 0.13 and 13.20 on the file but 80% of them fell within the range 0.71 - 1.29.

Computation of the weights involved considerable work, particularly since the inter-Censal distributions for the six variables had to be computed for each LGA and manual adjustments were required in the calculations. These adjustments were required because there were no survey data for some values of the weighting variables in some LGAs. In this particular weighting exercise, the adjustments required were minor but, if major adjustments are required, there must come a point beyond which there is insufficient spread of data within the sample to justify the application of socio-demographic weights, i.e., the weighting procedure cannot correct biases if the sample is so biased that many values of the socio-demographic variables are not represented in the sample.

On the other hand, given the lack of multi-dimensional Census data for computing socio-demographic weights, the iterative approach using only the marginal distributions does provide a reasonable alternative for correcting socio-demographic biases in the sample. From the work on the Melbourne survey, the final marginal household and person weights seem only slightly dependent on iteration order. The one remaining problem which could arise with this approach relates to sample size. When there are only a few survey records with some combinations of the characteristics, it may be difficult to satisfy a number of marginal Census distributions simultaneously. This means that the iteration process may not converge, or, only converge very slowly by rounding error to fall within the accepted range of tolerance.

For the Melbourne survey, application of the socio-demographic weights did not markedly change the distributions of critical trip variables, either at the MSD or the LGA level. But this result could not have been known prior to the validation and weighting. In fact, this result arose because the survey was reasonably well represented in terms of the six variables for which weights were derived. But the question still remains as to whether other socio-demographic variables were well represented in the survey and whether the trip results would be affected by weights from these variables. No attempt could be made to correct for suspected biases towards white collar workers, people studying, and motor vehicle licence holders because there were

no appropriate secondary data sources. Also, it was difficult to know whether or not there were biases with respect to employed people, industry of employment, and personal income because comparisons with the Census data were so weak. These problems illustrate quite clearly the value in identifying appropriate secondary data sources before the conduct of the travel survey.

Temporal Weighting

In order to avoid potential seasonal bias, the date of household travel (travel day) should be spread uniformly over the survey period (and the survey period should cover one calendar year). When the dates, or interviews, have not been spread uniformly, it is possible to adjust the survey data to give greater weight to the data from those months in which insufficient interviews were conducted and less weight to the data from those months in which too many interviews were conducted. For the Melbourne survey, this adjustment was made by means of a temporal weight, for each LGA, which compared the proportion of possible travel days in a month (no. travel days in month ÷ total no. travel days) with the proportion of travel days actually obtained in the LGA for that month (no. travel days in LGA in month ÷ total no. travel days in LGA).

The temporal effect was investigated by defining a temporal weight for households in two LGAs. For the month m, the weight was calculated as:

$$\frac{\text{no. travel days in m}}{\text{total no travel days}} \times \frac{\text{total no. travel days in LGA (= no. interviews in LGA)}}{\text{no travel days in LGA in m}}$$

For Waverley LGA, the temporal weights ranged between 0.53 and 16.00. This meant that trip records were assigned temporal weights in this range, depending on the month in which the household travel occurred.

An examination of several travel and household characteristics for the two LGAs showed that the addition of the temporal weight affected the distributions of household characteristics more so than the distributions of travel characteristics. This meant that trip rates were changed (reduced) by the introduction of the temporal weight. However, this result may not hold when socio-demographic weights are added to the data as well. In theory, the temporal and socio-demographic weights would be defined in a cumulative manner.

Ideally, the temporal weights should be calculated on a daily, not monthly, basis. For the Melbourne survey, however, it was not even possible to define LGA temporal weights for those months when there were potential travel days but no interviews were completed in the LGA. For this reason, temporal weights have not been defined on the final survey files.

Non-response Weighting

If it is known that the sample is completely unbiased with respect to socio-demographic and temporal characteristics, or that such biases have been removed by weighting, then any significant under- or over- reporting of trips

will probably be due to non-response problems. These problems may be due to non-response from households in the sample; the households may be very difficult to contact or they may refuse to participate in the survey. The problems may also derive from incomplete or inaccurate information from respondents. Sometimes the respondent may have difficulty in recalling detailed travel information or, alternatively, the question may not be phrased correctly to obtain the desired information. The use of proxy respondents introduces yet another possible source of bias.

