

lic at large. In this respect, bad surveys can do irreparable damage to the relationship with the pub-

lic. This, in turn, can undermine the acceptance of the products of planning.

State of the Art in the Collection of Travel Behavior Data

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From an historical perspective, it was only recently that transport planning began to use various survey methods to meet the growing need for the refinement of information. Lacking the experience or research background in this field, the transport planners who needed this information took the relevant survey instruments from social science with what might be described as gay abandon. Since humans were the most intelligent form of life, they were also assumed to be the perfect source of information; the only challenge lay in convincing them to take part in the surveys.

In accordance with this point of view, the discussions and research relating to the survey (which had now become a necessary item among the transport planner's tools) were focused on the optimal design of the sample. Ensuring that every survey began with what became known as a representative sample was the prime methodological concern to most of those carrying out surveys. This development became particularly problematic because it is known that representativeness only plays a limited role among the possible criteria available to evaluate empirical results and that reliability and validity are equally, if not more, important. A biased questionnaire administered to a large sample of people may achieve a very high degree of representativeness but also, precisely because of this, a high representation of the errors generated by the survey instrument.

It has only really been within the last five years that those working in the area of travel survey design and analysis have realized that aspects other than sampling techniques need to be considered in order to obtain the most valid results possible. The interviewee is seen, after all, as a normal person just like themselves, who has a propensity not only not to respond but also not to respond perfectly and, above all, not to respond in a manner that eliminates the errors built into the procedure by the survey designers themselves.

In other words, it was becoming clear that not only random errors (which are produced mainly as a result of not sampling the whole population) but, more important, systematic errors (which are induced by other aspects of the measurement procedure) deserved the attention of those involved in data collection. In addition, when it was considered that current knowledge (notably based on very little thorough methodological research) points to the fact that systematic errors are often substantially more significant than the random errors, there were both research and political implications. It suggested, in fact, that an improvement in accuracy of results could be achieved more effectively through questionnaire refinements (which are relatively cheap) than through larger sample sizes (which are relatively expensive).

In addition to survey refinements as a means of increasing the quality, and thereby validity and reliability, of survey results, some attempts have been initiated to address the issue of nonresponse in travel surveys by using various methods to weight or correct the data. Recently, a substantial number of reports have been published on these efforts, and the limited research has pointed to the significance of these procedures.

In this paper our goal is to summarize the results of basic methodological research of recent years and to present the most recent methods that are generally available. It is recognized that surveys that collect information on the transport system and its performance, on traffic counts, or on land use are an integral part of traffic engineering and planning. In this paper, however, we concentrate on the types of surveys used in transport planning studies, i.e., on the collection of data from the individual, particularly in the context of the household.

Data collection or measurement can be considered to be composed of individual elements, which can be listed as follows:

1. Definition of the problem, theoretical framework, and analytical concept;
2. Sampling frame, sampling unit, selection sample, and selection techniques;
3. Survey methods and instruments;
4. Survey implementation and response rate;
5. Data preparation;
6. Data correction and weighting and expansion; and
7. Data evaluation, analysis, and interpretation.

In the first section of the paper, we discuss techniques of sample selection. In the next section, survey methods and their implementation are dealt with. Three examples of new quantitative survey instruments and their application are discussed:

1. Techniques of the diary survey applied to travel behavior,
2. Large-scale personal-interview survey of travel behavior in Australia, and
3. Large-scale written survey of travel behavior in the Federal Republic of Germany.

In the third section, the possibilities of the qualitative correction of systematic errors will be addressed. Finally, the fourth section is concerned with the so-called "interactive measurement" technique and the possibilities of introducing it into transport planning.

SAMPLING

Problem Recognition

Although not specifically related to the collection of data on travel behavior, the literature in the

general area of sampling is extensive. It embraces all aspects of the sampling process, beginning with the definition of the study variable and delineation of the units of investigation and the sampling frame through the final estimation of the value of the study variable. As a general rule, most surveys in transport have considered many aspects of sampling theory in the sampling process.

The emphasis, however, has been on the necessity for a representative sample and little consideration has been given to the validity of the samples selected. A large sample size, for example, produces very representative results, but if a biased questionnaire is used, these results are also very representative of the errors of measurement induced by the inadequate survey instrument.

In general, only the random errors, which result from random sampling, and not the systematic errors, which result from other aspects of survey design, have been considered in the collection of travel data. Systematic errors, however, often have a much greater impact than their random counterparts. Since this problem could become serious because of research, and indeed political, grounds, recent studies in transport have investigated the problem and suggested measures for improvement. As has already been discussed, increasing the accuracy of empirical results can be achieved much more effectively by improving the survey instrument than by increasing the sample size.

The trend towards equating representativeness and correctness, which has been perpetuated by the media, has led to the fact that many people in many fields have been working with the wrong data. Recently, efforts have been made to address these problems by clearly identifying the errors attributable to sampling factors and attempting to introduce compensatory measures. Some aspects of the current thinking with regard to sampling are discussed below.

Definition of Study Variables, Units of Investigation, and Sampling Frame

The initial, and most basic, step in the planning of a survey is the definition of the study variables. In order to analyze travel behavior, two types of data need to be collected:

1. Data that describe the relevant behavioral characteristics (e.g., origin, destination, numbers of out-of-house activities) and
2. Data that may assist in explaining this behavior (e.g., sociodemographic characteristics or description of land use patterns).

The problem of defining the study variables is frequently underestimated. For example, if the difference between the behavior on the sample travel day and the usual behavior is overlooked, significant problems with the interpretation and use of the data have been shown to occur.

The unit of investigation (i.e., the travel-generating unit) is closely related to the study variables. The sum of all the units of investigation forms what is known as the sampling frame. The unit of investigation is, however, not to be confused with the sampling unit. In many studies of travel behavior, the household is considered both the unit of investigation and the sampling unit, although in individual travel-demand models the individual is used as the investigation unit even when the survey unit is represented by the household. In traditional planning practice this has often led to the situation where, in subsequent data processing and analysis, the sampled individuals are

considered a restructured quantity and the relationship to the household is consciously neglected.

