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Surveillance and Monitoring of a Bus System

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Most transit operators occasionally conduct an on-board survey of riders. Based on experiences in Washtenaw County (Ann Arbor) Michigan, Dade County (Miami) Florida, and Honolulu, Hawaii, this paper examines three aspects of such surveys. First, a survey instrument is described that permits considerably more information to be collected than is possible from the traditional postcard type of on-board survey. Descriptions of the types of data needed to be collected on the participatory self-administered survey of riders for both systemwide surveillance and individual route monitoring are provided. In addition, it is recommended that the survey personnel record observable information (e.g., passenger volumes) on bus operations. Second, procedures are described for reducing nonresponse bias for collecting at least some information from a subgroup of riders who would otherwise be nonrespondents. Third, sampling strategies (including the necessary sample sizes) are described both for systemwide surveillance and individual route monitoring.

Most transit operators maintain the collection of a certain amount of data about the system, mainly from the perspective of the operation of the system in contrast to data about the system delivery to the actual and potential rider. Data frequently collected include revenue, load profiles (including maximum load points), vehicle hours and vehicle miles of service operated, and a variety of similar operational and financial data. All of this information is necessary to the management of a transit property and provides much needed information on the system performance; however, it is not complete because it does not measure how people use the system and, therefore, who will be affected by system changes and in what way they will be affected.

Most transit operators, from time to time, conduct some form of on-board survey of riders. This survey is typically a brief set of questions on a postcard-size form that is distributed by drivers or survey personnel who ride the buses during the survey. Postcards are usually designed either to be returned on the bus or to be mailed back later. The main drawbacks to this type of survey are the perceived restriction of limiting questions to what will fit on (usually) one side of a postcard and the usually unscientific sampling that is used. Two aspects are of concern with respect to sampling. The first is the lack of application of basic sampling procedures that would lead to near-optimal efficiency in the data collection and will usually reduce considerably the sample sizes needed to obtain data of known and calculable reliability. The second is the problem of nonresponse that occurs in a self-administered survey of this type, and that in this kind of application is generally uncontrolled and provides no information on the biases that may be caused by nonresponse (1).

In this paper, we deal with three aspects of the design of on-board surveys. First is the issue of the amount of information that can be collected. A survey instrument design is described that provides considerably more information than is possible to obtain from the simple postcard survey. Second, procedures for reducing nonresponse through instrument design are described, where these procedures also provide information about a subgroup of nonrespondents and some indicators of the potential biases that may exist. Third, sampling strategies are described for two types of situation. The first context is that of systemwide surveillance, where the desire is to obtain data about all or a large sample of routes that make up the system, but only to a sufficient degree of accuracy to describe systemwide patronage and system use and sufficient to focus attention on routes that may not be performing to the standards desired or required and may warrant further, more detailed, study. The second context is that of individual route monitoring, where the need is to obtain data of sufficient accuracy on a single route to be able to identify changes that occur in patronage patterns as a result of specific changes to the route.

For these contexts, surveillance is defined as the collection of data for systemwide profiles and information, with sufficient detail and accuracy on individual routes to be able to identify any routes that require further, more detailed study but insufficient detail to reveal specific problems or actions required at the level of individual routes. A program of surveillance would involve a periodic survey effort design to produce systemwide statistics and ridership profiles on an annual basis and would satisfy most, if not all, requirements of state and federal agencies for system performance data. Monitoring is defined as a program of repeated surveys on individual routes, designed to measure the effects over time of changes made to each such route. In this case, the emphasis is on sufficient detail in the measurement of a route to permit detection of fairly small changes in use, patronage, and performance.

DESIGN PROBLEM

The first issue in the design of any survey is to define the data needs. There are distinct differences and some similarities between the needs of surveillance and monitoring. The basic data needs for surveillance are as follows:

1. Systemwide and route-by-route passenger volume;
2. Systemwide and route-by-route passenger miles;
3. Demographic characteristics of riders;
4. Use of transfers and patterns of route use;
5. Origin and destination pattern served by the system;
6. Maximum load factors on each route and location and maximum load points, starting with an existing maximum load point assumption;
7. Service reliability and schedule adherence;
8. Run completion rate and reasons for failure to complete;
9. Proportions of different fares used; and
10. Trip purposes served.

