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Contents

Field Data Collection and Sampling Procedures for Measuring Regional Vehicle Classification and Occupancy

Robert A. Ferlis, Peat, Marwick, Mitchell and Company, Washington, D.C.

Small-scale field survey procedures that can be used to measure vehicle classification and occupancy at predetermined levels of statistical precision are described. Potential uses of these data to support activities related to transportation system management, air quality, energy efficiency, validation of urban transportation planning models, and trend analysis are identified. Statistical sampling plans, including plans that use the results of parallel traffic-monitoring programs, are presented to enable local planning agencies to design cost-effective field surveys. Representative values for key sampling parameters based on previous surveys, which are needed to use these sampling techniques, are provided. These procedures are then applied to a problem of survey design that demonstrates that regional occupancy can be precisely measured through the use of a small field survey.

The growing need to get greater service and efficiency from the highway transportation system is leading urban transportation planning agencies to make a greater effort to monitor travel trends and to measure the impacts of policies and programs at the regional level. Vehicle classification and vehicle occupancy are increasingly being recognized as two key elements of an effective program to monitor urban travel (1).

Planning agencies and highway departments have typically conducted field surveys to measure vehicle classification and occupancy only on an occasional basis and to satisfy very specific needs. These studies have generally been extremely limited in scope because of the high personnel costs involved. Locations for data collection have usually been selected to address a specific need for information at one point or, more rarely, have been judgmentally selected as representative of particular geographic areas or highway types. These limited studies do not provide the kind of information that permits the development of valid regional estimates of vehicle classification and occupancy.

This paper presents a series of simple field survey procedures that can provide statistically valid estimates of vehicle classification and occupancy and derived travel measures at prespecified levels of precision. These survey designs are based on the random selection of locations and times at which data collection is performed. The specific objectives of this paper are to

1. Suggest possible uses for four regional travel-monitoring measures that can be estimated from field data: percentage of truck travel (TR), average occupancy of passenger vehicles (OCC), truck kilometers of travel (TRKT), and person kilometers of travel (PKT);
2. Present statistically sound sampling procedures to guide data collection in the field so that these measures can be economically estimated at preselected levels of precision; and
3. Illustrate how these procedures can be applied to provide useful travel-monitoring information at a relatively low cost.

DESIGN OF TRAFFIC-BASED MONITORING PROGRAM

Although a comprehensive program to monitor urban travel should encompass a wide range of measures at both the regional and local levels, this discussion is directed only toward regional measures that can be estimated on the basis of limited field surveys. These field surveys will therefore complement the relatively more extensive traffic-counting programs that agencies typically conduct with the aid of mechanical counters. Before a field survey program can be implemented, local agencies should identify their basic data needs and translate these needs into specific survey objectives.

Identifying Needs for Monitoring Data

Data on vehicle classification and occupancy and on truck and person travel can potentially be applied to five major categories of need: (a) evaluating the effectiveness of transportation system management (TSM) actions, (b) assessing changes in air quality indices in relation to travel, (c) monitoring the energy efficiency of travel, (d) validating urban transportation planning models, and (e) monitoring general trends in transportation characteristics. The following table gives a summary of the extent to which each monitoring measure is applicable to these five areas (XX = very useful and X = moderately useful):

Application	Percentage Trucks	Average Occupancy	Truck Travel	Person Travel
TSM actions		XX		XX
Air quality		X	XX	X
Energy efficiency		X	XX	X
Model validation		X	XX	XX
Trend analysis	X	XX	XX	XX

Although many TSM actions are directed toward alleviating extremely localized problems, the overall effectiveness of the TSM program can be assessed by measuring regional vehicle occupancy and person travel on an annual basis and by using this information to determine progress toward achieving more efficient patterns of vehicle use. These annual measurements must be very precise if small impacts are to be reliably discerned.

Current patterns and annual trends in transportation-related air quality can also be assessed by using traffic-based measures. The magnitude and distribution of travel by vehicle class can be combined with emissions factors for representative vehicle classes to provide a quantitative estimate of regional transportation-related air quality on a periodic basis. An unusually detailed scheme of vehicle classification that includes breakdowns by size of vehicle and engine type (gasoline versus diesel) may be needed to provide accurate estimates of air quality. In addition, supplementary data, such as the number of cold starts, are required. By using these relatively simple procedures for estimating air quality, local agencies can anticipate future problems with air quality that may result from increasing travel and assess the efficacy of possible actions to reduce travel. Parallel measures of vehicle occupancy and person travel are mainly useful for computing air quality indices weighted by person travel rather than simply by vehicle travel.

Similarly, periodic estimates of regional travel by type of vehicle can support local studies of the energy efficiency of transportation and of changes over time. Again, the usefulness of travel data for this purpose will depend on the availability of factors that can convert travel by vehicle type into regional estimates of energy consumption. Occupancy and person-travel estimates will again be useful primarily for computing indicators of energy consumption based on person rather than vehicle movements.

Traffic-based monitoring data can also be used to validate the continuing adequacy of transportation planning models at the regional level. Major discrepancies between current-year model replications and monitoring estimates of total vehicle, truck, and person travel could indicate a need for updated input data or calibration parameters.

In addition to the specific uses cited above, traffic-based monitoring data can also serve as an important element of the urban transportation surveillance program. By periodically examining average vehicle occupancy, percentage of trucks, travel by vehicle class, and person travel, local agencies can identify emerging trends in transportation use that can be addressed through policy formation and planning at the regional, state, and federal levels. These might include the impacts of increases in fuel prices, restrictions on fuel consumption, weight restrictions on commercial vehicles, changes in speed limits, and the response of the motorist to measures designed to reduce unnecessary travel in urban areas.

Defining Survey Objectives and Approach

After carefully reviewing their needs for traffic-based monitoring data, agencies should translate these needs into a series of specific survey objectives. This process consists of three major steps:

1. Select the most important measure or measures. These measures will control the sampling plan.
2. Define the survey population. The population should be defined in terms of geographic scope, type of highway, time of day, day of week, and seasonal coverage.
3. Specify the desired level of precision for each of these measures. Level of precision can be defined here as the combination of two parameters: tolerance level D, which represents the acceptable difference between the estimated measure and the true value, and level of significance α, which represents the probability that the sample estimate will fall outside this range.

For example, an agency that desires to monitor average vehicle occupancy on a yearly basis could decide to estimate this measure for (a) all streets and highways within the standard metropolitan statistical area (SMSA), (b) the period from 7:00 a.m. to 7:00 p.m. on nonholiday weekdays only, and (c) the months of June through August. The agency could also specify a desired tolerance level of ± 2 percent with an associated 5 percent level of significance. That is, the chance that the estimate of average occupancy will differ from the true value by more than 2 percent is only 1 in 20.

The technique for sampling and data collection can then be specified. The sampling procedures described in this paper were designed under four main assumptions:

1. All street and highway sections have an equal probability of being selected in the sample. This can be achieved by dividing the network into a set of "links" of uniform length for sampling purposes.
2. All days within the period of coverage have an equal probability of being selected in the sample. If the chance of selecting a holiday is felt to bias the sample, holidays should be explicitly excluded from the original population of days.
3. The sampling units of "link days" are randomly selected by using random numbers or similar techniques. The initial selection is not altered in an attempt to provide a more representative sample or to simplify the process of data collection.
4. If data collection is not conducted continuously throughout the selected link days, a systematic short-count technique is used to prevent bias and to maximize precision.

Since vehicle classification, vehicle occupancy, and traffic volume typically vary substantially during the day, a systematic short-count procedure in which observations are made for a fixed interval during each hour of the day offers the best potential for producing relatively accurate daily estimates while conserving personnel resources. In some urban situations, a single crew could conceivably collect data at several locations simultaneously by shifting from one site to the next on a fixed schedule so that each site is visited once an hour. A more likely approach, however, is for one person to systematically monitor one location by observing only a sample of lanes at any one time. For example, each lane on a three-lane, high-volume arterial could be observed for the same 15-min interval in each hour, and the fourth interval could be a rest period. This approach would produce a relatively accurate estimate of vehicle classification and occupancy while eliminating the need for a two-person crew.

SAMPLE SIZE FOR REGIONAL SURVEYS

The survey objectives and approach can now be translated into a sampling plan by computing the sample size of the link days needed to achieve the desired level of precision for each of the selected measures. As the formulas for sample size will show, the sample size is a function of level of precision and estimated sample variance. If an agency cannot accurately predict the sample variance that will be computed from the survey results, the estimate of the measure will still be valid but the level of precision may be either higher or lower than desired.

If more than one measure is felt to be important, the measure that requires the larger sample size controls the sampling plan. Although it is useful to specify concrete survey objectives before designing the sampling plan, an agency should also review the implications of the resulting plan in terms of sample size and survey cost. In some cases, an agency may choose to compromise its objectives to save costs.

As discussed earlier, these sampling formulas are designed for simple regional surveys that are appropriate for most traffic-monitoring needs. Agencies that wish to use relatively more complex stratified sampling plans, either to provide estimates for particular subsamples of the population or to reduce overall survey costs, will have to use more complicated sample-size formulas (2).

Percentage of Trucks

The first traffic-based monitoring measure that will be considered is percentage of trucks or, more conveniently, proportion of trucks, which represents a single regional ratio of truck travel to total vehicle travel. An agency should carefully define "truck" to meet the particular needs of the survey. The following procedure is directed toward a simple definition of the truck as a vehicle with double tires on at least one axle. The number of link days of data collection that would be needed to reliably estimate the proportion of trucks within a tolerance DTR at an α level of significance can be computed as

$$N = (Z^2 * ST^2)/DTR^2 \quad (1)$$

where

Z = normal variate for the $(1 - \alpha)$ level of confidence (two-tailed test),
ST = composite standard deviation of the proportion of trucks, and
DTR = acceptable difference between the estimated proportion of trucks and the true value.

This formula assumes that the ratio of sampled link days to total possible link days is so small that the finite population correction factor need not be considered. The composite standard deviation depends on the design objectives and the approach of the survey. It can be estimated as

$$ST = (STL^2 + STS^2 + STW^2)^{1/2} \quad (2)$$

where

STL = standard deviation of the proportion of trucks across link days within a season,
STS = standard deviation of the proportion of trucks across seasons, and
STW = standard deviation of the proportion of trucks across time periods during a day as a result of short counts.

The term for seasonal variation (STS) should only be included if the survey is intended to measure truck travel over an entire year and data collection will therefore extend throughout that period. If, on the other hand, data collection will be concentrated in a single season or in a period for which truck travel is not expected to vary significantly, this component should not be included in the computation of the composite standard deviation.

In the same way, the term for within-day variation (STW) should only be included if a short-count approach to data collection will be used. If all vehicles that pass a station during the selected link day will be observed by the data collectors, this term should not be included in the computation of the composite standard deviation.

Before local agencies can compute the minimum sample size, they must first estimate the composite standard deviation. The results of previous surveys should be used if they are available. Agencies that have not conducted such surveys should judgmentally estimate these variance terms. Table 1 gives representative values derived from surveys conducted in several urban areas. The seasonal standard deviation may be somewhat greater than what can be expected in most cities. The within-day standard deviation represents a systematic 25 percent sample of time periods within the day. These "default" values should be replaced by measured values after the first year. The key STL parameter should be replaced in all cases, but other terms should be replaced only if they can be estimated from either the survey results or special studies.

The relation among composite standard deviation, tolerance level, and resulting sample size at an assumed 95 percent confidence level is shown in Figure 1. If the composite standard deviation is estimated to be 0.045, a sample of approximately 20 link days will be required to estimate the proportion of trucks within ±0.02. If a considerably more precise estimate of the percentage of trucks is needed, a more complicated stratified sampling plan can be used instead of a simple survey to reduce survey costs (2).

Average Occupancy

A regional measure of average occupancy will probably be of considerably more interest to most agencies than the percentage (or proportion) of trucks. The sample size of link days needed to estimate average occupancy within a tolerance DOCC and a level of significance α can be computed as

$$N = (Z^2 * SO^2)/DOCC^2 \quad (3)$$

where DOCC = acceptable difference between the estimated average occupancy and the true value and SO = composite standard deviation of average occupancy.