All the inaccuracies that result from the inappropriate definition of the study variables or the unit of investigation are systematic in nature and cannot be compensated for in subsequent steps of the survey process. It is the recognition of the importance of minimizing these systematic errors that is characteristic of the state of the art at all levels of the sampling process.

Sample Selection

In addition to the reduction of systematic errors that may be generated by inappropriate definition of the study variables, the units of investigation, and the sample frame, the importance of reducing errors during sample selection has also been recognized. The major problem in sample surveys is the choice of sampling units in order to obtain the highest level of representativeness.

Sampling Unit

The sampling units are selected from the sampling frame by using various selection techniques, which can be divided into random and nonrandom methods. Random-sample surveys permit the estimation of random error and therefore offer the only really appropriate method of investigating a subject as complex as travel behavior. Fundamentally, the following techniques are available for the random selection of households:

1. Simple random sampling,
2. Stratified and multistage random sampling,
3. Single-stage and multistage stratified random sampling, and
4. Multiphase random or stratified sampling on successive occasions.

The choice of sampling techniques largely depends on the base population and on the secondary information available about it, i.e., data from a census or from a person or household register.

Since most surveys have defined the unit of investigation as the individual and the sampling unit as the household, research has been necessary to define any problems related to this approach. It is argued that the random sampling of households followed by the surveying of all household members actually represents a cluster-sampling procedure where the cluster is formed by the household. Compared with simple random sampling by using the same sample size, this leads to a random error known as the cluster effect. The magnitude of this effect on the data collected has, however, been shown to be both measurable and minor, and researchers have concluded that the benefits of efficiency outweigh the problems associated with cluster sampling on the basis of households.

If the household is chosen as the sampling unit, the manner in which these households are selected has been recognized to influence the validity of results. The clustering of household addresses for a survey is particularly frequent when personal-interview methods are used, since it minimizes the travel time, and thereby costs, of the interviewers. This clustering can lead to substantial errors if the results are not corrected accordingly and in fact the problem can be much more significant than the within-household cluster effect just described. It is, however, rarely recognized in data-collection procedures.

If the individual is chosen as the sampling unit and if they are selected from a sampling frame of

individuals rather than households (e.g., electoral rolls or personnel registers), other sampling problems need to be corrected. Large households will have a relatively high chance of selection in comparison with small households. If the data are used without taking this fact into account by appropriately weighting small households, the survey results will not validly represent the population's behavior.

Sample Size

Accuracy of survey results and the sample size are directly related. The size of the sample or the sampling fraction has been subject to a wide range of philosophies over the decades. Guidelines for surveys in the 1950s suggested that sample sizes of not less than 4 percent and up to 20 percent of households, depending on the size of the population, should be used. In contrast, the increasing use of disaggregate models to analyze survey results in the 1970s was associated with a trend toward the use of much smaller sample sizes. In recent years, however, even those surveys not conducted specifically for use with disaggregate models have tended to minimize sample size. Cost considerations have played an increasing role here, although the sophisticated techniques of correction, weighting, and expansion of results that have been developed recently (see section on correction and weighting) have tended to reduce the reliance on large sample sizes.

Nonresponse Problem

Sample-related problems occur not only in the sample-selection phase but also during the execution of the survey. In particular, even if the initial sample were to contain no errors, the fact that the response rate is never 100 percent would invalidate this condition. In addition, the concept of nonresponse includes the nonreporting of data elements (e.g., trips) even by those persons taking part in the survey. In general, this source of error has not been recognized by data collectors, even though research has shown that a high level of nonresponse results in data with very low statistical value.

The methods that have been developed to address this problem are discussed later.

Summary

It was stressed at the outset of this section that the current attitudes toward sampling have emphasized the importance of a representative sample at the expense of validity. There has been a recent realization that, although representative samples are important, the emphasis in survey design needs to be placed on the elimination of sampling problems leading to systematic errors that often cannot be corrected. For this reason, the nature of the possible problems occurring at each stage of the sampling process and the kind of errors they produce has been outlined in order to portray the level of development that has been reached in the area of sampling and travel surveys.

SURVEY INSTRUMENT

The survey instruments most commonly used to collect household travel data fall into two basic categories:

1. Written, self-administered techniques and
2. Personal-interview techniques.

Both methods have been used effectively under different circumstances and for different needs, and

each method has advantages that the other does not. Personal interviews give the respondents contact with the survey team and thereby serve as a motivating element and information source. Also, use of trained interviewers who are capable of dealing with fairly complex questionnaire designs permits the collection of comprehensive information. With written, self-administered surveys, on the other hand, the respondents are free to complete the form in their own time and are therefore often more willing to detail their behavior much more accurately than with an interviewer. Self-administered surveys eliminate the problem of interviewer bias and when well designed can achieve very high response rates. In addition, if travel behavior is to be collected for several days, a self-administered design leads to much better reporting than the recall technique, which is usually used with interviewers.

Ideally, the advantages of both personal-interview and written self-administered methods can be gained by using a self-completing travel diary that is distributed, collected, and checked periodically by an interviewer. If there were no limiting factors such as cost or other constraints, a carefully controlled diary method would provide data collection that maximized the benefits of both interviewer and respondent participation. In order to describe the state of the art in the design and implementation of all three survey instruments--travel diary, personal interview, and self-administered questionnaire--an example of each will be discussed in some detail. In view of the growing needs of transport planners for travel data in the context of out-of-house activities rather than simply as a set of origins and destinations, the role of each instrument in collecting this kind of data will be emphasized.

Diary Technique

Problem Recognition

The travel diary is the survey instrument that allows respondents to record all daily activities (including travel) for a given time period on a survey form. In general, the travel diary as described here is designed for, and therefore best suited to, longer periods of information collection (e.g., several days or longer). A number of questionnaire designs have been developed with the aim of encouraging respondents to give comprehensive information. Most include some sort of memory aids, and some have identified form layouts that are conducive to accurate and detailed reporting.