Brög and Meyburg (1980) have investigated the problem of non-response in mail-back travel surveys by considering the travel behaviour of respondents according to how quickly they returned their questionnaires. Initially, the respondents were stratified according to whether they mailed their questionnaire back after zero, one, two, three or four reminders. Even though the strata were similar with respect to trip structure (trip length, duration, purpose and mode) and socio-demographic characteristics, the trip rate and the share of mobiles (people who made trips) decreased as the number of reminders increased. This decrease was attributed to people with low mobility regarding their travel behaviour as unimportant to the survey and therefore not bothering to return their questionnaires.

Brög and Meyburg (1980) also found that trip rates for non-respondents could be satisfactorily estimated by extrapolating the cumulative trip rate analysed by response time. With this technique, the sample was divided into ten equal categories on the basis of the time taken to respond to the survey. The cumulative number of trips/day/person was calculated for the first eight categories on the basis of actual returns and these figures then extrapolated to give cumulative trip rates for 90 and 100% of the sample. The result of this work was to derive an overall lower average trip rate than that derived just from the sample respondents. A non-response weight to correct for the over-reporting of trips could then be defined by dividing the extrapolated average trip rate by the actual survey trip rate.

In contrast with mail back surveys, average trip rates in home interview surveys have traditionally been under- reported (Wilbur Smith and Associates and Len T. Frazer and Associates 1969, Moolman 1979). This under reporting has been associated with the relative ease of contacting less mobile people and the relative difficulty of contacting highly mobile people. It is possible to minimize this bias by adapting the cumulative response technique described above to the home interview situation (Moolman, 1979). The concept of "successful attempt number" can be used to define the response group where "successful attempt number" is defined as the number of times the household is visited by the interviewer in order to make contact.

With the Melbourne survey, there were some problems in applying the extrapolative approach. Firstly, although some households were called on up to 15 times and records were kept of each call, no distinction was made on the computer file between four or more attempts to gain the interview. There were, therefore, only four response categories, successful interview on the first call, successful interview on the second call, successful interview on

the third call and successful interview after four or more calls on the household. This meant that there were only four points for extrapolation. Secondly, the extrapolative approach assumes that non-respondents will be similar in travel behaviour to people successfully interviewed on the fourth or later attempt. For the Melbourne survey, the majority of non-respondents were "refusals" and they should be treated as being randomly spread over the response groups rather than being assumed similar to households contacted after many attempts (Wermuth, 1983). Also, further research is needed in Australia to show that the travel behaviour of "non-contact" households is indeed similar to those contacted after many attempts. Finally, the extrapolative approach attempts to correct for non-response associated with non-contact. It does not correct for under-reporting of trips due to forgetfulness by the respondent or lack of knowledge by a proxy respondent. These issues must be addressed by separate, additional, weighting factors. Because of these problems, no weights for non-response were finally applied to the Melbourne data.

EXPANSION

What are the Most Appropriate Expansion Factors?

As discussed in the introduction, survey results should be expanded by the inverse of the sampling fraction. However, the exact sampling fraction is not always known. For the Melbourne survey, the expansion factor should have been based on the fraction of private addresses interviewed in each LGA. However, the total number of addresses on the SEC registers with domestic tariff was not known by LGA. Further, there has always been some confusion in transport surveys as to whether the primary target population relates to households or to people. The expansion should be based on the population which has been sampled but home interview transport surveys have been expanded using LGA household and person expansion factors. The 1964 Melbourne Transport Survey was expanded using LGA household factors (Wilbur Smith et al, 1969) whereas the 1972 Melbourne Transport Survey used LGA person factors (Metropolitan Transportation Committee Working Group, 1973).

When the 1978-79 Melbourne survey data were first expanded in 1980 by the Ministry of Transport, two different variables were considered for defining a household factor - the number of private self-contained dwelling units and the number of occupied private dwellings in an LGA. Two different variables were also considered for a population expansion factor - the total population and the population aged 5 or more in an LGA. The person expansion factors tended to over-estimate the number of occupied private dwellings and the household expansion factors tended to under-estimate the population size. This situation arose because the average household size in the survey was less than the average household size from the 1976 Census.