The composite standard deviation will again depend on the design objectives and the approach of the survey. The composite standard deviation can be estimated as

$$SO = (SOL^2 + SOS^2 + SOW^2)^{1/2} \quad (4)$$

where

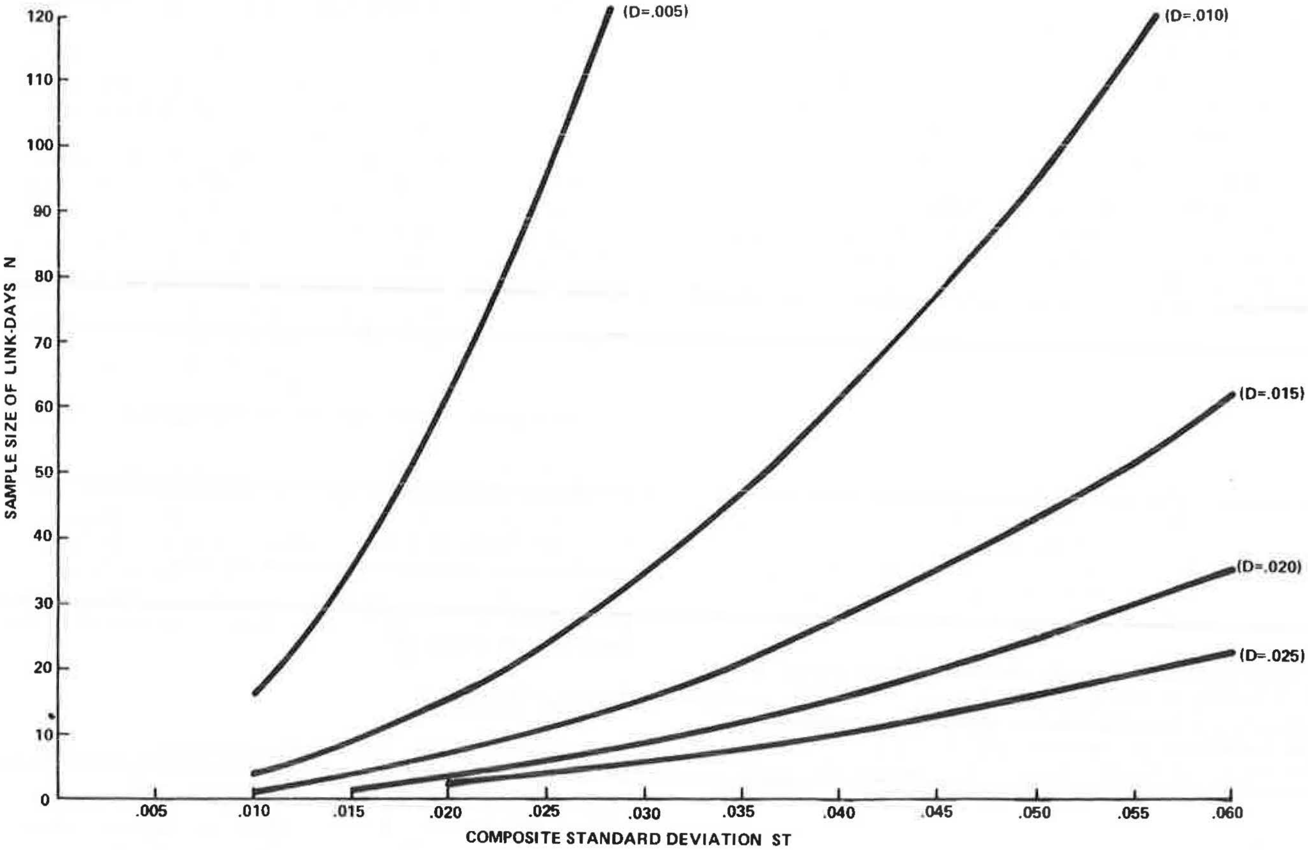
SOL = standard deviation of average occupancy across link days within a season,
SOS = standard deviation of average occupancy across seasons, and
SOW = standard deviation of average occupancy across time periods during a day as a result of short counts.

As in the case of the proportion of trucks, these terms should only be included if they are appropriate.

Table 1. Standard deviations for percentage trucks and average occupancy.

Measure	Source of Variation	Symbol	Value	City
Percentage trucks	Location and day	STL	0.021-0.054	Washington, DC; Kileen-Temple, TX
	Season	STS	0.014	Various Ohio cities
	Within day	STW	0.009	Washington, DC
Average occupancy	Location and day	SOL	0.057-0.069	Kileen-Temple, TX; Seattle
	Season	SOS	0.011-0.019	Minneapolis, Albany
	Within day	SOW	0.012-0.022	Seattle; Washington, DC

Figure 1. Sample sizes for estimating regional percentage trucks within tolerance D at 95 percent confidence.



The results of previous local surveys should ideally be used to estimate these terms. Representative ranges of the standard deviation terms for average occupancy are also given in Table 1. Again, these values should be replaced by actual variances after the initial survey is completed, both to assess the level of precision actually achieved and to compute sample size for future surveys of occupancy.

The relation among composite standard deviation, tolerance level, and sample size at the 95 percent confidence level for average occupancy is shown in Figure 2. An assumed composite standard deviation of 0.067 based on the default recommendations would provide an estimate of average occupancy within ±0.03 with a sample of 20 link days. Thus, if the survey results show that the estimate of the composite standard deviation is accurate and the estimated average occupancy is 1.45, the probability that the true regional occupancy is between 1.42 and 1.48 is 95 percent.

Truck Travel

Truck kilometers of travel (TRKT) can be developed directly from a series of field counts. But a more economical approach for urbanized areas, which measures total vehicle kilometers of travel through extensive mechanical traffic-counting programs, is to combine the estimate of vehicle kilometers with an estimate of the proportion of trucks derived from a relatively more limited program of field data collection. The number of link days of field data collection needed to estimate TRKT within a relative tolerance ETRKT with an α level of significance can be computed as

$$N = (Z^2 * ST^2)/(ETRKT^2 - EVKT^2) * TR^2 \quad (5)$$

where

ETRKT = acceptable relative error between the estimated TRKT and the true value,
EVKT = computed relative error between the estimated vehicle kilometers of travel and the true value based on the recent survey, and
TR = estimated regional proportion of truck travel.

The definitions of Z and ST are the same as before. In contrast with previous sample-size formulas, the tolerance levels are expressed in relative rather than in absolute terms—as proportions of total travel. The precision of the estimated TRKT can approach but never equal the precision of the estimated vehicle kilometers of travel from the recent study.

Person Travel

Person travel in person kilometers can also be estimated by combining the results of a limited field survey with a recent estimate of vehicle kilometers. Since the estimate of person kilometers of travel incorporates the effects of three separate variables (i.e., average occupancy, proportion of automobile travel, and total vehicle travel), a relatively more complex formula is required. The number of link days of data collection needed to estimate person kilometers of travel within a relative tolerance EPKT with an α level of significance can be computed as

$$N = [Z^2 * (PV^2 * SO^2 + OCC * ST^2)]/(EPKT^2 - EVKT^2) * (OCC * PV)^2 \quad (6)$$

where

PV = estimated proportion of passenger-vehicle travel (assumed to be equal to 1 - TR),
OCC = estimated average vehicle occupancy for passenger vehicles, and
EPKT = acceptable relative error between the estimated person kilometers of travel and the true value.

This formula assumes that the proportion of vehicles that are neither passenger vehicles nor trucks is insignificant. Therefore, the composite standard deviation for the proportion of trucks is used to estimate the composite standard deviation of the proportion of passenger vehicles.

APPLICATIONS OF THE SAMPLING FORMULAS

Consider a planning agency that wants to conduct a limited field survey to meet the following specific objectives:

1. Estimate regional average occupancy during the fall within a tolerance level of ±0.02 with a 95 percent level of confidence. This measurement will be repeated in subsequent years to assess the progress of the comprehensive TSM program.
2. Estimate regional person travel produced by private passenger vehicles within a relative tolerance level of ±5 percent with a 95 percent level of confidence. This measurement is desired for long-range trend analysis.
3. Estimate regional truck travel to validate certain aspects of the results of the urban transportation planning model, which will be used to assess air quality. No specific level of precision is required.

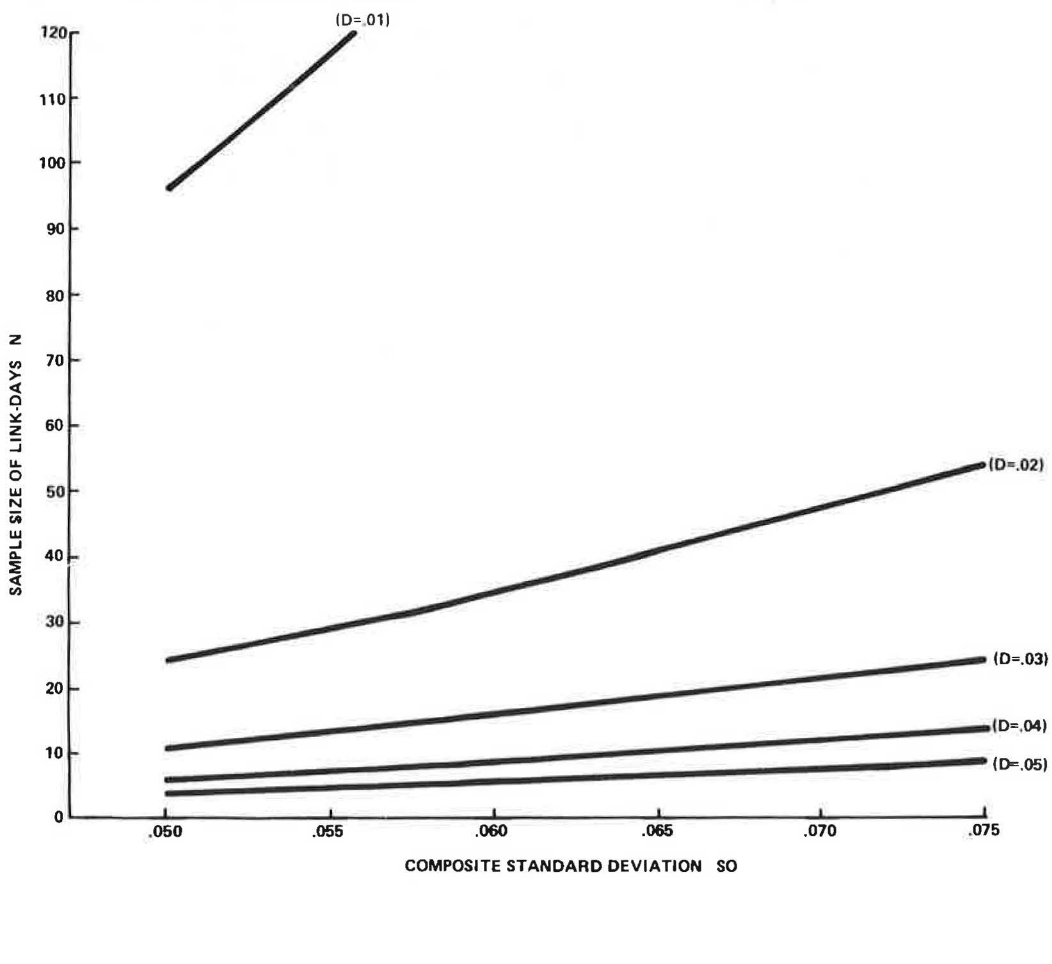
Assume that the survey will encompass all streets and highways in the region. The period of concern is a three-month period in the fall for which only travel between 7:00 a.m. and 7:00 p.m. on nonholiday weekdays is considered. A short-count procedure in which the field crew systematically monitors each lane for precisely 20 min/h is used for most data collection stations.

Before the sample sizes required for each of the measures can be computed, the composite standard deviations must be estimated. Assume that the agency previously conducted a survey of occupancy and estimates SOL as 0.062. Since the data collection effort will be performed in only one season, SOS can be assumed to be zero. Finally, since the short-count data collection plan involves a 33 percent coverage rather than the 25 percent coverage used to compute the default values summarized in Table 1, the agency selects an SOW value of 0.010. The composite standard deviation can then be computed as $SO = (0.062^2 + 0.010^2)^{1/2} = 0.063$.

Assuming that no previous vehicle classification studies were conducted, the composite standard deviation for the proportion of trucks can be estimated judgmentally from the default values as $ST = (0.045^2 + 0.008^2)^{1/2} = 0.046$.

Finally, the agency estimates the remaining parameters for sampling purposes. These estimates are derived from the survey objectives or the results of

Figure 2. Sample sizes for estimating regional average occupancy within tolerance D at 95 percent confidence.



previous surveys or judgmentally, as appropriate:

Parameter	Estimate	Process or Source
Z	1.96	For 5 percent level of significance
OCC	1.40	Judgment
TR	0.06	Judgment
PV	0.94	1 - TR
EVKT	0.04	Recent study
DOCC	0.02	Survey objectives
EPKT	0.05	Survey objectives

By substituting into Equation 3, the sample size of link days required to measure average occupancy can be computed as

$$N = (1.96^2 * 0.063^2)/0.02^2 = 39 \qquad (7)$$

Similarly, Equation 6 can be used to compute the sample size of link days of field data collection needed to factor the estimate of vehicle kilometers of travel from the traffic-counting program:

$$N = [1.96^2 * (0.94^2 * 0.063^2 + 1.40^2 * 0.046^2)]/(0.05^2 - 0.04^2) * (1.40 * 0.94)^2 = 19 \qquad (8)$$

The sample size required to estimate average occupancy is greater and is therefore used for the survey. The level of precision that can be expected for the estimate of truck travel can now be computed by rearranging the terms in Equation 5 as

$$ETRKT = \{[(Z^2 * ST^2)/(N * TR^2)] + EVKT^2\}^{1/2} = \{[(1.96^2 * 0.046^2)/(39 * 0.06^2)] + 0.04^2\}^{1/2} = 0.25 \qquad (9)$$

The estimate of TRKT can be expected to have a relative error of almost 25 percent of the true value. If the objectives of the survey design had included accurately estimating this measure, either the sample size would have to be substantially increased or a relatively more efficient stratified sampling plan would have to be used.