The diaries are usually preceded by an introductory letter and are personally delivered by an interviewer. Collection of the diaries is also done by an interviewer, who can check for omissions and assist with any difficulties.

The recording of behavior over several days is most reliably done as soon as the activities occur, and the self-administered, written nature of the travel diary combined with the assistance of interviewers both from a motivational and practical point of view makes this the most appropriate method of collecting such information. This section discusses the problems that diary techniques are designed to address by using an early (1972), but not outdated, example.

Need for Diary Approach

Many transport studies contain one or more of the following characteristics:

1. Average or usual and not actual travel behavior is collected,

2. Some answers (e.g., travel time) have to be estimated by the respondent, and

3. Only a portion of individual mobility is studied (e.g., only motorized travel).

Recent studies in which objective secondary data have been compared with survey data have given substantial evidence that the inclusion of any of these approaches in a survey design leads to unstable results. Car drivers, for example, tend to underestimate their travel time, whereas public transport users tend to significantly overestimate their travel time. This example highlights the fact that errors produced in this way are systematic in nature and appear to be related to the mode used.

Survey methodologies, therefore, needed to include approaches that attempted to overcome these problems. The diary technique has offered options that address each of the problems arising from the three characteristics mentioned and thereby offers a solution to the systematic errors caused by them:

1. The diary has to refer to a specific day and usual behavior has no meaning in terms of an average day,

2. The necessity for estimation of answers is eliminated (the diaries are a manageable size and are designed to be easily carried throughout the day), and

3. All individual mobility is reported as are all activities and all modes used.

The travel diary, because it is designed to collect information over several days, does not need to be distributed to all participants on one day, and the spread of this task over several days is an important positive characteristic of the approach. Finally, the use of interviewers to deliver and explain the diary to the respondents allows the survey designers to make the sample travel day "tomorrow" instead of "yesterday." Preparing the respondents in advance for the level of detail expected has been shown to result in much more accurate travel information than asking for a previous day's behavior.

Development of Travel Diary

In order to portray the state of the art of the diary as a survey tool, an actual example will be described. Although variations on this method exist, they are largely based on the same pattern.

This diary was a brochure small enough to fit into a woman's handbag. On the front cover appeared the name of the respondent, the day of the week, and the date of the sample day. On the inside of the cover there were 12 horizontal rows in which 12 trips could be recorded. The trips were numbered from 1 to 12; the odd rows were in blue in order to give a pleasing appearance. On this page there was space for the most important details from the respondent's perspective, e.g.,

1. Origin of the first activity of the day (usually home),
2. Starting time of the first trip,
3. Activity associated with this trip (e.g., work), and
4. Arrival time at the destination.

All further trips for the remainder of the day were to be recorded on this page below the first trip. In this way the pattern for the day and the basis for various out-of-house activities was fixed. In other words, the activities and brief details about them (e.g., purpose) were filled in as

they occurred and the remaining details (e.g., exact address) could be filled in at a later time.

On the right-hand page there was spiral at the top securing individual questionnaires for each trip. For each trip there were two sets of questions: the first referred to the person being surveyed and the second to any persons traveling with him or her. These individual questionnaires were clearly marked to indicate that two belonged to a single trip. In addition, those questions referring to odd trips were on blue paper to relate to the trips recorded on the left-hand page.

In the first set of questions the respondent had to record

1. Exact address of the destination,
2. Up to three accompanying persons (e.g., uncle, daughter, neighbor),
3. All modes used on this trip (in a structured format), and
4. Detailed description of the activity at the destination.

A window had been cut out of this part of the questionnaire so that the description of the accompanying person was visible on both sets of questions.

In the second group of questions for the trip, the following details were entered for all accompanying persons:

1. Whether they had been traveling with the respondent for the whole trip,
2. Whether they remained at the same destination as the respondent, and, if appropriate,
3. What they did after that.

Organizational Procedure for Delivering Travel Diary

Although the diary was expected to be self administered, it is clear that it could not simply be sent in the mail. The introduction of interviewers was therefore necessary, less for their function as the questioner than for their role as supervisor.

The procedure was as follows:

1. The interviewer carried out a preinterview with the respondent in which sociodemographic data were obtained;
2. The respondent was then shown how to fill in the diary and together with the interviewer, completed it for one day;
3. The respondent was given diaries to complete for the following days; and
4. After the survey period the interviewer returned to carry out a postinterview; among other things, experiences with the diary were discussed, corrections were made or expanded information was recorded, and the interviewer took the diary.

By using postsurvey contact in this way, it was possible to evaluate how well the respondent was able to handle the diary and to ensure the accuracy of the responses.

The travel diary presents advantages, however, not only in the information collected but also in the methodology. The side effect here was that by recording comprehensive activity patterns, information on walk and bike trips, which is often overlooked by transport planners, was obtained. Methodologically, the travel diary gains information on exact behavior and by using it over a number of sample days, the variation in individual mobility over time can be observed.

Since it was assumed that motivation would decline over the period, the supervisor visited the household every three days to encourage respondents

to continue. Only highly qualified interviewers could be used for this difficult task, and the total sample was therefore divided into several subpopulations so that the starting dates could be spread over several days. This meant that the interviewers did not have to carry out all the preinterviews on one day and a detailed schedule was devised to allow this to operate smoothly.

Finally, it should be noted that in this example the travel diaries were intensively pretested over a period of 6 months. This is a requirement that belongs to the state of the art but is frequently omitted.

Summary

The travel diary can be described from a purely methodological viewpoint as the ideal method to gather out-of-house activity patterns. The diary technique has also been used as a control device for large-scale surveys; because of such travel diary studies, it was realized (e.g., in the self-administered mail questionnaire survey discussed earlier) that there were about 0.5 trip too few reported when the diary technique was not associated with personal contact.

For two reasons the diary is not feasible for large-scale applications:

1. If the sample is not spatially (and temporally) concentrated but widely spread, the organization would be almost impossible and
2. The high cost of such a survey would inhibit its implementation on a large scale.

For small geographic areas, however, and as a control mechanism for large-scale surveys, it can be seen as an excellent technique.