Similarly, for a route that is to be monitored, the following data are required:

1. Passenger volume and passenger miles,
2. Demographic profile of passengers (e.g., minorities, elderly, handicapped, or carless),
3. Number or proportion of passengers who use transfers and routes (by type) transferred to or from,
4. Waiting time for transfers,
5. Passenger volume by time of day,
6. Schedule adherence and variability of running time per stop-arrival times,
7. Desired arrival times of passengers vis-a-vis bus times, and
8. Passenger attitudes to service before and after a change, including perception of travel time.

Thus, monitored routes require a more detailed level of information and, hence, a longer survey instrument.

Different levels of accuracy are required for the surveillance and monitoring data. For surveillance, the need is for a reasonably accurate picture of the functioning of the entire system, with sufficient accuracy on a route-by-route basis to determine whether special attention needs to be paid to a specific route. For monitoring, which requires a survey before and after a route is changed, the requirement is to be able to detect whether statistically significant changes have occurred between the before and after measurements. Precise sampling rates cannot be determined without estimates of the standard deviations of key variables to be measured (2). At the design stage, it is only possible to estimate order-of-magnitude differences in sampling rates and to make some assumptions about the probable sizes of standard deviations. This topic is addressed at greater length later in this paper and in a related report by the Kaiser Transit Group (3). Its significance here is mainly to note that, in addition to a more detailed survey instrument, higher sampling rates are required for monitored routes.

SURVEY METHODS

The data collection envisaged here involves two elements:

1. A participatory survey of bus passengers and
2. Recording information on bus operation and passenger volumes experienced by the participating passengers.

The participatory survey is designed as a self-administered on-board survey. For the surveillance data, a survey form that could be completed while a passenger is on the bus is desired. Therefore, on-board distribution and collection should be undertaken by using a trained survey person to distribute questionnaires, assist respondents when necessary, help ensure that completed forms are returned before passengers disembark, and also record key information (passenger volumes, time) about bus operation. Vehicle data provide a tie between riders' reports of system performance and objective measures of that performance.

For monitoring, where the data needs are not likely to be obtainable by an instrument that can be completed during a bus ride, a two-part survey instrument has been devised. This instrument consists of a short questionnaire to be completed during the bus ride that requests data about that bus ride, some key demographic characteristics, and the respondent's address. The address is requested to permit a mail follow-up scheme to be implemented for nonresponse and may be presented as a means to provide free bus passes or some other incentive to respondents, thus the request is unlikely to affect response rates negatively. The second part of the survey instrument is a long questionnaire that is designed to be completed at home and mailed back in a reply-paid envelope provided. Also, it is assumed that the action of completing the short form on the bus will help to fix that bus ride in the respondent's mind and thus make it easier to complete the longer form later.

NONRESPONSE INFORMATION

A key issue in this survey design is nonresponse. Any participatory survey is affected by nonresponse. In general, the existence of nonresponse should lead to a presumption of bias. However, in past transportation surveys, nonresponse has been assumed to be unbiased and little or no attempt was made to determine the validity of this assumption. Recent work suggests that this assumption is a dubious one and that significant and important biases do arise in any transportation survey (4,5). Unfortunately, a detailed study of nonresponse is generally infeasible within the time and cost constraints of most transportation surveys. Certainly, it seems unlikely that such a study can be included in a surveillance and monitoring activity. For a self-administered survey mechanism, the issue of nonresponse takes on additional importance and it is especially important to exercise some control over this in the monitoring study. The two-part survey design allows some limited study and control of nonresponse bias. The greatest potential for nonresponse arises with the long take-home portion of the monitoring instrument. Based on standard procedures, one might expect the take-home form to achieve no more than a 10-20 percent response rate prior to any followup process, although a good design might increase this fairly significantly. In comparison, the on-board instrument should receive a fairly high response rate because (a) it provides a diversion during the bus ride, (b) peer pressure to complete it will arise as some bus passengers decide to fill it out, and (c) there is no problem of remembering to do it, as might occur for a mail-out or take-home survey.

For this two-part survey, there are two groups of nonrespondents. One group responds neither to the short, on-board form nor to the long, take-home form. The second group responds to the short, on-board form, but not to the take-home form. (A third group responds to the take-home but not to the on-board form. Because most needed information is on the take-home form, this group need not be considered as a nonrespondent group.) The design provides no information on the first group but does provide data on the second. An analysis of the characteristics of those returning the on-board form compared with those who return the take-home form should reveal whether or not certain population groups or certain types of bus riders are under- or over-represented in the take-home responses. A bias correction can then be computed in the form of a reweighting of the data to conform with the response pattern of the on-board form. If no differences are found between the two groups, then a nonresponse bias would not be apparent. Although this procedure provides no evidence that a nonresponse bias does not exist for those who respond to neither form, it does seem to suggest that there might need to be less concern for that.