After the survey is completed, the agency can compute many of the variance and other parameters by using the survey results. The sample-size formulas should then be rearranged and applied to compute the actual level of precision achieved. Depending on the accuracy of the various parameter estimates, the actual precision may be higher or lower than anticipated. Parameter values should therefore be conservatively estimated in cases where failure to achieve minimum levels of precision can seriously compromise the utility of the survey.

CONCLUSIONS

This paper identifies potential uses for traffic-based monitoring measures, presents cost-effective sampling and data collection procedures to estimate these measures, and demonstrates how these procedures may be applied. The following conclusions can be made:

1. Traffic-based regional measures of vehicle classification and occupancy, truck travel, and person travel can support a variety of possible uses that relate to TSM actions, air quality, energy efficiency, model validation, and trend analysis.
2. Simple regional field surveys can be designed to estimate these measures at predetermined levels of statistical precision.
3. These field surveys can complement existing or anticipated programs of vehicle counting and travel estimation.
4. Systematic short-count data collection techniques can be used to substantially reduce crew size without seriously reducing the accuracy of daily summary data.
5. Average vehicle occupancy and person travel can be estimated at a high level of precision with a small number of field surveys.
6. If percentage of trucks and truck travel are used, a relatively larger sample of field surveys is required to produce highly precise estimates.

ACKNOWLEDGMENT

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Techniques for Monitoring Automobile Occupancy: Research in the Seattle Area

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Research directed at developing and testing analysis techniques for evaluating changes in average automobile occupancy is reported. The goal was to develop low-cost techniques that would be sensitive to variables of season, time, and commuting distance and then to test several hypotheses that relate to variations in the parameters of automobile occupancy. A list of four study tasks was drawn up, and data on automobile occupancy were collected at a number of sites in the Seattle region over a 15-month period. Statistical techniques that specifically address the issue of automobile occupancy were developed. The data were synthesized by computer and analyzed statistically to determine whether patterns existed among sites or over time or distance. The results show no predictable patterns or trends in automobile occupancy by type of facility, traffic volume, level of transit service, distance to the Seattle central business district, month or season, day of week, or time of day. These results contradict initial hypotheses that patterns did exist that would make an abbreviated count program sufficient for measuring changes in automobile occupancy. Other variables that might relate to automobile occupancy are identified, and areas for further study are suggested. Guidelines are presented for other transportation engineers who may wish to conduct monitoring studies of automobile occupancy.

Federal, state, and regional transportation policy has recently been redirected from increasing capacity to accommodate travel growth to increasing vehicle occupancy to handle travel growth as well as reduce fuel consumption, manage congestion, and control air pollution. As policy is redirected, decision makers begin to look for some form of measurement that will tell them about the effects of the policy shift. Attempts to measure such a change have been uncertain at best.

Vehicle-occupancy counts have not been collected on a systematic basis so as to indicate the effect of commuting distance, seasonal variation, access incentives, or regional programs for carpool development. Such counts require expensive person hours of field observation in poor working conditions.

During the 1960s, when transportation planning was done on a regional, systemwide basis, a series of home-interview transportation surveys were taken in regions around the county, including Puget Sound. The purpose of this data gathering was to survey automobile occupancy for all trip purposes as an aid in calibrating transportation system models.

More recently, federal policy has emphasized short-range transportation system management (TSM) techniques to derive greater efficiency from the existing system. There has increasingly been a call to look at the existing system, find the congested spots, and consider priority treatment for high-occupancy vehicles (HOVs) as a way to ease congestion and induce greater efficiency. It is recognized that, if ride sharing is to be significantly increased, real incentives such as time savings are required. Unfortunately, a good data base for automobile occupancy—one that is "corridor specific" to indicate what currently exists and help estimate what would happen if existing conditions were modified—is not available.

For instance, in the Seattle area, two modifications were made in the mid-1970s on the Evergreen Point Bridge that links Seattle with suburbs east of Lake Washington. During the energy crisis, the regular 35-cent automobile toll was reduced to 10 cents for vehicles with three or more occupants. In 1975, an exclusive HOV lane was added along the westbound approach to the bridge; that lane provides HOVs with as much as a 6-min advantage to the head of the queue in the morning peak period.

How effective have these techniques been? When planners tried to answer that question, they discovered a dearth of reliable automobile-occupancy data for the period before the toll reduction and institution of the HOV lane. In addition, occupancy values after the differential toll was instituted fluctuated widely depending on the season, the day of the week, and the type of crew that collected the data. For a number of months after the change in the toll, planners were unsure of the significance of the findings since no statistical guidelines were available. With this gap in knowledge in mind, the Seattle-King County Commuter Pool Program, a regionally funded ride-sharing project, responded to a general Federal Highway Administration (FHWA) request for proposals on techniques for monitoring automobile occupancy.

The premise of the research was that sampling techniques existed that would enable an ongoing regional program to be implemented, at a relatively low cost, to monitor changes in vehicle occupancy that result from various transportation system strategies. The program would also meet the requirements for urban transportation data reporting suggested to the U. S. Department of Transportation (DOT) by the Transportation Research Board (1). The sampling techniques would be sensitive to the variables of season, time, and commuting distance and would test them against baseline occupancy data for the morning peak period. This would provide the basis for a low-cost monitoring program for use by regional TSM programs throughout the country and specifically in the Puget Sound region.

Why the morning peak? The researchers decided to use the morning peak period because most ride-sharing strategies are directed at the work trip, which is repetitive in nature and has the lowest vehicle occupancy of any trip purpose. It is also the time period in which the highest percentage of work trips are made in the shortest time span. The evening peak is longer and flatter and includes other trip purposes that would not be particularly sensitive to HOV incentives.

To achieve these objectives, vehicle-occupancy counts were taken over a 15-month period in the Seattle area to provide data for a number of individual analysis tasks. Briefly, these tasks were to determine the following:

1. Whether occupancy rates vary in a consistent, predictable manner, by month or season of the year, by day of the week, or by time of day;
2. Variations in occupancy rates as a function of

distance from the Seattle central business district (CBD) along major corridors;

3. Occupancy rates at stations along the CBD cordons for Seattle, Bellevue, and Renton; and

4. The degree of statistical variation in occupancy counts as a function of the technique of data collection and the rate of traffic flow (redundancy counts).

The data were synthesized through several computer programs and then analyzed statistically to determine whether significant differences existed among the various counts and what factors might explain any variations.

One interesting relation to keep in mind throughout this paper is that between the average automobile occupancy for a site and the percentage of persons in vehicles with three or more occupants. Plotting points for a number of sites on a set of axes according to their values on these two variables yields a visual indication of the type of ride sharing at each site (see Figure 1). Points located farthest from the regression line of all data points have high proportions of either (a) riders in two-occupant vehicles compared with riders in vehicles with three or more occupants or (b) vice versa. A graph such as this may be of particular value in assessing the effects of a carpool-incentive program. In the Seattle area, for instance, a carpool must be a vehicle with three or more occupants to qualify for reduced tolls and exclusive lanes. Thus, a new carpool incentive in a corridor would benefit only riders in vehicles with three or more occupants and not ride sharers in two-occupant vehicles. Monitoring the movement of the point for a site on this graph over time will reveal whether, for an increase in carpools with three or more riders, these ride sharers are being drawn from single-occupant automobiles or vehicles that previously carried two riders.

These shifts cannot always be determined from average automobile occupancy alone. Since the ultimate goal of a carpool-incentive program is to increase the person-carrying capacity of a corridor, other measures in addition to average automobile occupancy may be of value, especially to persons unacquainted with occupancy studies. For instance, the change in degree of ride sharing at a site after the start of a carpool-incentive program could be described in several ways. One would be to state that average automobile occupancy rose from 1.242 to 1.269, but a more meaningful statement to the layperson might be that the percentage of people sharing a ride increased from 36.1 to 38.5 percent.

The various components of the Seattle area study are discussed in the following sections of this paper.

DATA COLLECTION PROCEDURES

First, it was necessary to determine at how many sites automobile occupancy should be surveyed and where these sites should be located to maximize their usefulness. Figure 2 shows the primary highways and employment centers in the Seattle region. For the task that involved corridor variations, counts were taken once only at every inbound on-ramp along I-5 North, I-5 South, WA-520, and I-90 and at selected northbound and southbound on-ramps along I-405. For the analysis of the CBD cordons, occupancy was surveyed at stations and ramps that encircle the Seattle, Bellevue, and Renton CBDs.

For the remaining tasks, which involved variations over time, a number of site-selection criteria were considered by the study team. These included the type of facility (expressways, expressway ramps, and arterials in both the central city and the suburbs), traffic volume (a variety within a reasonable range to reduce the effects of sample variation but to stay within staff and budget constraints), level of transit service (a range from no direct commuter transit service to 42 buses in the peak two hours as well as corridors that serve park-and-ride lots), land-use characteristics (a mix of densities at varying distances from the Seattle CBD), and general utility for future planning efforts. By using these general criteria, the study team drew up a list of potential sites and then selected 18 regional sites from this list (Figure 2).

To explore monthly and seasonal variations, a midweek (Tuesday, Wednesday, or Thursday) occupancy count was scheduled once each month at each of the 18 sites in the region over the 15-month survey period. For the analysis of day-of-week variation, 7 sites were selected from the pool of 18 sites; these were chosen to represent a variety of characteristics according to

Figure 1. Relation between average automobile occupancy and percentage of persons in vehicles with three or more occupants.

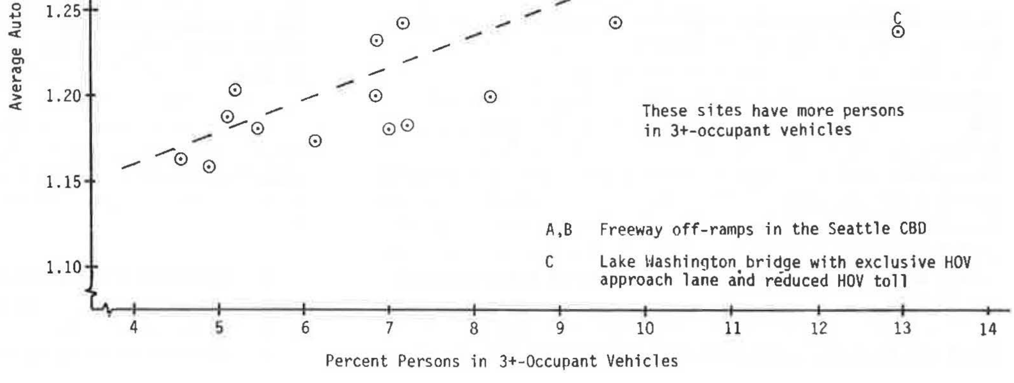
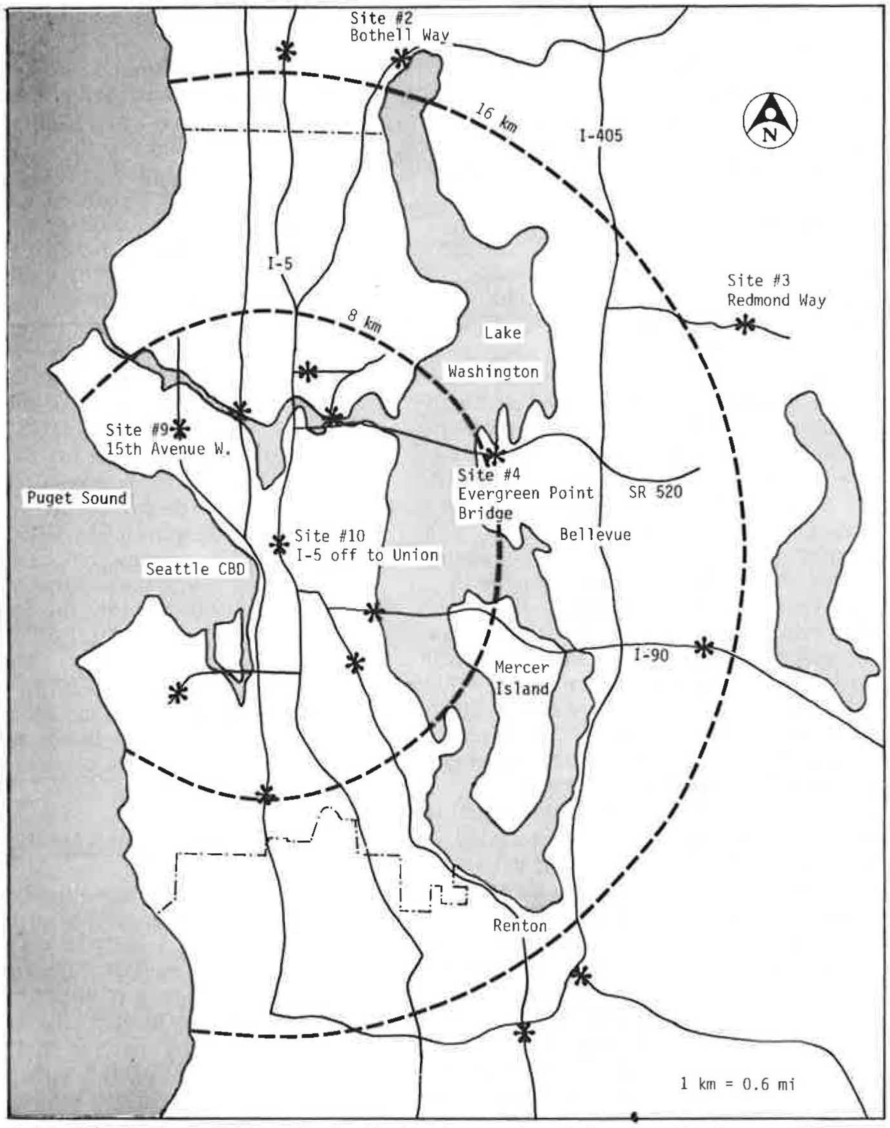


Figure 2. Seattle regional highways and survey sites.