Personal-Interview Technique

Problem Recognition

The personal-interview technique has been shown to be most appropriate when

1. Travel information to be gathered is limited to one sample day,
2. Geographic distribution of the population is not extremely great (i.e., does not extend over a whole country), and
3. Sufficient finances are available to expend considerably large amounts of money to obtain one entire household's travel behavior.

In addition, because of the presence of an interviewer in this technique, it is possible to incorporate certain methods of eliciting more comprehensive reporting of travel behavior than is the case with self-administered surveys.

General Description

The example to be used to describe the most recent advances in the personal-interview technique in the collection of travel data is a survey of about 25 000 households that took place in Sydney, Australia, in the last 6 months of 1981. In this survey, the 1981 Sydney Travel Survey, all persons 15 years of age and over were personally interviewed about their travel on one sample travel day. The same travel information was obtained for those 4-14 years old either personally or by proxy. The respondents were personally contacted before the travel day and interviewed as soon as possible after that day. The survey was carried out by the State

Transport Study Group of New South Wales. The most important methodological aspects that contributed to the minimization of the systematic errors (described in the sampling section) for the Sydney study were as follows:

1. Two years of intensive planning were allocated to the research and design of the survey. An exploratory survey and three pilot tests formed part of this preparation.
2. The management of the survey was limited to the study group to allow maximum interface between methodological and operational needs.
3. Care in the preparation of the questionnaire included detailed testing of content, phrasing, and layout of the survey forms. The design and content of other travel surveys were examined and, where possible, the data were reviewed. All pilot surveys were conducted by experienced interviewers and concluded with one day of debriefing where all aspects of questionnaire design and administration were thoroughly debated.
4. Travel days, about which all information was obtained from respondents, were distributed evenly throughout the survey period. An equal amount of information was obtained for each of the seven days of the week.
5. The vital role played by the interviewer in ensuring that reliable results were obtained was recognized and reflected in the recruitment and training programs. Recruitment spanned 8 weeks and included extensive testing and interviewing of applicants. A four-day training session in groups of no more than 28 was designed to produce thorough, consistent interviewing techniques. Part of the training was an explanation of the purpose and use of all elements of data to be collected. This knowledge has been shown to foster good rapport with respondents and interviewer loyalty to the survey aims.
6. Systematic survey control for the duration of field operations included following up on initially noncontactable households to discover whether they were in the study area on the assigned travel day (i.e., eligible for the survey), periodic supervision of interviewers during an actual interview, and gathering basic demographic and car availability data wherever possible even if a household or a person refused to give travel information.

Underreporting of Trips

Since the trip or, more specifically, the travel movement that it represents is a very basic unit in transportation planning, the underreporting of trip data has received the attention of both transport researchers and modelers. Researchers cite examples from the United Kingdom where, even after adjustment, there were differences of up to 100 percent between home-based vehicle trips reported in home-interview surveys and those observed at external cordon points. Underenumeration was approached in two ways in the 1981 Sydney Travel Survey--by not allowing proxy interviews and by using a verbal activity-recall framework (i.e., asking respondents to verbally recall their travel in the framework of all out-of-house activities).

Nonproxy Interviews

An earlier Sydney study in 1971 had shown that whereas underreporting occurred throughout the day, it was most significant in the middle of the day off peak (i.e., between 9:00 a.m. and 4:00 p.m.). It was suspected that much of this discrepancy was attributable to the acceptance of proxy responses on

trip data. Although household members were frequently aware of most household movements in the morning and evening, daytime trips (characterized by not having home as an origin or destination and general irregularity) were often not known to everyone.

In the 1981 survey, personal interviews were conducted with all members of the sampled households 15 years of age and over. It was hypothesized that because travel is reported directly by the traveler, results would more closely approximate reality and the number of reported trips would increase. Survey results supported this hypothesis.

Verbal Activity-Recall Framework

Many travel surveys have collected trip data by focusing on travel only, i.e., by asking the respondent what trips were made during the period of time under investigation. This technique neither ensures that all travel is recorded nor defines the researcher's notion of trip to the respondent. An activity-recall framework that uses activity rather than trip diaries has been shown to substantially increase trip reporting by using the self-administered questionnaire design. Indeed, increases of up to 13 percent have been reported between activity surveys and traditional travel surveys.

In order to apply this approach to the personal-interview survey, a technique was developed that combined the use of the activity-recall framework with the recording of trips in a relatively conventional manner. Quite simply, after establishing the location at which the respondent began the day, the interviewer asked, "What did you do next?" (activity) rather than "Where did you go next?" (trip). Non-travel-related responses (got dressed, had breakfast, etc.) were even recorded when they occurred at home, since they have proved to be the vital connections linking all activities and thereby enabling easy recall of all trips. It was expected that better recall would be reflected by an increased number of trips per person. This was found to be the case when an early pilot survey in which the normal trip-recall approach was used was compared with the later pilot surveys and the final results.

In addition, the significant increase in walk trips recorded in the survey when compared with earlier data gives definite support to the notion that the nonproxy personal interview and the activity framework are important tools in the accurate recording of travel behavior.

Response Rate

Low response rates are known to seriously affect the validity of survey results. Personal-interview methods, in particular, are susceptible to lower-than-average response rates, often due to the inappropriate times that the interviewer approaches the respondent. Two steps were taken to achieve high response rates. Contact prior to the actual interview was made first by letter and then in person to inform households about the survey and collect household information. Pilot testing showed significantly better response rates with this technique than with reliance on a letter precontact only. At precontact, all respondents were given a memory jogger on which to make notes about travel activities during the travel day. Each individual's name was written on the memory jogger, and each person was given a travel survey magnet so that these joggers could be attached to the refrigerator and thereby be less easily overlooked. The use-

fulness of this method was shown to be greatest when interviewing occurred more than one day after the travel day.

This example of a personal-interview survey method was very cost intensive due to the use of interviewers and due to the fact that at least six, and up to nine, callbacks were made at all sample households. The technique resulted in a response rate of 87.8 percent, however, which is unprecedented in survey methodologies of this kind.