Finally it was decided that a household expansion factor better reflected the sampling methodology, and that the factor based on occupied private dwellings produced the better population estimates. Even the number of occupied dwellings in each LGA had to be estimated for 1978, since these

data were only collected at Census time. Initially, the estimation was performed by extrapolating Census figures for persons per household by LGA but once the 1981 Census results became available, the estimation was based on interpolating the 1976 and 1981 Census figures for the number of occupied private dwellings by LGA.

For the 1978-79 Melbourne survey, the final LGA household expansion factors ranged between 14.5 and 114.3. The 25%, 50% and 75% quartiles were 54.2, 70.0, and 86.6 respectively.

CONCLUSION

Transport is important to the State, both in terms of the money expended on it and the service provided to the community. In order that planners can make rational decisions regarding transport investment they require the best possible descriptions of existing and future travel. However, because people's travel patterns are so complex, such descriptions can only be generated from sample surveys. It is the responsibility of the survey manager not only to use the best available data collection techniques but, also, to define appropriate weights and expansion factors so that the final survey results portray travel in the real world as closely as possible. The travel survey is not completed until the weighting and expansion work has been attempted. At the minimum, the socio-demographic characteristics of the sample need to be validated. The survey manager can only be sure that socio-demographic weights do not have a significant effect on the travel survey results once the validation and weighting have been done. Users of the data need to know that this basic comparison work has been done and whether there are any significant implications for their use of the data.

The main lesson to emerge from the validation, weighting and expansion of the 1978-79 Melbourne survey is the importance of organizing secondary data sets (both socio-demographic and transport) prior to the conduct of the travel survey. The important process of validation, weighting and expansion can only be weakly attempted when this stage is not considered until after the survey has been completed.

The following practical lessons can be learned from the sample validation of the 1978/79 Melbourne survey:

- if possible, a large-scale travel survey should be conducted in a Census year or close to it; it is tedious and possibly misleading to interpolate Census data.

- survey questions should be as close as possible to Census questions on the same topic; also, the set of responses should be identical, if possible.

- survey data should be coded using the same code frames as the Census; the classifications used by ABS are quite complex and survey coders need special training in their use; ideally, coders trained by ABS should be used to code the survey data.

- appropriate tabulations and files from the Census should be requested from ABS before the Census is conducted; ABS does not publish results for occupied private dwellings, as distinct from all dwellings, as a matter of course while travel surveys are usually only conducted for residents of private dwellings; the tabulations and files need to be requested as early as possible since ABS takes a long time to process non-standard requests.

- people working in the area of travel surveys should continue to press for the inclusion of travel-related topics in the Census; ABS is under a great deal of pressure to reduce the number of topics in the Census and the question on "motor vehicles garaged" was almost dropped from the 1986 Census schedule.

- people using travel survey data validated with Census data should be prepared to support the ABS in encouraging people to complete their Census forms accurately; high non-response for Census questions results in dubious sample validation.

Temporal and non-response weights were explored for the 1978/79 Melbourne survey. Lack of survey data within each LGA for each possible date of travel made it difficult to assign temporal weights, and lack of sufficient response categories made it difficult to have confidence in estimates of non-response weights. Both of these problems could have been avoided. The conduct of the survey could have been controlled more tightly so that the interviews were distributed evenly in time and space and more response categories could have been defined if more information had been stored on the computer files. In calculating the non-response weights, there was also the untested assumption that non-respondents (people who refused and those who could not be contacted) were similar in travel behaviour to those who were interviewed on the fourth or later attempt. Further, non-response weights should be computed in a cumulative manner, taking into account the effects of the socio-demographic weights and the temporal weights.

In short, it is now conceptually possible to correct travel survey data for geographic, socio-demographic, temporal and non-response biases. The treatment of non-response can even be extended to include the effects of proxy respondents and under-reporting of trips (Brög and Ampt, 1983). However, this state of the art is still far removed from the state of practice in Australia. Our survey managers should now be researching and preparing to define such survey weights as part of the standard survey procedure.

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