Note: Only 16 stars are shown for the 18 sites because two of the stars identify two sites each (located adjacent to each other).

the criteria outlined above. Counts were conducted four times a year on five consecutive weekdays at these 7 sites. Three sites (suburban, urban, and CBD) were selected for the time-of-day analysis, and two 12-h occupancy surveys (autumn and spring) were conducted at these sites. (The process of site selection for the analysis of redundancy counts is described later in this paper.) For all tasks except the analysis of time-of-day variation, the morning peak period (6:30-8:30 a.m. or 6:45-8:45 a.m., whichever had the greater traffic volume at a site) was selected for occupancy counts.

Techniques for gathering the data were fairly straightforward. The members of a crew of traffic recorders were each assigned a particular count for a particular 2-h period and were each supplied with a five-register pushbutton counter and a sheet for recording the data. The five registers were to be used for counting vehicles with one occupant, those with two occupants, and so forth up to vehicles with five or more occupants. Motorcycles were included, but buses and commercial trucks were not. Pets and inflatable dolls were also excluded. Except for the 12-h time-of-day counts, during which both directions of traffic flow were surveyed, only the major direction of flow was counted.

At 15-min intervals, the counter would record the data on the data sheet; each 2-h count thus yielded eight 15-min-interval counts. These data were synthesized through a computer program that produced a summary printout of occupancy parameters for each interval and for the 2-h period. It was these 2-h summary values, broken down by one-occupant vehicles, two-occupant vehicles, and vehicles with three or more occupants that were subsequently analyzed statistically to explore potential variations in occupancy.

Measurement of the error made by each recorder in the collection of data was considered an integral part of the project. This task was approached through the series of redundancy counts. Four sites that represented traffic volumes from 16 to 47 vehicles/min were selected. It was hypothesized that, as traffic volume exceeded a certain threshold level, the accuracy of the individual recorder would decrease. In addition to measuring the amount of error in the counts, it was hoped that an estimate could be made of the threshold volume at which accuracy began to be significantly compromised. To this end, a single traffic recorder carried out the count at a site in his or her normal manner. In addition, two other counters split the traffic flow at that site (usually taking one lane each), thereby reducing the volume of traffic each had to monitor. The sum of these two partial counts was then compared with the count of the individual recorder.

STATISTICAL METHODOLOGY

Several different analysis techniques were considered to evaluate the various research tasks. Briefly, statistical techniques designed to test for differences between or among data sets were used to analyze the monthly, seasonal, and day-of-week occupancy counts, and simple linear regression was selected as an appropriate technique for exploring possible relations between occupancy and a number of other variables. The regression method used was a straightforward procedure that can be found in any basic statistics text. However, since very little research has been done in the area of monitoring and evaluating changes in occupancy over time, statistical procedures to accomplish this are not well established. Thus, a primary goal of this project was to explore various techniques for monitoring and evaluating automobile occupancy and to provide guidelines for future efforts in this area. The statistical procedures used in the study are discussed only briefly here. The statistical method used and many of the issues raised in such research are discussed in detail elsewhere (2).

Both parametric and nonparametric statistical tests were evaluated for use in this study of occupancy. The general distinction between the two is that parametric tests involve the use of parameters such as sample means and variances whereas nonparametric tests usually treat only the observations themselves. The primary statistical tests used in this study were the analysis of variance (ANOVA) test (a parametric test) and the chi-square test (a nonparametric test). Both of these tests are capable of evaluating several time periods or survey sites simultaneously to determine whether significant differences exist among the data samples. Significance levels of 0.01 and 0.05 were chosen for this study to indicate how strong the results were. In addition, a studentized range test, although rather obscure, was used to supplement the results of the other tests (3); for example, when the ANOVA or chi-square tests showed that significant differences did exist, the studentized range test helped to determine which days were contributing to the differences.

The sample size required for analyses of occupancy is often a question of concern for transportation engineers. The required sample size can be calculated for a survey of automobile occupancy by using accepted statistical methods. But the required sample sizes are almost always somewhat stringent for occupancy studies, usually because the differences of interest are quite small in comparison with the mean occupancy values. An alternative procedure that is much less conservative takes into consideration the fact that most surveys of occupancy actually count a very high percentage of the total population, i.e., total vehicle flow in a corridor. In some cases, almost 100 percent of the vehicles at a site are counted, and it does not seem reasonable to recount what are, in effect, the same people on successive days. In such a case, a finite population correction factor should be applied to the variance to allow the required sample size to be adjusted accordingly (4).

ANALYSIS RESULTS

The data file accumulated during the study consisted of a total of 657 records, one for each 2-h occupancy count. There were problems with data collection in the first 3 months, so the counts collected during that time were disregarded. For the monthly and seasonal analyses, a 202-record subfile (18 sites for 12 months with 14 counts missing) was used as the basis for the analysis. The 267-record day-of-week file consisted of data for 7 sites for eight weeks (two per site per quarter for a single year) in which 13 counts were missing. For most of the analysis, one full set of day-of-week counts per site per quarter (i.e., with no days missing) was used; this yielded a total of 140 records for that part of the analysis. Some within-month day-of-week analysis was done in which there were sufficient data for two weeks in the same month at a site. The data on time-of-day variation consisted of 48 records for 3 sites. During the fall, only the inbound direction of traffic was surveyed. During the spring, however, the outbound direction was added for 2 of the 3 sites; the third site was an inbound-only freeway off-ramp in the Seattle CBD.

There were a total of 73 records for the corridor analysis of occupancy. The number of records per corridor ranged from 7 to 19. There were 29 records for the analysis of the Seattle CBD cordon and 6 and 4 records for the Bellevue and Renton CBD cordons, respectively. The results of each analysis task are described below.

Redundancy-Count Variations

Before the data were analyzed in order to explore possible relations, patterns, or trends among sites or time periods, the quality of the data was evaluated by using redundancy counts. This was done primarily to determine the degree of variation in occupancy surveys as a function of rate of traffic flow. Four sites with volumes that averaged from 16 to 47 vehicles/min during the 2-h morning peak period were selected from the 18 monthly sites. At the sites that had volumes of 47, 39, and 26 vehicles/min, a two-counter team and one or more individual counters surveyed occupancy. At the site that had a volume of 16 vehicles/min—a downtown freeway off-ramp—three recorders, working individually, performed the survey.

When the statistical methods designed to test for significant variation between or among counts were used, no significant differences emerged for any of the redundancy counts. The differences in automobile occupancy were all less than 1.1 percent; the maximum difference for a single site was 0.013. These results demonstrated that, under a variety of conditions, variation in flow rate or differences in staff assignments at a site did not result in significant differences in the occupancy counts. This was interpreted as support for the generally high quality of the data and an indication that any variations that might be identified were not likely to have been caused by these extraneous factors.

General Variations

For all 18 sites in the main data file, average automobile occupancy for the year August 1977 through July 1978 ranged from a low of 1.108 persons/vehicle to a high of 1.403 persons/vehicle. Before the statistical analyses were performed, some general comparisons of the data were made to see if any trends or patterns emerged. By using the midweek morning-peak counts collected for the monthly and seasonal analyses, an annual average automobile occupancy was calculated for each site to serve as a basis for a first-cut comparison of various sites. These averages ranged from a low of 1.157 persons/vehicle on a suburban expressway to a high of 1.348 persons/vehicle on a freeway off-ramp in downtown Seattle.

When the sites were categorized by type of facility—i.e., expressway, arterial, or expressway ramp—none of the groups showed a pattern of consistently higher or lower average occupancies than the others. An ANOVA test of average automobile occupancy by the three facility types resulted in a failure to reject the null hypothesis, which means that the data did not support a conclusion that facility types differed with respect to average automobile occupancy.

Average automobile occupancy at these 18 sites was also viewed from the perspectives of varying traffic volumes, levels of transit service, and distances to the Seattle CBD. Three scattergrams were created by using these three variables as the independent variable and average automobile occupancy as the dependent variable. No visible relations emerged, and the R^2 for a simple linear regression ranged from 0.002 to 0.412, which indicated no significant relations.

Since none of these variables showed a significant or promising relation with average automobile occupancy, these lines of investigation were not pursued further. The analysis continued with the statistical evaluation of variations in occupancy by month, season, day of week, and time of day and analysis of occupancy in major corridors and at CBD cordon stations.

Monthly and Seasonal Variations

Of the 18 sites surveyed each month, all but one showed statistically significant differences among the monthly counts. In many cases, the cause of these differences appeared to be the fact that one or two months showed particularly high or low occupancy rates at an individual site and considerably less variation among the rest of the months. There were no consistent patterns of high or low occupancy rates for particular months over the spectrum of sites nor seasonal trends of high or low occupancy. Furthermore, when either urban or suburban sites were viewed as a group, no patterns emerged.

In many cases, there was considerable variation and the occurrence of highs and lows over the entire 12-month survey period. Yet no patterns emerged to suggest that occupancies varied in a predictable manner that might allow future occupancy rates to be reasonably estimated from a single count in a particular month. Figure 3 shows monthly data plots for an urban and a suburban site.

Day-of-Week Variations

Seven survey sites, including two expressways and five arterials, were selected for the day-of-week analysis. Three of the sites were suburban and four were urban. To explore day-of-week variations at individual sites, data that consisted of five-day counts taken in October 1977 and January, April, and June and July 1978 at each site were used. The analysis techniques were designed to test whether significant differences existed among the days in a single week at an individual site and, if differences did exist, whether there were consistent patterns.

Only one site showed significant differences among the days for all four survey months, and two sites showed no significant differences for any month. The remaining sites showed significant differences for some months and no differences for others. Where significant differences did exist, they appeared to be the result of particularly high or low vehicle occupancies on one or two days. Yet there were no consistencies to these patterns, either among months at a single site or among sites. At one site, for instance, in October Tuesday had the lowest occupancy and Friday the highest whereas in January the situation was exactly the reverse. The data plot in Figure 4 shows automobile occupancy by day of week for a single site during two different weeks. During one week occupancy was relatively constant, whereas in the second week Monday showed a partic-

Figure 3. Sample monthly data plot.

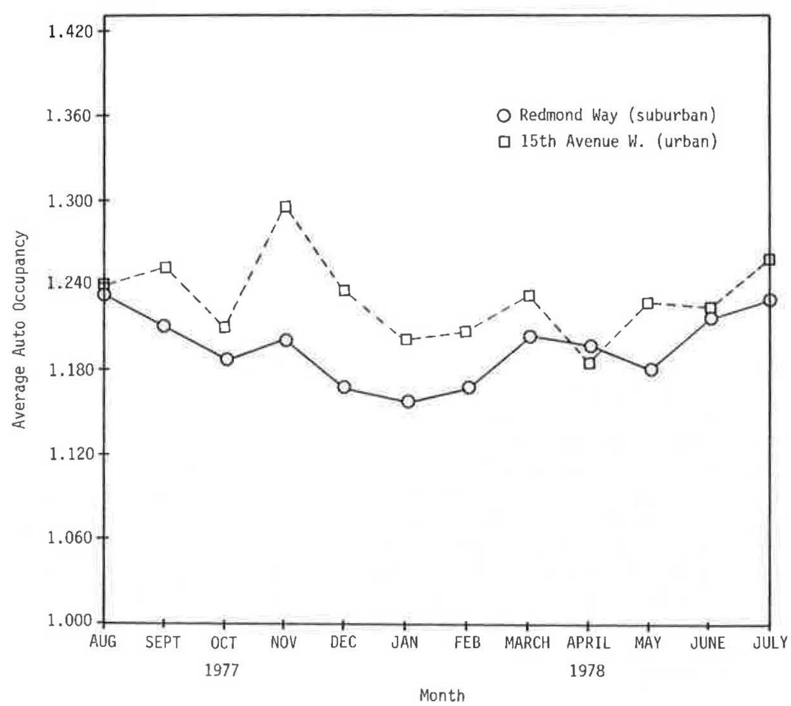


Figure 4. Sample day-of-week data plot.