To reduce nonresponse, a three-step follow-up procedure should be included as part of the monitoring strategy. This follow-up involves a postcard reminder to respondents to the on-board form who provided addresses but who had not returned the take-home form 7-10 days after receiving the survey instrument. Seven to 10 days after that, a letter reminder with another copy of the take-home survey form would be sent. Finally, if warranted by the responses to the two previous reminders, a third postcard reminder would be sent after a further 7-10 days. This follow-up procedure should serve to reduce the magnitude of the nonresponse to the take-home portion of the survey and thereby reduce the potential biases.

As an additional mechanism to increase response, the return address can be used to generate an incentive that is mailed to those who provide their address. The most effective incentive is a pass that entitles the holder to some small number of free rides on the bus. As with any use of an incentive in a survey, care is required to select an incentive that is large enough to be effective but not large enough to bias the responses (6). An effective incentive on most transit systems would be a free pass for a week or something of similar value. This is large enough to encourage response, but is not likely to cause a significant bias in the response nor to give rise to serious attempts at forgery or the development of black markets.

Recording Information on Bus Operations and Passenger Volumes

Some information should also be collected by the survey workers. Such information includes readings of revenue and transfer meters (if these are installed on fare-collection devices), the time the bus departs from important intersections or timing points, passenger volumes, and number of riders who refuse to take the forms. Information is also required on any abnormality that occurs on the bus trip (e.g., a traffic accident or a breakdown of the surveyed bus). Other information could be asked of the respondents but is collected more accurately by a survey worker. This includes the time and location at which each passenger boards the bus. Also, not having to ask these questions on the survey form helps to shorten the form.

Thus, a log sheet has been designed to be completed by the survey worker. At locations spaced approximately one mile or more apart, survey workers record the time of day, the number of passengers on the bus at that location, and the identification number of the next form to be distributed after leaving the location. This last data item depends on the use of prenumbered forms that are handed out in strict sequence. The control and traceability offered by sequential distribution of prenumbered forms are a significant advantage that makes the small cost of this well worthwhile. Given this prenumbering, it is then possible to reconstruct approximately when and where (within one mile or so) each form was handed out. Although the recording of such information at shorter intervals would be beneficial, it will make it exceedingly difficult for survey personnel to perform all their tasks (distribution and collection of forms and pencils and the answering of questions from passengers) and fill out the log sheets at closer intervals.

From the log sheets it becomes possible to compute such information as systemwide and route-by-route passenger volumes, maximum load factors and location of maximum load points, time-of-day distribution of ridership for the system and for each route, and schedule adherence.

Sampling Design

The basic sampling unit is the bus rider. The annual ridership of the bus system is the universe being sampled for a rider survey of the type envisaged here, whether the survey is for surveillance or for monitoring. For most transit properties, this universe will be large enough that the population can be considered infinite for sampling purposes and corrections for finite populations or large sampling rates are not necessary in computing sampling error.

Given that the survey design requires distribution of a survey instrument to bus riders, a simple random sample of bus riders from the entire system on a given day would be inefficient and unduly expensive. Given the idea of an intercept survey, it makes far more sense to survey passengers on a bus trip and use at least a two-stage sampling procedure. In fact, given the mode of operation of most bus systems, the ideal procedure is the three-stage sample described in this section.

There are two primary modes of operation of a bus system and these affect the sampling method to some degree. One type of operation is based on extensive interlining of each vehicle, so that a bus will operate consecutively as two or more routes and will repeat this pattern throughout much of the day. The other type of operation uses almost no interlining, so that a specific vehicle is allocated to a route on leaving the garage and remains as that route for the entire day. The second operational mode is the one most amenable to the sampling design of an on-board survey, because a surveyor can be assigned to ride a specific vehicle and that assignment represents a sample from the route operated by that vehicle.

The initial sampling unit is the bus route. For monitoring, this is likely to be a purposeful, as opposed to random, sample of certain routes for which monitoring is needed, either to track the effects of route changes or to provide more data about a route on which changes appear to be warranted. For surveillance, this is a random sample, although the sample may, in certain cases, be designed to cover all routes.