Interviewer Bias

It is recognized that interviewers can easily bias the responses to travel behavior surveys. The structured questionnaire design and the extensive training and quality-control measures described above were implemented in order to minimize the interviewer effect. Detailed analysis of results is also instrumental in pointing to interviewer effects (e.g., significantly higher or lower trip rates or refusals) and can be dealt with to some degree by the application of correction factors.

Summary

The personal-interview technique as it currently exists is refined enough to deal with many of the problems that have been associated with this type of survey instrument in the past. Although it is costly and not suited to extremely large geographic areas, it is an extremely valid method of collecting travel data.

Self-Administered Questionnaire

Problem Recognition

Many researchers and practitioners believe that the self-administered questionnaire is the best technique for measuring individuals' travel behavior. When carefully designed and executed, it has many advantages in comparison with other techniques:

1. It can be completed at the leisure of the respondent and need not be filled in at the convenience of the interviewer;
2. Being written, it encourages the reporting of trips that may not be revealed to an interviewer;
3. It can be combined with interviews in order to achieve a personal approach; and
4. It is much cheaper than similar personal-interview methods.

General Description

An example of the use of the written questionnaire for the collection of data in a travel survey can be seen from the German context. In 1975-1977, the Federal Ministry of Transport commissioned a countrywide study of travel behavior, which was undertaken by the firm Socialdata. The study, *Kontinuierliche Erhebung zum Verkehrsverhalten (KONTIV)*, or continuous study of travel behavior, took place over a whole year (i.e., every day was a sample day), and information on all out-of-house activities was obtained from about 135 000 households in the Federal Republic of Germany. In the households selected in the survey, all of the German population 10 years old and older was surveyed and each person was asked about two days of activities. A multistage stratified sample was selected in three stages based on planning regions, municipalities, and households.

The survey instrument was a self-administered mail questionnaire. It was developed as a result of experiments in which travel diaries were adapted to

large-scale use, i.e., without the necessity of using an interviewer. The questionnaire consisted of a household form, which collected sociodemographic and vehicle-ownership information on all persons 10 years old and older, and a person form, on which each person could complete details about his or her travel behavior.

The approach to the respondents consisted of an introductory letter, a mailed questionnaire, and three reminder notices, including a further questionnaire. The respondents were required to return the completed forms in a stamped envelope provided for this purpose.

The self-administered mail survey technique was shown to be ideal for the large-scale and extensive geographic area necessary for this exercise.

Problems with Self-Administered Mail Questionnaire

Interviewer Bias

Preliminary studies had shown that the influence of the interviewer in a personal-interview situation significantly affected both the response rate and the quality (validity) of results. The self-administered mail questionnaire does not have any interviewer effect.

Distribution of Sampling Days

Even though results are aggregated to monthly or annual values, the distribution of sampling days over the entire year can result in small daily sample sizes. This problem was approached by gathering out-of-house activity information for all persons on two successive days, thereby effectively doubling the sample size. Although only two days were sampled, a nonreported trip effect was already noticeable for the second day. This effect and measures that can be taken to address it are discussed later.

Exploratory research had also shown that seasonal variations existed due to the effect of holiday periods. In order to counteract these variations, a disproportionate sample was selected in which each quarterly period of the year was differently represented.

Finally, in order to compensate for the lower response rates that had been shown to exist for weekends, sampling-day pairs that included a weekend day were slightly oversampled.

Nonreported Trips

As noted in the section on personal interviews, the solution to the problem of unreported trips is central to the development of a successful survey instrument. In the case of the self-administered mail questionnaire, the recording of trips themselves is generally less of a problem than the recording of the mode used. In particular, when several modes are used for one trip, it has been observed that the respondent has difficulty in recording this information. In order to make this process easy for the respondent and at the same time valid for the researcher, pilot tests were conducted. Two methods were examined:

1. Changing the definition of a trip so that each trip leg was recorded instead of the overall trip; this method elicited many mistakes by the respondent, lengthened the time necessary to complete the form, and generally reduced the accuracy of reporting; and

2. Open questioning of the mode used; this resulted in entries that only referred to a small part of the trip.

There remained the technique in which respondents could check the box next to the mode or activity listed on the form. This presented a problem; preliminary tests showed that on the one hand respondents preferred the easiest solution (box checking) but on the other hand it was not easy to understand what activities fell within such categories as leisure. The solution was to opt for a semistructured approach in which boxes were supplied for the common, clearly understood modes and activities (e.g., car driver, school, work) and there was a category marked "Other, please describe" for the remaining alternatives.

With this technique and with the occasional help of street directories and maps of the public transport system, it was possible to reconstruct most trips even when only one mode was given. A post-enumeration study reinforced the success of this technique.

Response Rate

In order to motivate respondents to take part in the survey and thereby to achieve a high response rate, several methods were used:

1. Approach letters had two return addresses: that of the Ministry of Transport and that of the research institute. The mention of the Ministry underlined the importance and the official character of the letter. The name of the institute, on the other hand, ensured the respondents anonymity with respect to the Ministry. In addition, special-issue stamps were used so that the letter itself was esthetically pleasing.

2. When the questionnaire was mailed, the envelope also had special-issue stamps on it. A letter of motivation from the Ministry was included for all respondents. It described the purpose and value of participation and assured the respondents of anonymity in addition to giving basic instructions as to how to fill out the form.

3. Information on government privacy regulations and on the citizens' rights in this respect was also included.

4. A reply-paid envelope was included to encourage return of the forms.

5. The reminder cards were prepared with equal care.

The response rate achieved (for households in which all persons responded) by using this example of a self-administered mail questionnaire was 72 percent over the whole year.

Mailing System

An important component of a mail survey based on sample days is the field operations exercise. An imprecise mailing system can result in imbalances in sampling days, the necessity for respondents to recall past behavior, or the nonresponse of the household.

It was therefore necessary to develop a mailing system that overcame these problems and therefore guaranteed a high response rate.