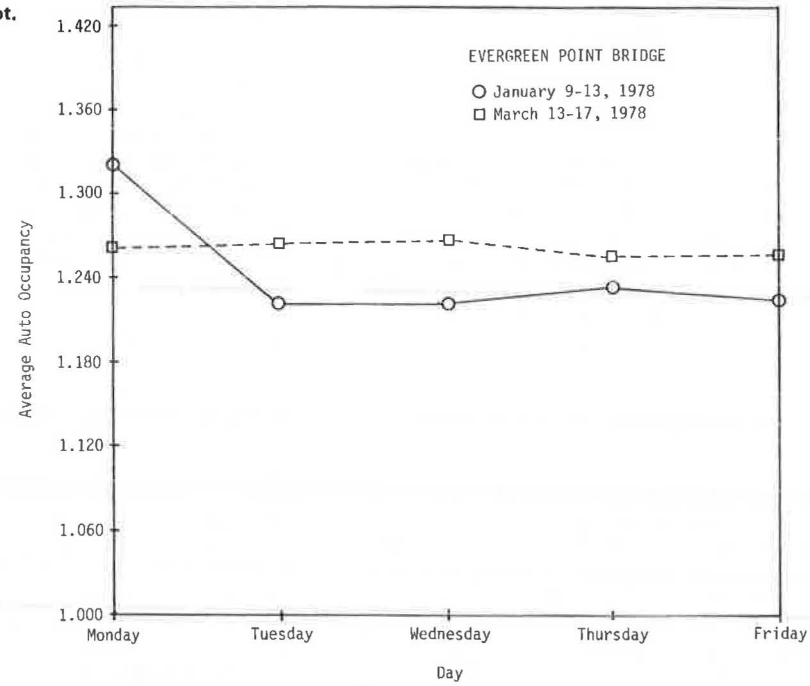
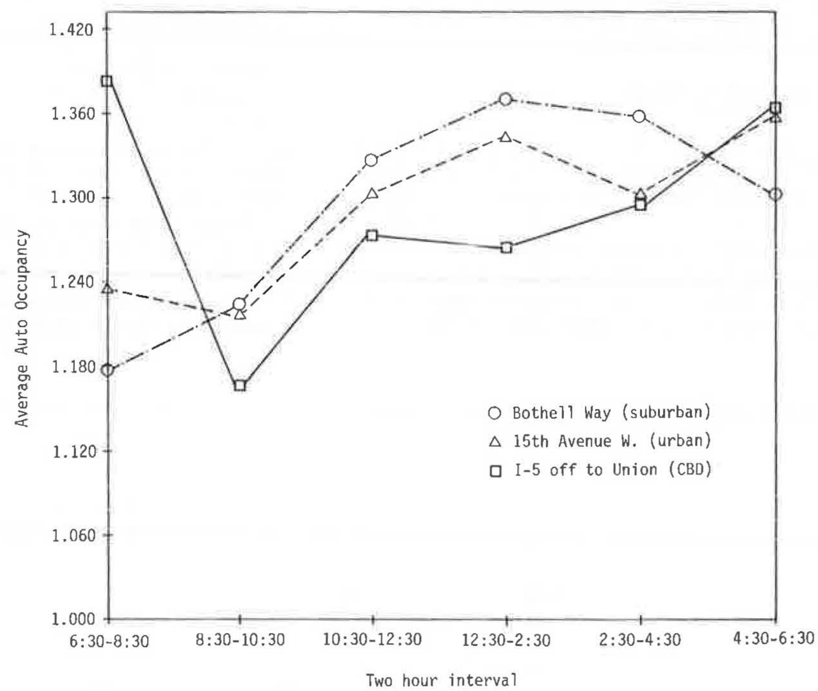


Figure 5. Sample time-of-day data plot.



ularly high automobile occupancy.

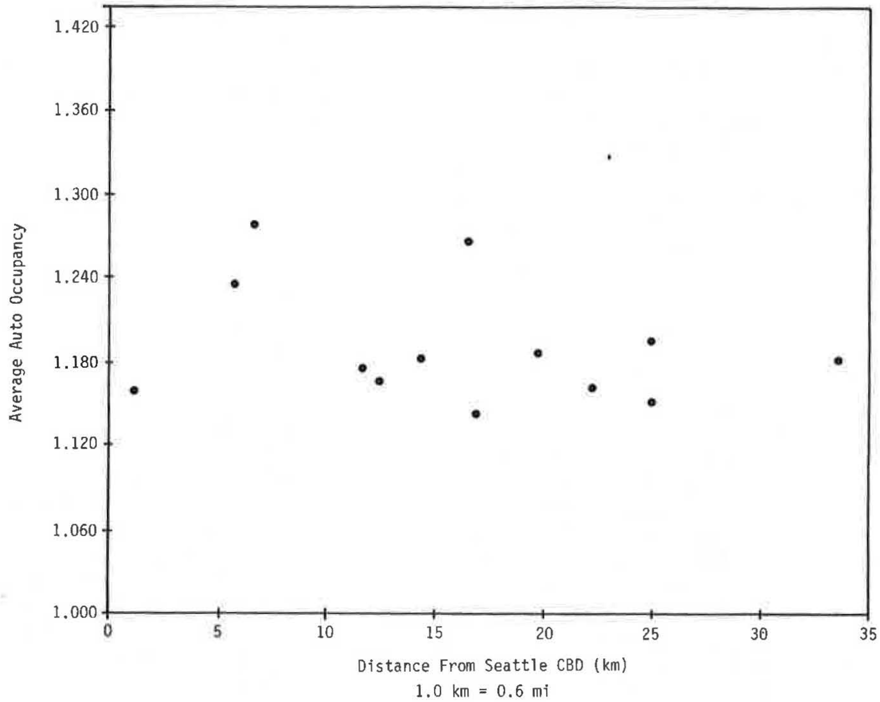
Several other avenues of investigation were also explored, but these yielded no more positive results. Viewing either urban or suburban locations as a group yielded no patterns among days, and there were no trends among the four seasons across the spectrum of sites. Where data were available, two five-day counts within a single month at a site were compared. In many cases there were no significant differences among the days for either week, whereas in other cases there was an aberrant day in one week or the other or both. Again, there were no consistencies among days that showed particularly high or low occupancies.

Time-of-Day Variations

The amount of exploration of time-of-day variations that was possible was limited by the small amount of data collected for this task. Figure 5 shows sample data plots for the three sites at which 6:30 a.m. to 6:30 p.m. time-of-day surveys were conducted; only occupancies in the inbound direction are shown. As can be seen, there was great variation among the three sites. At one site the morning peak period had the highest occupancy of the 12-h day whereas at another it had the lowest. There was additional variation at other times of day.

One valuable finding from these data is that, con-

Figure 6. Average automobile occupancy versus distance to Seattle CBD for I-5 South corridor.



trary to widespread belief, the morning peak period does not always exhibit the lowest occupancy of the day. This may have ramifications for future efforts to promote carpooling since it indicates that, in relation to other types of trip makers, peak-hour commuters may already be ride sharing to a relatively high degree in some locations. In addition, the considerable variation among the three occupancy patterns for the three different sites indicated that time-of-day variations are not consistent for different locations and that it would be difficult, if not impossible, to derive useful expansion factors for occupancy at various times of day.

Major-Corridor Variations

A major goal of the analysis of major-corridor variations was to determine whether occupancy varied in a predictable manner along corridors that lead from suburban areas into central Seattle. The four primary corridors—I-5 North, I-5 South, I-90, and WA-520—were selected, and one-time-only surveys of occupancy were conducted at every inbound on-ramp. The amount of data collected for these four corridors ranged from 7 to 19 records/corridor.

The primary technique used here was a simple linear regression of average automobile occupancy versus distance to the Seattle CBD. For the WA-520 corridor, the R^2 was 0.211; for the other three corridors, the R^2s were all less than 0.07. An overall regression of all corridor on-ramps versus distance yielded an R^2 of 0.036. These low values indicated that no linear relations existed between corridor occupancies and distances to the CBD. The data plot of automobile occupancy versus distance for the I-5 South corridor is shown in Figure 6.

In addition to these four main corridors, occupancy was surveyed at selected ramps along I-405, the primary north-south freeway route linking the suburbs east of Lake Washington. The length of I-405 was divided into three (sometimes overlapping) sections and, in a given section, either southbound or northbound on-ramps were surveyed. These divisions were made according to general travel patterns of I-405 traffic toward several routes leading to the Seattle CBD. As in the other corridors, no relations emerged between average occupancy and distance along the corridor.

Analysis of CBD Cordons

The stated purpose of the analysis of the CBD cordons was to determine occupancy rates at stations along the Seattle, Bellevue, and Renton CBD cordons. Because the counts taken for this task were one time only, no comparisons over time were possible. From the data records for each CBD (29 for Seattle, 6 for Bellevue, and 4 for Renton), overall average automobile occupancy along the cordon line was computed. This average value for the Seattle CBD was 1.300, which was considerably higher than that for either Bellevue (1.133) or Renton (1.188). There was also significant variation within an individual CBD: All but one of the counts for the Seattle CBD cordon resulted in values between 1.107 and 1.453, and there was an average value of 2.734 at a freeway off-ramp restricted to carpools and transit.

CONCLUSIONS AND RECOMMENDATIONS

The results of the study described in this paper are evidence of the lack of predictable relations, patterns, or trends found in the study data on vehicle occupancy. The task of investigating automobile occupancy at CBD cordons was designed primarily to determine automobile-occupancy rates at particular locations, and this was accomplished by selecting appropriate sites and surveying occupancy. The remaining tasks, however, were directed toward exploring variations in automobile occupancy over time or distance and trying to find explanations for any variations; in these areas, differences in occupancy were found to exist, but no patterns could be identified to explain the variations. This outcome proved extremely frustrating since it was felt that there must be clues somewhere in the wealth of data collected in the study that would help to explain the variations encountered.

Several possible factors were considered that might account for the lack of consistency in the data. The first factor is possible uncertainty in the accuracy of the occupancy counts. Although several redundancy counts were conducted to check for variations caused by the rate of traffic flow or individual recorder differences, these were not exhaustive and additional tests are needed before the question of the accuracy of the data can be entirely resolved. Factors such as the visibility of passengers and the potential for missing some vehicles may cause variations in the data. This is especially important in surveys conducted during the winter months when it is still dark during the morning peak period.

Assuming that the data collected for this study are accurate, no explanation has been found for variations in automobile occupancy among the 18 sites around the region. Since none of the variables investigated here—type of facility, traffic volume, level of transit service, distance to the CBD, or urban versus suburban location—showed a relation with average automobile occupancy, other possible explanations were hypothesized. Unfortunately, budget constraints precluded additional analyses that might have shed more light on the issue of variations and changes in automobile occupancy. Variables that were not explored in this study but that might hold promise for future efforts include the income level of the commuter shed for particular sites, which is admittedly difficult to measure in most cases, and characteristics of ride sharers in a corridor (whether they are co-workers, kiss-and-riders, and so on).

Aside from variations among the various sites, no consistent patterns were found in the time-series data over the 12-month period. One possible explanation relates to whether this was a realistic time frame for exploration of variations in occupancy. Although the study analyses made use of a large amount of data collected over a one-year span, one year may be too short a period in which to identify any longer-term trends in the data. The results of this study indicate that there are not predictable variations in automobile occupancy by day of week or by month or season. Yet it may be that occupancy is affected by and responds to longer-term changes in, for instance, regionwide economic or employment trends. To explore these possibilities, it is necessary to conduct a continuing survey of automobile occupancy over time.

In relation to what sites should be selected for occupancy surveys, evaluation revealed that 9 of the 18 sites chosen for monthly counts as the basis of this project could be eliminated from future surveys. This conclusion stemmed from a number of factors. At the outset of the study, there was some desire to attempt to establish, and to monitor variations in, a regionwide average automobile occupancy. Yet, after close analysis of the data gathered at the sites included in the project, it was concluded that it would be essentially impossible to calculate a value for regionwide automobile occupancy by using the methodology outlined here. Furthermore, such a value would be of only limited use in evaluating trends in carpooling.

The sites at which automobile occupancy is of interest are those at which, because of high traffic volumes, existing or expected future congestion, or special transportation considerations, there is an interest in monitoring changing commuting patterns. For instance, several of the 18 sites used in this project were outlying suburban expressways, expressway ramps, or arterials where volumes are relatively low, congestion is not a problem, and, because of their remoteness from downtown Seattle and other primary employment centers, there is relatively little potential for much participation in a ridesharing promotion effort. In addition, since no correlations were found between occupancy and either distance to the Seattle CBD or traffic volume, it is not necessary to include remote or low-volume sites for the specific purpose of providing balance over the total spectrum of sites. It was recognized that the areas of real interest are those where future changes, either in a particular corridor (such as institution of a peak-hour exclusive HOV lane) or in more general policies (such as parking restrictions in the CBD core), may affect the degree of ride sharing. It is at these locations that it will be important to try to assess the actual impacts of such changes.