The second stage of the sampling is to select a specific component of the scheduled operation of each route selected in the first stage. This is where the operational procedures of the system affect the form of the sampling. In any system there will usually exist a vehicle schedule that is organized differently from the published schedules and identifies what a given vehicle (and driver) will do from the time it leaves the garage until it returns at the end of its scheduled day. During this period, the vehicle may be driven by more than one driver, which is immaterial to the sampling, and may operate on more than one route, which is of primary concern to the sampling. The vehicle schedule will also include details of the deadhead runs required for the vehicle's operation and these details are needed to plan efficient allocation of survey personnel for an on-board survey.

For ease of explaining the stages in the sampling procedure, it is assumed that each vehicle in the schedule is assigned a unique identification number (as distinct from the bus number that identifies and is painted on the vehicle itself). On an interlined system, this might mean that three routes are interlined for daily operation and require seven vehicles to operate the timetabled headways of those three routes. Each of these seven vehicles is identified as a run number. In a base-vehicle system, the base vehicles on each route are assigned run numbers that provide an identical unique identification for each element of operation of the timetable. Unique identifiers are also assumed to exist for either operation for trippers, and these will usually be specific to a route in both systems, although the vehicle may interline.

For each route selected in the first-stage sample, the number of runs of that route is identified next and is kept separate between base vehicle runs and trippers. The second stage of the sampling consists of drawing a predetermined number of these base runs and trippers at random for each route in the sample. In the interlined system this selection will probably identify most or all of the individual vehicles that operate on the sampled route, and it will be necessary to build surveyor schedules that will have the surveyors transferring between buses from time to time. In the base-vehicle operation, the second-stage sampling identifies a vehicle that the survey personnel will ride all day, thus simplifying the design and administration of the survey considerably.

The third-stage sampling consists of the drawing of days for the sampled routes and runs. Ideally, this should be done on a random basis within a quota sampling scheme that produces an even distribution of the sample over the days of the week. It is desirable that, in those cases where both a tripper and a base vehicle have been sampled for a given route, a bus run and a tripper from a route are allocated the same survey day. This is particularly important when transit operations are subject to frequent minor aberrations in service delivery, such as last-minute cancellations of trippers or base vehicles and other departures from the printed schedule. Such aberrations tend to have significant impacts on the other base and tripper runs of the affected route and to distort the representativeness of the sample.

In the sampling procedure proposed here, all passengers on the sampled runs are to be included in the survey, subject to exceptions described below. Thus, the three-stage sampling technique selects the routes, the specific runs (base and tripper), and the day or days of the week for the survey and thereby identifies the sample of passengers to be surveyed. The exceptions, for a self-administered survey of this type, would generally be children under the age of 12, who would be unlikely to be able to complete the survey competently. In addition, it is usually appropriate to give the surveyor discretion about including groups of schoolchildren between the ages of 12 and 16, based on the group mood and the expectation that forms will be taken seriously and genuine attempts made to complete them.

Sample Size

Remember in determining sample size, although the measurement unit is a bus-rider trip, many fewer distinct individuals ride the bus than there are bus-rider trips. Most individuals make at least two trips per day (to and from work or shopping), for several days per week, for most of the year. Generally, individuals do not like to be subjected to repeated surveys. Therefore, the pool of riders is much smaller than the daily volume of bus-rider trips.

The determination of the required sample size is derived from the desired accuracy of the data and a knowledge of the population variance of the critical measures for the survey. This is the case for both surveillance and monitoring.

For surveillance, by using the formula for the sampling error from a simple random sample (which understates slightly the error of a multistage sample), the desired sample size is given by

$$n = (\text{standard deviation of } Y)^2/(\text{required sampling error of } Y)^2 \qquad (1)$$

where n is the desired sample size and Y is the critical variable for the sample design.

A useful example of the application of this formula is provided by the Dade County, Florida, Metrobus system. On the 1978 Metrobus system, an average of 3.2 base vehicles and 1.2 trippers were assigned to each route. The average time of a one-way bus trip (i.e., from the origin point of a bus route to the destination point, in one primary direction) was 90 min. In 1978, an average of 211 000 passengers/day were carried on about 96 separately numbered routes. An average of 270 passenger miles were made per bus trip and the average route operated about 18 h/weekday. Most routes operated on Saturdays and about half on Sundays.