Initially, tests were made to discover the exact length of time taken for mail to reach all survey areas. The following system was then developed:

1. One week before the first sample day, the household received an approach letter. This had the advantage that genuine nonrespondents (e.g., because of vacant or demolished dwellings) were identified by the return of these letters. It was also a cost-saving method since these households did not have to be contacted in the future.

2. The forms for the household arrived two days before the first sample travel day.

3. At weekly intervals, all households that had not replied received first and then second reminders together with new sample dates; the same day of the week was maintained.

4. Those who had not responded one month after the original sample day received a new questionnaire as well as the notification of the new sample date.

5. One week after this, a third reminder was sent.

This process has the advantage that for each day (and date) of the year, there is a group of persons who answer immediately and a group who respond only after one reminder, two reminders, and so on. It thereby eliminates some of the important nonresponse effects, which are discussed in the next section.

Service to Respondents

Finally, in order to reduce negative reactions of those persons in the survey, a complete service to respondents was set up. All letters were answered and these as well as the letters of motivation were hand signed. A telephone service was also provided. Special telephone numbers were dedicated entirely to the survey, and respondents could use them at any time. Long-distance calls were returned to minimize costs to the survey participants. The project leader spent a considerable amount of time answering calls himself, thereby keeping himself in direct contact with any difficulties that could be avoided in the future.

Summary

The self-administered mail questionnaire technique has shown the current level of sophistication in this form of data collection. The survey instrument is a valid, reliable, and relatively cost-effective technique to use for gathering travel data. Recent adaptations of the original questionnaire form have shown that it is also suitable for persons whose language is not German. The degree of knowledge of many error sources and the experience at overcoming or correcting for them suggest that this method will form the basis for a growing number of travel surveys. The example illustrated has already become a methodological standard in countries outside the one for which it was originally designed.

CORRECTION AND WEIGHTING

Problem Definition

Since travel surveys have almost always been sample surveys, it has usually been recognized that the data do not represent the behavior of the whole population. Although the travel survey was primarily the domain of the engineer and the true unit of investigation was frequently the vehicle or the trip, the most common method of adjusting the sample to the population as a whole was expansion. This was often done simply on a geographic and household basis (e.g., if a 2 percent sample was selected from a certain area, all data elements were multiplied by 50). The very crude nature of this technique resulted in many data inadequacies, which were often the basis for arguing that increased sample sizes were necessary. The realization that simple expansion was less than adequate led to the application of some slightly more sophisticated methods, which included sociodemographic weighting to a greater or lesser degree.

The existence of a wide range of both secondary and primary data sources, however, has made it pos-

sible to consider much more extensive procedures, and it is these procedures that represent the state of the art in weighting and correction techniques. These procedures recognize that all empirical measurement is subject to errors of two kinds--those that can be attributed to the measurement technique and those that can be attributed to the subject being measured. In travel surveys, where the unit of observation is the individual, the second type of error (respondent-related) is particularly significant due to the large number of subjective errors and deficiencies. The new techniques are based on the assumption that it is possible to evaluate the degree and direction of the error to a large extent by

1. Identifying those variables that are particularly subject to error,
2. Studying the direction of the effect of these errors, and
3. Estimating the magnitude of these errors.

Even though the correction of these errors requires complex conceptual methods, the actual application of the weighting factors that correct the data set is a fairly simple mathematical procedure. It must be recognized, however, that although approximation to reality is improved, reality itself is never reached.

There are numerous examples of ways in which data can be corrected. Indicative of the wide range of possibilities are

1. Use of secondary data to correct for sample size and response rate,
2. Use of stratified sampling techniques for the correction of holiday behavior and the subsequent low response rates,
3. Correction with regard to the representation of foreign workers in the sample, and
4. Use of internal survey data to correct for nonresponse errors and for nonreported trips.

The ideal state of the art would be a methodology that allowed the correction of all these problems. In addition, it would include correction for the individual differences that have been observed for the perception of trips. Although the methodology of social science in this field has not yet reached this pinnacle, there are many known examples that attempt to minimize sampling errors and errors attributable to interviewers' response. These will be discussed in the following sections.

Sample-Related Weighting

The type of correction necessary to adjust for errors in sample selection varies with the technique used for the sampling procedure. Stratified samples, which are an example of a disproportionate sampling technique and are not used frequently, have a well documented and relatively straightforward weighting methodology.

If the sample is based on addresses that are clustered along a random route to minimize interviewer travel costs, many systematic errors are introduced into the data, particularly those related to land use characteristics. Since the magnitude of this type of error cannot be measured effectively after the survey, it has not been possible to develop correction or weighting measures to apply to these errors. Mailed questionnaires are generally considered the best way of overcoming this problem, although noncluster sampling has also been used in personal-interview surveys.

In contrast, the most commonly used sampling

frame, a set of address files, presents a problem that can be rectified with simple correction methods. In general, this type of survey is household based, whereas the comparable data (e.g., age and sex) available from other official (secondary) sources is usually person based. In other words, the sampling unit (the household) and the unit of investigation (the individual) are not identical. This means that the behavior of persons from large households will be overrepresented and that of persons from small (in particular single-person) households will be underrepresented.

In order to correct for this error, the household size of the sample is compared with that of the population and the corresponding adjustments are made. In general, the result is that those in one- and two-person households are given factors greater than 1 and those in larger households are assigned factors less than 1. Research has shown that the effect of this type of weighting represents an overall change (decrease) in trip rate of about 5 percent per person. In addition it has the effect of changing the mode split by increasing the proportion of nonmotorized trips and those made with public transport and slightly decreasing the share of motorized travel.

Another aspect of sample-related weighting has been used to correct for day-of-week errors. Most samples used in the collection of travel data survey either only weekdays or both weekdays and weekends. In both cases the unit of analysis is usually the average day. It has been shown that the variation in travel behavior by day of the week is significant and for this reason correction for daily variations is an important part of eliminating errors in the sample. This principle has been extended to seasons of the year, since it has been shown that it cannot be assumed that any particular month or months are typical with respect to travel behavior.

The method of correction in this case is to check the distribution of the sample by day of week or by season and compare it with the distribution that would have occurred if the sample had been selected perfectly (i.e., one-seventh of the sample per weekday or one-quarter of the sample per season of the year).