Several recommendations can be made as a result of this study. To accurately assess changing commuting patterns, a long-term, continuing program should monitor carefully selected sites at regular intervals, perhaps monthly. These occupancy rates should be plotted regularly so that any variations can be seen in the context of changing external circumstances. In the Seattle area, 9 of the 18 sites have been chosen for an ongoing program in which occupancy will continue to be surveyed once each month at each site. Since no consistent day-of-week variations were found, the monthly counts can be taken on any weekday. One way of viewing these values is to calculate a moving average. For example, beginning at the time when 12 months of data have been accumulated, a 12-month average is computed; for each succeeding month, the earliest value is replaced by the most recent value, and a new 12-month average is computed. Plotting these values yields a 12-month moving average, which can often help identify longer-term trends by eliminating the interference of month-to-month or seasonal fluctuations. Another technique would be to average monthly occupancies into quarterly values for plotting and analysis purposes; as in the case of the moving average, this would level out shorter-term variations.

As discussed earlier in this paper, the relation between average automobile occupancy and other carpooling measures, such as the percentage of persons in vehicles with three or more occupants, should be kept in mind. Because of local conditions (such as the definition of a carpool for a local incentive program) or the characteristics of a particular location, one measure may be better suited to describe the situation than another. Furthermore, the percentage of persons who carpool tends to be a more tangible and meaningful value for most laypersons than average automobile occupancy.

This study recommends an ongoing program to continuously monitor automobile occupancy. In some cases, this is not feasible because of staff, financial, or other constraints. In these instances, however, it may still be of interest to attempt to assess the impact of individual programs to promote ridesharing or other changes in circumstances. To address this need, guidelines have been developed to aid planners in monitoring automobile occupancy at a limited number of locations for the purpose of evaluating specific programs. In such cases, it is necessary to conduct before-and-after surveys of automobile occupancy to help evaluate the effectiveness of the program. Although this research has shown that variations in occupancy rates may be irregular and apparently nonsystematic, a carefully conducted before-and-after survey may help reflect changes caused by a carpool-incentive program. A detailed set of guidelines for conducting surveys of automobile occupancy has been developed as part of this research project (5). Again, one must be careful not to automatically attribute any changes in occupancy to the carpool program.

One aim of future research in the area of variations in automobile occupancy should be to verify whether the results of this study apply in other metropolitan areas. Since nearly all of the factors that relate to levels of ride sharing can vary from one city to another, occupancy rates and their variability over time and at different sites may also be significantly different. Since analysis of automobile occupancy is a relatively new field of research, ongoing projects will be needed before the complex interactions among the variables can be better understood and explained. This will then enable engineers, planners, and policy makers to work together to address transportation problems in metropolitan areas.

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Georgia's Evaluation of Federal Highway Administration Procedures for Estimating Urban Vehicle Miles of Travel

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The once relatively obscure statistic of vehicle miles of travel has taken on a much higher profile with the advent of air quality standards and energy policies. It is probable that federal agencies such as the U.S. Departments of Transportation and Energy and the Environmental Protection Agency will use statistics on vehicle miles of travel in establishing future national transportation policies. In late 1977, recognizing the need for a uniform method of calculating estimations of vehicle miles of travel, the Georgia Department of Transportation contracted with the Federal Highway Administration to test the draft procedural manual, Guide to Urban Traffic Volume Counting. This paper outlines Georgia's testing procedures and presents a comparison between procedures in the Guide and the current method of calculating vehicle miles of travel. Statistical tests are reported, and the advantages and disadvantages of each methodology are evaluated.

This paper presents the approach taken by the Georgia Department of Transportation (GDOT) in evaluating the procedures described in the Guide to Urban Traffic Volume Counting, which outlines a methodology for estimating vehicle miles of travel. GDOT has for a number of years provided a statewide estimate of vehicle miles of travel. This statistic is based on traffic information collected by Georgia's coverage count program. In GDOT's testing of the procedures, data were collected as prescribed and were then compared with the data collected in the coverage count program.

This paper covers the experience gained in the project and recommends procedural modifications based on this experience (since the basis of the research is the determination of vehicle miles of travel, no SI equivalents are given except in certain general references to distance).

BACKGROUND

In Georgia, traffic data collection and reporting are primarily the responsibility of GDOT. This applies to both rural and urban areas. However, some local governments do collect a limited amount of data, primarily for traffic engineering applications and to supplement annual traffic data provided to them by the coverage count program of GDOT.

GDOT currently operates 61 continuous-count and 96 seasonal-control stations throughout the state that provide trends and factors used in expanding 24-h coverage counts to estimates of average daily traffic.

Figure 1. Map of study area.

Approximately 25 000 of these 24-h coverage counts are collected annually on all highways classed functionally above the local system. In addition, a random 5 percent sample of local county roads and city streets is obtained in counties scheduled for reinventory of physical road characteristics. Vehicle miles of travel are estimated for each county and urban area and then totaled to provide a statewide estimate.

URBAN STUDY AREA

Selection

All major Georgia cities were considered for the testing of this procedure; by a subjective process, Savannah was selected. The following considerations were used in this process:

1. Coordination with local planning agencies,
2. Availability of historical traffic data,
3. Availability of up-to-date inventory data on road characteristics,
4. Availability of current functional classification information on the city street network, and
5. Availability of a current and adequately detailed set of base maps.

The data available from GDOT and the Chatham County-Savannah Metro Planning Commission were sufficient for conducting the study. More current information was available for the Savannah area than for any other areas of comparable size in Georgia.

Description

Planning data for the Savannah urban area are assembled according to "planning districts". There are 12 districts in the surrounding county and 1 district that includes the incorporated city limits of Savannah. These districts encompass the planning commission's geographical area of responsibility.

The research guidelines recommend using a minimum of geographic subareas. A compromise was reached by aggregating the planning districts into eight subareas that did not violate the boundaries of the local planning districts or reflect any significant differences in potential traffic patterns (see Figure 1).

Savannah is not a typical city inasmuch as there are distinct areas of land use that generate different types of traffic. Some examples of the ways in which these diverse travel patterns are generated that were considered in subdividing the study area are as follows:

1. The suburb of Savannah Beach generates a significant amount of seasonal tourist traffic.
2. The metropolitan area adjacent to the Savannah River, one of the larger coastal ports in the southeastern region, generates a substantial amount of long-range, freight-hauling truck traffic. The area is a major overland distribution center.
3. The suburban area to the northwest is almost exclusively a heavy industrial district that generates freight movement and work-related trips.
4. The northern portion of the incorporated city contains many historical landmarks that generate tourist traffic and the central business district (CBD), which generates shopping and work-related trips. This portion of the incorporated city is bordered on the south by Victory Drive, a major east-west arterial.
5. The southern and southeastern portions of the area are primarily marshland, but they contain an expanding residential district.

DEFINITION OF STREET NETWORK

Base Maps

The base maps provided by the Chatham County-Savannah Metro Planning Commission were up to date and detailed. GDOT personnel had recently completed a physical inventory of the street network in the area. With these two sources of data, the street network could be defined.

Road Definition

The definition of a public road as outlined in the Georgia Transportation Code was applied to this research in identifying the street network. This definition concurs with that used by the Federal Highway Administration (FHWA). By identifying the public road network, private facilities were eliminated. Consideration was given to those private facilities that are open to public use; however, because they can be closed to the public at the discretion of the owner, they were not included in the street network in this research. The various definitions of road type that were used (with the exception of private roads) are given in the following table:

Road Type	Definition
State route	All routes designated on the state highway system by resolution of the GDOT Transportation Board
County road	All roads designated by the county to be on the county road system
Public road	Any new road in a county that has not been declared a county road by the county
City street	All routes inside incorporated areas that are not designated as state routes or county or private roads
Access road	Roads (maintained by the state) primarily located parallel to Interstate roads that provide local access to other roads
Private road	Roads that can be closed to the public at the discretion of the owner

Functional Classification

The approved functional classification system, which was developed in cooperation with local governmental agencies, GDOT, and FHWA, was used for this project. Each facility was classified as a freeway, arterial, collector, or local street.

Link Definition

A link was defined primarily as a section of road that represents a homogeneous traffic volume. The secondary consideration was that the length of the link be uniform within each functional classification. An effort was made to conform to the allowable variations in link lengths set forth in the FHWA Guide.

The following guidelines were used in assigning links throughout the street network of the study area:

1. Freeways are primarily divided at interchanges or where full control of access is terminated.
2. Arterials and collectors are divided at major intersections that affect traffic flow within a 0.62-km (1-mile) distance; otherwise, they are divided at minor intersections.
3. Arterials and collectors are divided at lane transitions; e.g., a link node is placed at a location where a facility marks the end of a two-lane section and the beginning of a four-lane section.
4. Locals are divided at intersecting streets and at major changes in type of surface.
5. All streets are divided at locations where significant changes in traffic flow occur and in a manner to conform to the recommended link lengths prescribed in the FHWA Guide.
6. Half nodes are used where intersecting streets do not define link nodes—i.e., to prevent more link breaks than necessary on streets with homogeneous volumes.
7. One-way loops around city parks are treated as a part of the link on major approaching streets.
8. Divided streets with a median are considered to be one link.

NETWORK ASSIGNMENT

Historic Traffic Data

GDOT's coverage count program is primarily focused on the state highway system and on selected major off-state-system streets. In the Chatham County-Savannah area, the entire freeway and arterial system, a majority of the collector systems, and approximately 5 percent of the local road system are counted annually.

Each street was stratified by volume according to its functional classification. The traffic volume data used for stratification were obtained in the last quarter of 1976. Since historic traffic data were available for freeway, arterial, and collector systems, stratified random sampling methods could be used in determining the sample size for these groups. For collector streets where no previous traffic volumes were available, the mean lane capacities suggested in the FHWA Guide were used for volume stratification. Simple random sampling methods were used for the local system because of the lack of available historic data.

Link Numbering Scheme

The numbering scheme for link identification (ID) identifies the geographic subarea, facility type, volume stratum, specific location, and mileage of each link in the study network. Numeric codes are used to identify facility type and selected ranges of traffic volume for each functional classification. Because of the length of these code numbers, a decision was made to use a smaller 5-digit number, referred to as the "map link ID". The map link ID was used on the base maps and incorporates the geographical area number in the left-most digit, and the remaining 4 digits are the unique link digits from the 10-digit number. A table of equivalence was then developed to include the link ID, map link ID, the "traffic section ID number" used by GDOT in its coverage count program, and available 1976 annual average daily traffic volumes.

A file containing the link network data was compiled on a computer. The file was then sorted by geographic area, functional classification, and traffic volume. Summaries of the link file were developed and aggregated into 32 subpopulations.

ESTIMATION OF SAMPLE SIZE

The calculations of sample size outlined here use the standard probability sampling theory described in the FHWA Guide. Reliance on the proper identification of links and their summaries was necessary for the application of these techniques.

In identifying methods of sample selection, the cost and accuracy of field use of such methods were assessed. Statistical parameters were selected to allow a 68 percent confidence level with desired ranges for relative error.

Two basic techniques were used in determining the sample size for each subpopulation. Simple random sampling was used for the collector and arterial systems. Stratified random sampling was considered for the freeway system but, because of the small number of freeway links, a 100 percent sampling was done. The sample calculations resulted in mileages that were converted to links by dividing the average link lengths for each subpopulation.

Simple Random Sampling

Because of a relatively large group population and an inability to further stratify local links by traffic volume (caused by the lack of historical data), a simple random sampling technique was used for determining sample size for the local street system. Accounting for a finite population correction factor, the following formula was used to determine the sample size for each geographic area from which to collect local traffic data:

$$n = Z^2(C_s^2 + C_t^2)/[e^2 + (C_s^2/N)Z^2] \quad (1)$$

where

- n = sample size, i.e., number of miles (to the hundredth) of roadway to count;
- Z = normal variate = 1.0 for 68 percent confidence level and 2.0 for 95 percent confidence;
- C_s = spatial coefficient of variation;
- C_t = temporal coefficient of variation;
- e = relative error = $E/\bar{x}$, where E = absolute error in mean vehicle miles per mile and $\bar{x}$ = mean vehicle miles of travel per mile; and
- N = number of miles in a road class, i.e., local street mileage for a given geographic subarea.

In maintaining a 68 percent confidence level, a normal variate of 1.0 and a relative error of 15 percent were assumed. Through a review of a case study conducted in Tulsa, Oklahoma, and other sources, values of 60 percent for the spatial coefficient of variation and 30 percent for the temporal coefficient were chosen. These parameters were held constant while the value of N was variable. As given in the summary Table 1, 124.93 miles of the local system were selected for sampling from a total system mileage of 645.12. Table 2 illustrates the sample selection computations made for the local network described above by using Equation 1, where Z = 1.0, C_s = 0.60, C_t = 0.30, and e = 0.15.