By using the figures noted above, an order-of-magnitude estimate can be made of the desired sample size, given a specified level of required accuracy. Suppose that passenger mileage is the critical variable on which the survey is designed and that the desire is to achieve a level of accuracy of ±10 percent with 95 percent confidence for each route. Suppose that, for the mean of 270 passenger miles/trip, the standard deviation is ±75 passenger miles. A 10 percent accuracy level is 27 passenger miles and requires a sampling error of

$$\text{Required sampling error} = 27/1.96 = 13.78 \qquad (2)$$

By applying the formula for determining the sample size for a simple random sample, shown in Equation 1, the required sample size is about 30 vehicle trips/year per route, or about 2.5 bus runs/year per route (each bus run comprises about 12 trips) as shown in Equation 3.

$$n = (75)^2/(13.78)^2 = 29.6 \text{ vehicle trips} \quad (3)$$

For convenience, a sample of two bus runs per route per year (about 24 vehicle trips) may be selected. By using the same equation, this would provide an accuracy of ±11.1 percent with 95 percent confidence ($\pm 1.96 \times 75/\sqrt{24}$). Until data accrue to permit more accurate computation from Equation 1, this would be the recommended sample size.

Similarly, for any variable measured by the rider survey, a level of accuracy can be calculated from Equation 4.

$$\text{Percentage sampling error} = \text{percentage standard deviation of a unit}/n \quad (4)$$

For example, suppose a measure of interest has a percentage standard deviation of ±50 and the sample size is 500 passengers (the average ridership per bus run), the percentage sampling error is ±4.5 percent with 95 percent confidence--a very adequate measurement accuracy.

The key issue in monitoring is to be able to detect significant changes between the before and after periods. As a result, the relevant sample sizes (n) would be obtained from Equation 5 for the mean of a continuous variable (such as passenger miles) or from Equation 6 for a dichotomous variable (such as percentage of handicapped persons riding the route) (2).

$$n = [(s^2_1 + s^2_2)/\text{s.e.}\,(\bar{y}_1 - \bar{y}_2)]^2 \quad (5)$$

$$n = [(p_1q_1 + p_2q_2)/\text{s.e.}\,(p_1 - p_2)]^2 \quad (6)$$

where

n = required sample size,
s_1, s_2 = standard deviations of y before and after the change,
$\bar{y}_1, \bar{y}_2$ = means of y before and after the change,
p_1, p_2 = probability of finding a characteristic before or after,
$q_1 = 1 - p_1$, and
$q_2 = 1 - p_2$.

The sample size is assumed to be the same on each occasion.

Again, an example is useful to demonstrate the implications of these equations. Suppose one considers reported waiting time as a variable to be measured to within ±1 min for a change in system operation, at a 95 percent confidence level. Suppose the standard deviation is now known to be ±6 min and that this will be halved by system improvement. The number of samples (n) that will be required in each of the before and after surveys is then 173.

Given the accuracy considerations for detecting significant change and the problem of attempting to survey the same individuals more than once, the monitoring samples could be selected as follows: In a system with base vehicles and trippers, for a route that has more than three base vehicles allocated, one bus run should be selected at random for each weekday to yield a sample of five bus runs for the route. Note that, for a route with four base vehicles, one run would be surveyed twice by using this procedure. For routes that have five base vehicles or more, runs are selected randomly and repeats of a run will occur relatively infrequently. For routes with three or fewer base vehicles, three different weekdays would be selected at random and one run selected randomly for each of the selected weekdays. The weekdays should be ordered randomly and preferably should be scheduled within one calendar month for each of the before and the after surveys.

A final consideration in sample size concerns the rate of sampling bus riders. The sampling errors indicate that sampling one in two or one in three bus riders normally would be adequate. However, a number of potential disadvantages to such a procedure exists. First, it would have to be left to the on-board survey person to select passengers to receive forms. The obvious problem is that there is no way to know if the surveyor is following the rules about handing out the forms. Second, a potential public-relations problem is created if some riders receive surveys and others do not, particularly if there exists a free pass or some similar survey incentive. Third, if response rates are lower than expected, sampling errors will be higher than desired. Because the cost of printing the forms is trivial compared with the costs of the logistics of performing an on-board survey and the cost of labor, it is logical to distribute forms to all passengers to minimize the possibility of a low response rate. To avoid these problems, all riders should be given survey forms.