Respondent-Related Weighting

The correction of respondent-related errors in travel survey data can be divided into three categories:

1. Sociodemographic correction: the correction for sociodemographic inequalities between the population and the sample from which it was chosen,
2. Correction for nonresponse: correction due to the total nonresponse of some individuals within the sample and in particular to the variation in travel behavior between respondents and nonrespondents, and
3. Correction for nonreported trips: correction for partial nonresponse by individuals and for inaccurate answers.

Sociodemographic Weighting

Sociodemographic weighting is the most common form of correction and has been applied to most data sets on travel behavior.

The data on age and sex that are available from secondary sources are usually available by geographic region (e.g., traffic zone). The sociodemographic weighting process is therefore most commonly done on a zonal basis. For example, if there are data for 7 age groups by sex, for 10 traffic zones there would be 340 (7 x 2 x 10) cells to

be weighted. The survey data are analyzed on the basis of these cells. This distribution is the so-called "survey distribution" and its relationship to the actual distribution of secondary statistics produces the relevant correction factor for each cell.

An error made frequently in sociodemographic expansion has been to expand data only on the basis of households, disregarding the varying response rates for different-sized households. The effect is to produce a total population that in overrepresenting large households also generates between 10 and 20 percent too many trips. This type of error becomes particularly important if all sections of the population were not included in the original sample (e.g., foreigners).

Although secondary statistics usually represent the actual distribution of the variables being checked, it has been identified that in some cases the secondary data do not actually improve the survey results. If, for example, secondary data define two unmarried persons living together as two households, it would not be appropriate to correct survey data that defined them as one household, particularly in the light of the numerous studies that have shown the influence of other household members. In this case, household size would be best corrected by using nonresponse estimates, which are discussed below.

Correction for Nonresponse

Although sociodemographic weighting is not uncommon, correction for nonresponse errors is a much more recent phenomenon. Significant distorting effects occur in empirical surveys due to the fact that not all households or persons respond. In travel surveys, even when 75 percent of households respond, there is still no information on the remaining 25 percent. A series of basic studies has shown that there is a definite relationship between nonresponse and travel behavior and that the errors produced by it cannot be corrected completely by using sociodemographic weighting alone.

A technique that estimates both the direction and the degree of error has therefore been developed. The technique is based on studying trends with reference to the speed of response and the observation of the following variables: household size, share of out-of-house activities, mobility per mobile person (tripmaker), and a combination of mode and purpose.

The total sample is divided into five response categories according to the speed of response. For correction of written mail questionnaires the speed of response can be measured by the time elapsed since initial mailing. For personal-interview surveys, on the other hand, the number of contacts necessary to obtain an interview can be used.

The results of the nonresponse estimates are incorporated into the data as weighting factors. This usually takes place after the sociodemographic weighting has occurred. The importance of nonresponse correction has been highlighted by the facts that

1. Nonresponse estimates are not always in the same direction as the sociodemographic corrections and
2. Nonresponse estimates result in significant changes to the survey data.

Results of the RONTIV survey (mail questionnaire) and the Sydney personal-interview survey have clearly indicated differences in nonresponse for these two methods. Mail questionnaires result in an overrepresentation of trips and mobile persons,

because the nonmobile persons tend not to understand the importance of their completing a travel survey. Personal-interview surveys, however, produce the opposite results, since mobile persons are often the most difficult to contact.

These factors become particularly important in surveys that, unlike the Sydney Travel Survey and KONTIV, have very low response rates.

Correction for Nonreported Trips

The correction for nonreported trips, like that for nonresponse, has also had limited, although important, application. The nonreporting of trips is particularly significant when the survey period is longer than one day (e.g., trip diaries). Willingness to respond and hence actual reporting of trips decline. Even over two consecutive days, trip reporting declines on the second day. Correction is therefore a necessary measure.

This phenomenon has been studied comprehensively only recently. It has been shown that it is necessary to differentiate among

1. Respondent errors that can be corrected with careful coding,
2. Respondent errors that can be identified by retrospective checking, and
3. Respondent errors that cannot be identified.

Although the methodology for estimating nonreported trips is still in its formative stages, analysis of trips identified by retrospective checking had been reported to result in about 14 percent additional trips. Most of these trips were short trips by nonmotorized modes for shopping or recreational purposes.

Summary

The correction and weighting methodology applicable to the data collected in travel surveys has only recently developed beyond straightforward expansion and sociodemographic techniques. Results of recent approaches that have included nonresponse estimates and correction for nonreported trips have indicated that important benefits to the data accrue from the use of these techniques, even though all of these methods are only estimates that improve the results but do reproduce reality.

INTERACTIVE-MEASUREMENT TECHNIQUES

Problem Definition

The examples of travel survey instruments that were discussed earlier described the way in which measurement techniques have been developed and adapted to meet the special problems and needs of travel surveys. The problems involved in providing a logical explanation of current behavior and at the same time giving a useful estimate of future behavior have always constituted the central theme in all areas of applied empirical research and particularly in the field of travel behavior. In this regard, the usual survey instruments are not able to deal with questions about

1. The relationship between behavior and its motivation,
2. Changes in behavior resulting from changes to individual variables within the individual's activity space, or
3. Changes in behavior when the activity space is substantially altered.

In seeking to find an acceptable solution, re-

searchers in the field of travel data collection have therefore had to address the problems that existed in known survey techniques:

1. Straightforward questioning of behavior often measures subjective estimates of this behavior,
2. The explanation of travel behavior by individuals includes either intentional or unintentional deviations from reality,
3. Intended future (travel) behavior reported by respondents is rarely actually carried out, and
4. "What-if" techniques that elicit responses about situations not previously encountered by the respondent have minimal forecasting power.