Table 1. Summary of sampled links and mileages.

System	Links Total	Links Sampled	Mileage Total	Mileage Sampled
Freeway	30	30	48.12	48.12
Arterial	355	129	175.16	77.96
Collector	218	107	113.68	65.03
Local	2006	665	645.12	124.93
Total	3609	931	982.08	316.04

Stratified Random Sampling

Since historic traffic data were available for the arterial and collector systems, stratified random sampling was used for these groups. These data allowed the links to be further grouped into volume strata, which permitted narrower strata, lower variance, and hence lower sample size. Again, the finite population correction factor was considered as the following formula was used for computing sample size for each subpopulation within these systems:

$$n = \Sigma(W_h S_h)^2/[(E^2/Z^2) + (1/N)(\Sigma W_h S_h^2)] \quad (2)$$

where

- W_h = weight of stratum h;
- S_h = composite standard deviation of vehicle miles per mile in stratum h = $\sqrt{S_s^2 + S_t^2}$, where S_s^2 = spatial variance and S_t^2 = temporal variance;
- E = absolute error in average vehicle miles per mile = relative error x (total vehicle miles ÷ total miles of roadway);
- Z = normal variate; and
- N = total miles of streets.

In maintaining a 68 percent confidence level, a normal variate of 1.0 and a relative error of 5 percent were used for both arterial and collector systems. E was computed for geographic subareas by multiplying the 1976 average annual daily traffic (AADT) for an area by the relative error e.

The spatial standard deviation S_s was assumed to be 30 percent of the range of each volume stratum. The temporal standard deviation S_t was computed from the product of the mean strata volume and the temporal coefficient of variation C_t. The suggested C_t values listed in the FHWA Guide were applied to the appropriate strata for this study.

Once the required mileage was computed for each stratum, the required links were determined by dividing the average strata link mileage into the sampled mileage. Table 3 gives an example of the procedure for stratified random sampling computation for arterials and collectors in one area by using Equation 2, where Z = 1 and E = 0.05.

One-Hundred Percent Sampling

Consideration was given to using the stratified random

Table 2. Sample-size computations by simple random sampling.

Area	N	Links	Miles Per Link	N Miles	N Links	Equivalent Percentage of Sample	Numeric Range Beginning Number	Numeric Range Ending Number
Areawide	645.12	3006	0.215	19.52	91	-[a]	-[a]	-[a]
1	161.20	800	0.202	18.19	90	11.25	249	1048
2	118.62	657	0.181	17.62	98	14.92	1124	1780
3	89.55	408	0.219	16.97	77	18.87	1827	2234
4	26.50	106	0.250	12.47	50	47.17	2249	2354
5	94.02	440	0.214	17.09	80	18.18	2423	2862
6	39.07	163	0.240	14.19	59	36.20	2909	3071
7	66.33	189	0.351	16.11	46	24.34	3114	3302
8	49.83	243	0.205	15.14	74	30.45	3367	3609
Total	645.12	3006	0.215	147.30	665	22.12		

[a]Use sample computations by area.

Table 3. Sample-size computations for area 1 by stratified random sampling.

Volume Range (vehicles/ day)	Mean Volume (vehicles/ day)	N_h	W_h	No. of Links	C_t	S_t	S_s	S_h	W_hS_h	$W_hS_h^2 \times 10^3$	Links in Sample
Arterials											
0-5000	2 500	6.59	0.144	27	0.20	500	1500	1581	227.56	360	7
5000-10 000	7 500	22.29	0.487	86	0.14	1050	1500	1831	891.70	1633	23
10 000-15 000	12 500	9.81	0.214	32	0.12	1500	1500	2121	453.89	963	10
15 000-20 000	17 500	2.48	0.054	11	0.10	1750	1500	2305	124.47	287	3
20 000-35 000	27 500	4.61	0.101	14	0.09	2475	4500	5136	518.74	2664	5
Total[a]		45.78	1.000	170					2216.36	5907	48
Collectors											
0-2500	1 250	6.84	0.404	35	0.20	250	750	791	319.96	253	12
2500-5000	3 750	3.27	0.193	13	0.14	525	750	915	176.94	162	6
5000-7500	6 250	4.00	0.237	14	0.12	750	750	1061	250.98	266	7
7500-10 000	8 750	2.03	0.120	9	0.10	875	750	1152	138.30	159	4
10 000-20 000	15 000	0.77	0.046	2	0.09	1350	3000	3290	149.81	493	1
Total[b]		16.91	1.000	73					1035.99	1333	30

[a] Average miles per link = 0.269, average daily traffic = 10 110, absolute error E = 506, and miles in sample = 12.758.
[b] Average miles per link = 0.232, average daily traffic = 5539, absolute error E = 277, and miles in sample = 6.898.

sampling technique for the freeway system in determining sample size, but a review of the link summaries, which revealed a small number of links per stratum, made the applicability of this methodology questionable. To maintain a recommended minimum sample size and the desired statistical reliability, a decision was made to sample 100 percent of this system.

SAMPLE SELECTION

Once the sample size for each subpopulation was determined, count locations were selected by using a computer program that generated random numbers. Each subpopulation represented a universe. The computer program was then given the varying number of samples desired. Randomly selected samples were identified, and a file of these records was created.

The data collection phase of the study covered 261 weekdays over a 12-month period. By using another computer program, a series of randomly generated numbers between 1 and 261 were selected to equal the total number of samples for each subpopulation. These numbers were then added to the selected sample file in order of their selection. Except for only minor modifications, this method of using random spatial and temporal selection of counting stations followed the statistical theories presented in the FHWA Guide. This obviated the necessity to factor the results obtained from the count stations.

DATA COLLECTION

The actual collection of sample traffic data began the week of December 15, 1977. Nondirectional hourly counts over a 24-h period within each selected link constituted a sample unit.

The collection of field data was assigned as an additional duty to an area traffic recorder. In most cases in this study, the traffic counters were set out on a weekly basis and hourly recorders were used. The sample day required was then obtained from an hourly paper-tape printout. The area recorder is assigned on a permanent basis to an area that includes the Chatham County-Savannah area; using these personnel therefore seemed to be the only satisfactory solution. A review of the work schedule indicated that fewer than 30 machines would be required for any given week and that this could easily be managed for a one-year period. Because of the spatial randomness of the samples, there was a wide dispersement throughout the area on an average setout and pickup schedule. The required travel for each schedule often exceeded 200 miles.

Prior to the assignment, the area recorder was instructed on how the machines were to be set and was provided with the following information:

1. A calendar schedule that indicated the actual calendar date, the weekday number (1 to 261), and the number of sets required on any given day;
2. A computer printout of selected samples that indicated the day to count, the exact location description, the weekday to count, and the proper area map to use;
3. A set of area maps that showed each selected sample on the appropriate map and each link number; and
4. An operation schedule that indicated the number of sets and pickups for each day during the project.

With this information, the area recorder was able to satisfactorily and expeditiously perform the assigned task. However, there were a greater number of machine failures than anticipated. These were attributed to several local situations that existed in the area at the time of the project but were in no way related to the project. During this time, there was an upheaval in property assessments for tax purposes, and annexation of unincorporated areas of Chatham County into Savannah was being considered. This situation resulted in acts of vandalism that were intended to abort counting activity on a given street. When residents adjacent to count sites were informed of the purpose of the traffic data, resets were usually obtained. It was decided that resets would be made the week after the occurrence of a failure, which worked very satisfactorily.

In addition to this method of collecting data, an alternate method was used in which the data collected from the annual coverage count program were used in estimating vehicle miles of travel (VMT). These traffic data are collected annually for 24-h periods and factored to account for temporal variations. A 5 percent random sample based on the number of local county roads and city streets were counted to estimate local VMT as in previous estimations.

DATA ANALYSIS

Once link volumes were obtained from selected sample locations throughout the study area, computations of VMT were made. The variability in VMT was then determined by first computing the data variance by each subpopulation and then the standard deviation from the mean VMT. This procedure is discussed in detail below.

Estimation of Vehicle Miles of Travel

The first step in calculating VMT was to simply multiply the 24-h traffic volume by corresponding link length. This was done for each sampled link in a given stratum by using the following formula:

$$vmt_{hj} = ADT \times l_{hj} \qquad (3)$$

where

vmt_{hj} = vehicle miles of travel for sample link j in stratum h,
ADT = average daily traffic, and
l_{hj} = sample link mileage in stratum h for sample j.

Since only a sample of the link network was counted, the VMT computed for these samples must be expanded to represent total VMT for a given stratum. In order to make this expansion, the rate of VMT per mile was determined by stratum by using the sample population. This rate was determined by using the following equation:

$$R_h = (\Sigma vmt_{hj}/\Sigma l_{hj}) = (vmt_h/l_h) \qquad (4)$$

where

R_h = rate of VMT per mile for stratum h;
vmt_h = total sample VMT in stratum h, and
l_h = total mileage of the links sampled in stratum h.

Once this rate was established, total VMT for a given stratum was obtained by using the expansion equation

$$VMT_h = R_h \times L_h \qquad (5)$$

where VMT_h = total VMT for stratum h and L_h = total link mileage in stratum h.

Variability

To evaluate the estimates generated by this project, some statistical measure must be developed. Since the measurements outlined in the FHWA Guide assumed uniform link length, the prescribed evaluation was not applicable to this effort. Thus, the standard procedure for obtaining variance and standard deviation was applied.

The variance of mean VMT per mile for each stratum was first obtained by using the following formula:

$$S_h^2 = \Sigma(ADT_{hj} - \overline{VMT}_h)^2/(n-1) \qquad (6)$$

where

S_h^2 = variance of VMT per mile in stratum h,
$\overline{ADT}_{hj}$ = average daily traffic of link j in stratum h,
$\overline{VMT}_h$ = mean VMT per mile in stratum h (i.e., the weighted average ADT for stratum h), and
n = total samples in stratum h.

The overall variance by highway functional classification was then computed by using

$$S_c^2 = (\overline{VMT}_{hc} - \overline{VMT}_c)^2/N_c \qquad (7)$$

where

S_c^2 = variance of VMT per mile of functional classification c,
$\overline{VMT}_{hc}$ = mean VMT per mile in stratum h that falls in functional classification c,
$\overline{VMT}_c$ = mean VMT per mile in functional classification c (i.e., the mean of the h strata containing functional classification c), and
N_c = number of strata that contain functional classification c.

The variance for the entire study area can be computed similarly; however, because of the wide dispersion in VMT rates by functional classification (such as the rate for a local road compared with an Interstate rate), this statistic was considered to be insignificant.

The coefficient of variation was then computed for each stratum and for each functional classification by

$$C = S/R \qquad (8)$$

where

C = coefficient of variation,
S = $\sqrt{S^2}$ = standard deviation of the mean VMT rate per mile, and
R = mean VMT rate per mile.

STUDY RESULTS AND COMPARISONS

Estimations of VMT were computed for each of the eight geographic subareas previously defined and for four highway functional classifications in each subarea. Since three of these subareas did not contain any freeway links, a total of 29 subtotals were obtained. A sample of the VMT computations, which follows the procedure previously outlined, is given below (ADT based on a 5 percent sample):

Strata	Number of Samples	Total Sample Mileage	Total Sample VMT	VMT Rate per Mile		Total Mileage		Expanded VMT
23	15	6.96	42 841.04	6155.32	x	13.11	=	80 696.25

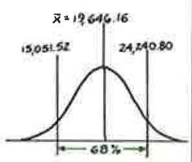
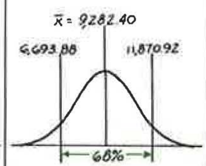
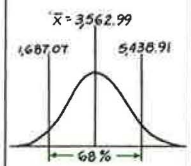
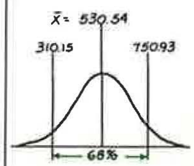
This method, which uses Equations 3, 4, and 5, was followed for expanding VMT for each stratification throughout the study area.

The geographic stratification was made in order to provide local planners with the ability to assess relative travel and make VMT comparisons within their area of responsibility. For the purpose of this research evaluation, VMT estimations were compiled by functional classification, as given below:

Functional Classification	Total Mileage	Total VMT
Freeways	48.12	846 170.28
Arterials	175.16	1 739 944.93
Collectors	113.68	392 031.93
Locals	645.12	376 284.53
Total	982.08	3 354 431.67

A comparison of the total VMT estimation with the VMT estimation produced annually through Georgia's coverage counting program was made (for city street

Figure 2. Variability of estimates of vehicle miles of travel.