Thus, based on certain assumptions about standard deviations and critical variables, sample sizes for the surveillance and monitoring activities can be defined. Note that the accuracy of the surveillance activity exceeds that required by the Urban Mass Transportation Administration (UMTA) (7) but at a lower survey effort than UMTA recommends.

Given this rather small sampling requirement, selection of the time of the year for the surveys is important. Many bus systems have a specific time in the year when route changes are made (as infrequently as once a year, but more often two to four times a year) and these will dictate when the monitoring surveys take place. In general, the before survey should be done one or two months before the changes will go into effect. Depending on how many routes are to be monitored and the survey team that it is planned to maintain, these surveys may take one to three months to execute. The after survey should be done about 6 months after the changes were effected or 1 month before the next set of system changes is scheduled, whichever is sooner. Conventional wisdom maintains that 6 months are needed for a steady state to be achieved after a change is made, although intervention of other system changes may make it impossible to determine what system changes caused what passenger reactions. We have no reason to question the conventional wisdom, and the timing of the after survey is based on acceptance of this.

For surveillance, the scheduling during the year of the survey activity is an important issue because not only do seasonal changes in patronage exist but also there are probably seasonal variations in the various measures of concern. Two alternative strategies can be considered. The first involves increasing the sample size and surveying each route on several occasions throughout the year, thereby obtaining some information on seasonal variations, but at a considerably higher cost. By using available historic information, the second strategy for surveillance appears preferable, where this involves selection of two occasions during the year. In this case, again, surveying should not take place in the month in which system changes are made, because of the instability these changes may cause, not to mention the potential public-relations problems of such timing.

Once experience has accumulated on route differences, some modification may be needed for routes that have low ridership, as the sample generated may be too small to permit sufficiently accurate data to be obtained. The day of the week and the bus run should each be chosen at random for each route. A quota sample should be used for days of the week to ensure an equal representation of each weekday to provide data on the day-by-day variations in systemwide operations and to facilitate the logistics of scheduling survey workers. A simple random sample of weekdays can lead to an inordinate number of bus runs being scheduled on one weekday.

In conclusion, the careful application of sampling theory and the use of prior information on the variance of measures of importance can be used to produce small samples that meet requirements of measurement accuracy. Furthermore, the institution of a regular surveillance and monitoring program will itself reduce sample requirements as regular updates to the data base are produced and the accuracy of existing information is progressively enhanced. This argues against the common practice of occasional surveys, often years apart, that use instruments or questions that differ so markedly that updating is not possible.

SOME ILLUSTRATIVE CASES

Some extracts from three recent surveys are useful to illustrate some of the points in this paper. First, a survey of the type described here was undertaken in Washtenaw County in southern Michigan (8). This involved an on-board survey form in two parts--a card to be completed and returned on board the bus and a longer form to be taken away and mailed back. The on-board survey form was returned by 88 percent of the passengers who were handed a form, and 44 percent of these passengers (38 percent of the total number of passengers who were handed forms) returned the mail survey. Both of these response rates are higher than those that would normally be expected, even though no incentive was used. The surveys collected information that is of the order of the specifications given in this paper for the monitoring activity. From a comparison of the two forms, the extent to which the mail-back survey was biased was established by its lower response (9), and it was found that relatively little bias was present on the basis of questions asked on both forms. No comparison of the two-part survey with a mail-back only was made in the study, but both response rates compare favorably with other mail and on-board surveys.

A second example is provided from an on-board survey conducted for the Dade County Transportation Administration on the Metrobus system (10). This survey was carried out on a sample of bus routes in early fall 1980, having been postponed by four months because of the civil disturbances in Miami in May 1980. (The outbreak began the night before the on-board bus survey was to have started; no connection between these two events has been established.) Two problems of some magnitude affected this survey and reduced the performance of the instruments. First, the survey instruments were produced in both Spanish and English. Although people were offered either form, it was apparent in both the pretest and the main survey that many Spanish-speaking people opted to take an English form. It is not known to what extent this might have reduced the response rate, but the response from the Spanish-language forms was well below that from the English forms. Also, the Spanish-speaking population of Miami appears to have different community goals and loyalties and it was found to be very difficult to motivate this group to respond to the survey. Inducements to cooperate that worked on the English-speaking population were not effective on the Spanish-speaking population, judging from the difference in response rates. Second, a number of Haitians and illegal immigrants use Dade County buses. Given that many of the Haitians speak only Haitian French and that survey forms were not provided in their language, this group probably did not respond to the survey. Clearly, illegal immigrants would not complete and return surveys because they would have an expectation that this would be a means by which they could be traced.