As a response to these problems, interactive-measurement techniques of various forms are currently being practiced. These techniques consider the gathering of information as a special type of communication process. As such, the respondent and the interviewer play an equally important role. In other words, all elements of the well-known Lasswell formula are taken into consideration by the approach; i.e., who says what to whom using what medium with what effect? The interviewee is seen not only as a reacting and reporting element in the interview situation but as an active partner in the communication process. This approach is completely opposite to that adopted by those transport planners who use quantitative scaling techniques to measure attitudes.

Problems Addressed

Basically, there are four classic areas in which interactive-measurement techniques can be applied:

1. To obtain realistic information through interaction in the social context (e.g., in the household),
2. To overcome the problem that respondents verbalize perceptions other than those that they actually experience,
3. For the controlled reorganization of activity patterns, and
4. As a mechanism for collective decisionmaking.

The techniques are therefore particularly suited to dealing with problems associated with the measurement of attitudes and to examining complex behavioral determinants.

Problems in Measurement of Attitudes

Attitudes in this case refer to opinions and ways of thinking that are socially acquired. One problem with most existing methods of measuring attitudes is that they usually consider only the target person's account of his or her own attitudes. Traditional research has not commonly dealt with the fact that an individual's account of attitudes is subjective and not necessarily reliable. Other factors, such as the desire to conform to the perceived needs of the interviewer, also need to be considered.

Precise empirical explanation of the factors that influence mobility requires the use of the most appropriate survey instruments. The complex nature of mobility makes it necessary to ask a great number of questions, which makes face-to-face interviews essential. The survey instrument needs to deal with at least two problems:

1. It is difficult to make the interviewees aware of all aspects of their daily routine, some of which are performed or decided on almost unconsciously.
2. Decisions concerning manner, scope, and type

of transportation are not always individual decisions. It is important, therefore, that the interview take place in a real-life context, i.e., together with all household members.

When questions are aimed at the household as a whole, empirical methods that realistically depict the group's decisionmaking process must be used. Interactive-measurement techniques are designed to be used in the survey process in order to approach many of the problems associated with the measurement of attitudes.

Role in Total Survey Design

Interactive measurement has been found to fit easily within the framework of a comprehensive survey design, particularly when the object of investigation--for example, mobility--is relatively complex. An integrated approach to survey design in which each stage of data collection uses the most appropriate survey method usually includes several phases in which interactive measurement is appropriate. Examples of this integrated approach would be as follows:

1. Sociodemographic data, for which any form of direct questioning could be used;
2. Activity patterns, which would be recorded in a travel diary;
3. Data on the existing environment and the transport infrastructure, which could be obtained from official statistics or observation;
4. Data on subjective perceptions, which would be gathered by using personal interviews since the respondents do not realize that their view of reality is only their perception of it; in order to avoid undesirable feedback, a spontaneous survey technique is necessary;
5. Data on personality and psychological characteristics, which would also be gathered by using explorative personal interviews;
6. Data on the internal organization and structure within the household, which have been shown to be most reliable when an interactive discussion method is used; dominance of individuals, organizational details, and decisionmaking processes can be clearly established in this way; and
7. Data on dynamic aspects and behavioral sensitivities, which require the introduction of forecasting mechanisms into the technique, so that the relationships between a change in the objective situation and the corresponding behavior can be measured. (This is particularly difficult since the respondents themselves are often not clear on how their behavior would change nor do they understand the complex structure of all the variables that would influence the new situation. In this case it has been shown to be very successful to confront the household with the assumed situation and to allow them to react to it and to discuss possible decisions about behavioral changes. The result is a very good insight into the decisionmaking process, its constraints, extent, etc.)

Examples of Application

Two applications of interactive measurement will be used to show

1. The way in which the interaction between respondent and interviewer leads to increased precision in responses and
2. The way in which behavior can be realistically forecast by using controlled reorganization of activity patterns.

Interaction with Interviewer

In the example, respondents were asked to estimate total monthly expenditure on their cars. The cost estimates were divided into four successive stages, in each of which progressively more information was gained. The interactive-measurement technique used by the interviewers had the following sequence:

1. The respondent was requested to estimate monthly car costs as accurately as possible without the use of any documents;
2. Any comments made by the respondent on purchase, maintenance, use, and so on as self-support were used to revise the first estimate;
3. The interviewer listed all conceivable costs in order to gain another estimate; and
4. An estimate was made that took into consideration the household budget and any available accounts.

In this case the interaction with the interviewer not only made possible the nonverbal measurement of complex perceptual relations but also allowed the recording of cost sensitivities.

Controlled Reorganization

Interactive measurement has the advantage of requiring the household members to make a realistic and controlled reorganization of activity patterns. The actual activity patterns, determined from previous written surveys, are used as a basis for reorganization. The technique ensures that reorganization is realistic and the mutual interviewing of the group allows the interviewer to interrupt if contradictions occur.

An example illustrates the potential reorganization of the household's outdoor activity pattern. It can be useful for forecasting demand if changes in the urban public transit system are to be made.

The household is shown a set of information that includes data pertaining to actual activity patterns. While the interviewer explains how to change different constraints and options, the information that has been collected is checked, and it is then symbolically represented--visually--thus enabling the respondents to understand the implications of their decisions.

Those persons taking part in the exercise are told that the supply of the urban public transit system has been changed and that they must therefore try to reorganize their activity patterns (displayed in front of them) so that all trips are made by using an alternative mode. The alternatives are symbolized by new figures. It is the interviewer's responsibility to

1. Make sure that the interviewees give realistic answers concerning their options for reorganizing their activities,
2. Check to see whether the changed activity patterns of the individuals are mutually compatible within the given household structure,
3. Note the constraints that partly or totally influence the household's activity pattern,
4. Keep a protocol of the reorganized activity pattern, and
5. Explore the household's general alternatives for reorganization, e.g., substitute modes for the specific routes traveled.

Each respondent is therefore forced to consider the multiplicity of effects of each activity change. The method can be used to observe reactions to a wide range of both transport and nontransport measures.

SUMMARY

This paper has approached description of the state of the art in data collection for travel behavior by using examples that represent the most recent advances in several areas of measurement. Sampling methods, the design and implementation of different survey instruments, the correction of travel data, and the use of interactive-measurement techniques have been approached in this manner.

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