Despite these problems, of a total of some 58 000 forms handed out in a six-week intensive survey, a little more than 13 000 (22.4 percent) of the on-board forms were returned and a little more than 9000 (16 percent) of the mail-back forms were sent back. Again, the responses from the 13 000 were used to determine the degree to which biases existed and could be corrected for in the 9000, and several bias adjustments were made (11). Although most of the adjustments were small, one group (males aged 45-54) were missing completely from the mail-back survey but not from the on-board survey; this was determined from comparing the two response sets. Also note that the on-board survey form covered both sides of a legal-size sheet of card, and that the mail-back form was a six-page questionnaire, printed on sheets midway between legal and letter size.

The third example is a recently completed on-board bus survey in Honolulu, Hawaii (12), conducted for the Oahu Metropolitan Planning Organization. In this case, the survey was only an on-board survey, of the type described in this paper for the surveillance activity. The survey form again covered both sides of a legal-size card. The bottom of the second side consisted of a reply-paid panel for return of the survey form by mail, for those unable to complete it on the bus. A total of 4928 forms were distributed and 58 percent of these (2815) were returned. No incentive was offered for completion of the survey forms, and it is estimated that a reasonable incentive, such as the bus passes used in Dade County, could have boosted the response to as much as 75-80 percent. Of the 58 percent response, 45 percent came back off the bus and 13 percent by mail. A problem that is likely to have decreased the response rate is that the Hololulu buses travel fully loaded in the peak hours. The surveyors counted loads of around 100 passengers on most peak-hour trips (on standard 49-seat buses) and one bus had around 120 passengers. Drivers assured the survey team that these were normal and expected loads. Notable in this instance is that, although the survey purpose was different from the other two (to supplement data for travel-forecasting calibration) and a system profile was not the primary motivation, this sample of 2815 returned forms provides a statistically sound description of one-third of the system's routes.

CONCLUSIONS

The issues addressed by this paper involve the design of an efficient and cost-effective measurement procedure for a bus operation that will allow system changes to be monitored and will provide annual data on systemwide operation (surveillance) for both federal and state reporting requirements as well as statistically sound data on the patronage of the system and responses of riders to system changes. Four elements of the problem are addressed: data needs, survey mechanisms, sampling procedure, and sample sizes. Monitoring and surveillance each require different measurements and sample sizes but are otherwise similar in design.

The recommended procedure is a mix of observation and participation, whereby survey personnel ride sampled buses, note various items of information on bus operation (passenger loads and times at various locations), and distribute self-administered survey forms to all passengers. For surveillance, where data needs are less extensive, the survey form can be restricted to one sheet of light card stock that can be completed by most passengers before disembarking. However, a mail-return capability is essential to this survey because otherwise the survey will be biased against those who make very short trips, those who travel on very crowded peak-hour buses, and the riders who have poor vision or other problems that make completion of the form on the bus difficult or impossible. For monitoring, a two-part survey form is recommended. The first part can be the same as the surveillance form. The second part is designed to be taken home and mailed back. To permit follow-up and tracking of nonresponse bias on the take-home form, the respondent's home address should be requested on the on-board form and a system used that allows the returned take-home and on-board forms to be matched up.

Principally, this paper has put forward a design of survey instruments that provides collection of much more data than would usually be obtained in an on-board survey, but, based on the case studies noted here, without loss of response. Second, the paper has described means of tracking part of the nonresponse and determining the extent to which the responses from a self-administered survey of this type should be weighted to correct for nonresponse bias.

The paper has provided details on the computation of sample sizes that yield significantly smaller samples that are statistically adequate. In developing this design into an annual activity for Dade County, Florida, it was estimated that a full surveillance and monitoring activity for this 99-route system with a bus fleet of nearly 700 buses (daily ridership on the order of 225 000 rides) would require 1050 surveyor-days of weekdays per year and 400 surveyor-days of weekends. By careful scheduling of the survey activities, this translates into 6-8 survey workers, working for eight months of the year in two four-month periods. The interviewers can be used in the remaining four months to assist in data processing, thereby permitting their retention as a permanent work force.

With the possibility of minor modifications to the sampling rates based on actual measured standard deviations, the sampling rates described should provide data of adequate accuracy for the required measurements. Furthermore, the basis for generating the sample here should be readily applicable to other transit properties.

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