	Freeways	Arterials	Collectors	Locals
Mean VMT: $\overline{VMT}_{(fc)} = \frac{\overline{VMT}_{h(fc)}}{n_{(fc)}}$	19,646.16	9,282.40	3,562.99	530.54
Variance: $s^2_{(fc)} = \frac{\overline{VMT}_{h(fc)} - \overline{VMT}^2_{(fc)}}{n_{(fc)}}$	21,110,718.00	6,700,447.60	3,519,079.88	48,573.17
Standard Deviation: $s_{(fc)} = s^2_{(fc)}$	4,594.64	2,588.52	1,875.92	220.39
Coefficient of Variation: $c_{(fc)} = \frac{s_{(fc)}}{\overline{VMT}_{(fc)}}$	0.234	0.279	0.527	0.415
Distribution Curve:				

and county road estimates, ADT was based on a 5 percent sample):

Route Designation	Miles	VMT Rate (mean ADT)	Total VMT
State routes			
Savannah urban area	66.66	15 243	1 016 098
Chatham County	91.77	10 151	931 557
Estimated	16.38	12 293	201 366
City streets			
Savannah urban area	100.13	7 976	798 603
Chatham County	1.76	510	899
Estimated	309.47	317	98 102
County roads			
Chatham County	33.17	2 099	69 619
Estimated	395.89	317	125 497
Total	982.08		3 241 740

As noted, the research methodology produced a daily total VMT of 3 354 431 compared with 3 241 740 produced by Georgia's current methodology—a difference of only 3.48 percent.

A comparison was also made between these two methodologies in the cost of field data collection:

Item	Amount ($)
Research methodology	
Salary (54.9 days at $45.39/day)	2491.67
Benefits (at 37.05 percent)	923.17
Subsistence	0
Vehicle use (4888 miles at $0.094/mile)	459.47
Total	3874.31
Coverage count methodology	
Salary (22 days at $45.39/day)	998.58
Benefits (at 37.05 percent)	369.97
Subsistence (15 days at $22.00/day)	330.00
Vehicle use (1392 miles at $0.094/mile)	130.85
Total	1829.40

In summary, the research methodology cost 111.78 percent more than Georgia's conventional method and yielded only a 3.48 percent difference in the VMT estimation.

VARIABILITY OF ESTIMATIONS OF VMT

Once the computations were made for each stratum, the variance from the mean VMT per mile for the corresponding stratum was obtained by using Equation 6. To maintain consistency with the VMT tabulations, variance was computed by functional classification. This was accomplished by using Equation 7 to compute the variance of the mean VMT rate per mile by functional classification. A standard deviation for the estimate by road class was then obtained by simply taking square root of the variance.

The variability of VMT estimations could then be computed by finding the coefficient of variation by using Equation 8. These computations and numeric distributions for each functional classification are shown in Figure 2.

CONCLUSIONS

The once obscure statistic, vehicle miles of travel, required annually by the Statistical Division of FHWA, has in recent years become very important information. With the U.S. Department of Energy and the Environmental Protection Agency now requiring VMT estimates in their planning and policy evaluation process, VMT estimates have assumed new significance. In the past, many methods and combinations of methods have been used to calculate this statistic. Recent survey documentations indicate a wide range in methodologies for calculating VMT and in the variance of the data provided.

This approach of sampling links in various strata selected randomly to account for spatial and temporal variations provides a uniform systematic method for computing VMT. The idea of a uniform method is a positive approach to resolving a problem that will increase in magnitude as programs become more dependent on the VMT statistic.

As shown by the comparisons presented in this paper, the temporal variation can be addressed in a less costly manner than that outlined in the FHWA Guide with only a minor variation in results. Factors of temporal variation are readily available from continuous-count and seasonal-control programs that are currently maintained in most states. This study does, however, point out the desirability of using counting locations that are randomly selected by functional classification to allow for spatial variation in computing VMT.

In summary, the use of current counting programs combined with this research methodology could yield a better procedure for estimating VMT to provide consistent reporting in the future.

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Travel Data from the U.S. Census: A New Foundation for Transportation Planning

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The 1980 U.S. Census of Population and Housing will include the largest source of urban transportation data ever available for a single point in time. To properly use these data requires that planners understand the difference between census definitions and those commonly used in transportation. This paper describes those differences as well as the data that will not be included in the census. It recommends methods of local data collection that can supplement the census data to complete the measurement of total travel. Finally, it proposes a method of keeping the census commuting data up to date without extensive inventory data for 1980. The method is suitable for small urban areas as well as large metropolitan regions.

Plans for the 20th decennial census of the United States are virtually complete. Since the 1970 census, there have been drastic changes in the nature of transportation planning. At the same time, almost no new data on areawide travel patterns have been collected through regional transportation studies. This makes it essential for those interested in obtaining current travel information to learn about possible applications of census data as well as supplemental data needed to fill in the picture of total travel. Now is the time to plan for the supplemental data that must be collected by state, county, and municipal transportation agencies to get the maximum value from the 1980 census.

This paper identifies additional data needed to measure commuting in terms that are useful to transportation planners as well as appropriate measures of nonwork travel. Perhaps even more importantly, it proposes a means of keeping the commuting data up to date so that the 1990 census could be used to verify such information rather than being used as the sole source.

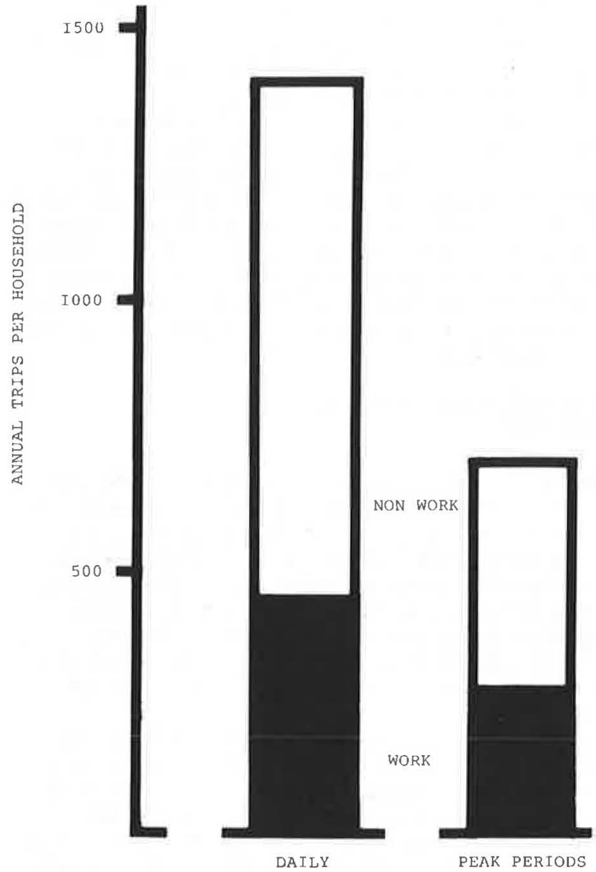
SUPPLEMENTAL DATA ON COMMUTING

As described elsewhere (1), the journey-to-work data included in the 1980 U.S. Census of Housing and Population will include work destination, "usual" means of travel, and average travel time. Although this information, if properly collected and coded, will provide an excellent means of estimating overall commuting patterns within an urbanized area, it leaves some significant gaps in comparison with data that are commonly available through travel surveys. Trip frequency and work schedules are believed to be essential items for all urban areas if census commuting data are to be used properly. The other items described should probably be considered only for large urban areas.

1. Trip frequency—The 1980 census plans to ask about the usual means of travel used in the preceding week. Transportation planners generally use an average-day definition. Although work-trip generation rates have been relatively stable in the past, it would be very valuable to verify these rates for 1980, especially with increasing opportunities for four-day weeks and part-time employment.

2. Work schedules—An understanding of work schedules is critical to factoring average daily work trips to estimates of peak-hour utilization. Although the per-

Figure 1. Trips by U.S. households in 1970.



centage of workers commuting during the traditional 7:00 to 9:00 a.m. and 4:00 to 6:00 p.m. peak periods remained markedly stable between 1955 and 1968 in the Washington, D.C., area (2), there are some indications that this rate may now be changing. Staggered work hours, flextime, and four-day weeks appear to be reducing the percentage of commuting during peak periods. Such a critical parameter needs to be checked once more in 1980.

Obtaining these missing data items requires some special data collection. A survey of commuters gives the opportunity to collect additional data that, although not essential for all urban areas, will be extremely useful in analyzing current commuting patterns and projecting them into the future.

The principal characteristics that would probably be of interest to most transportation planners are described below. Since these supplemental surveys are likely to be conducted locally, other items of interest could easily be added.

1. Alternate mode—In investigating why commuters choose certain travel modes, it has been found that many commuters have no choice, or at least no reasonable one. The most common example of such limitation is the person who is a transit captive because the household does not own an automobile. This information will be included in the 1980 census. Many commuters from automobile-owning households, however, are relegated to the status of transit captive by other family members who preempt the family automobile for commuting or other purposes. In contrast to transit captives are automobile captives—those whose neighborhood has no bus service. Finally, a factor that can almost force a downtown commuter into an automobile regardless of transit service is the availability of free parking. Free parking for commuters is surprisingly common even in some large cities. To better define these options, a survey of commuters should inquire about automobile availability (as opposed to automobile ownership), transit availability, and the availability of free parking.

2. Land use at destination—To relate nonresidential travel demands to the composition of a commercial or industrial district, it is necessary to obtain information about type of land use at the destination or attraction end of the work trip. When these data are merged with local government files, it will be possible to calculate trip-attraction rates per job, per unit of land area, or per area unit of floor space.

3. Transit access—A major concern in large- and even moderate-sized regions is the mode of access used to get to transit. For rail rapid transit systems, the means of access is important. However, the census will not identify such mixed-mode trips but will collect data on the predominant mode.

This analysis has identified two additional data items that are felt to be critical to maintaining consistency between the 1980 census journey-to-work data and regional travel data. Both work schedules and trip frequency can probably be obtained from a sample of employers without direct surveys of commuters. Alternate mode, land use at destination, and mode of access to transit, where necessary, must be obtained from a direct commuter survey. Trip routing for transit trips could be largely determined through some minor adjustments to the coding of the census questionnaire in such a way that all modes used, rather than simply the predominant mode, would be identified. The other two additional data items must be obtained through a supplemental survey at the local level. However, since they are of principal concern for downtown workers, it is felt that such needs could be met by a carefully designed, small-scale survey of downtown workers distributed through the cooperation of private businesses and major downtown government agencies.

NONWORK TRAVEL DATA

It can be seen in Figure 1 that in 1970 commuting represented a minority of daily household travel in the United States even though it did account for a majority of peak-hour trips. Moreover, although there is a broad range of research on commuting as well as a generally acceptable theory and operational models, there are many unknowns about nonwork trips. For this reason, we are not attempting in this paper to design a detailed methodology for measuring nonwork trips to supplement the census. Establishment of a monitoring system to keep the commuting data current is felt to be much more critical. However, in areas that have the resources to do both, it is felt that a small survey to measure total nonwork travel would be desirable. Because of the underreporting of nonwork trips in most travel surveys, it is felt that measuring the total vehicle kilometers of travel for nonwork trips would be more productive than a non-work-trip survey. Nonwork transit trips could be reported separately (it was found in the 1968 home-interview survey of the Washington, D.C., area that, although there was more than 50 percent underreporting of some categories of nonwork trips, there was virtually complete reporting of transit trips). In fact, the controlling factor would probably be total vehicle kilometers of travel for an average day and week. If the automobile were driven to work, the number of kilometers traveled on that trip could be subtracted to estimate nonwork vehicle kilometers traveled.

Monitoring vehicle travel (and perhaps person travel) in this fashion would produce some new data that could satisfy two emerging issues in transportation. The first of these is the possible trade-off between weekday work trips and weekend recreational trips that might occur if commuters were confronted with gas rationing or major gasoline price increases. Most older travel surveys measure an average weekday and ignore weekend travel completely. The second concern is the need to relate vehicle kilometers of travel to the vehicle fleet mix, which is generally impossible with any of the older surveys. Such estimates are necessary to meet air quality planning needs.

Finally, relating vehicle kilometers of travel directly to automobiles would make it possible to estimate future changes in travel indirectly by monitoring changes in vehicle registrations. Since vehicle registrations have been found to correlate closely with vehicle kilometers of travel, this is a simple method of simulating aggregate travel on a current basis. When this measure of total travel demand is compared with commuting travel as determined by the methods described above, it should give a good estimate of changes in nonwork automobile travel at a fraction of the cost of a continuing home-interview survey.

SUPPLEMENTAL DATA ON USE OF FACILITIES

Since the approach recommended here will generally not allow the estimation of volumes of travel on individual routes, it does not justify an extensive traffic-counting program to support it. In fact, it is felt that a count program designed to measure changes after the census, especially in growing areas, would be much more valuable than a complete coverage count at a single point in time—i.e., 1980. It is recommended that the measurement of the use of transportation facilities in 1980 concentrate on the following areas:

1. Regional vehicle travel—There are recommended procedures that can be used to estimate regional vehicle travel through a carefully designed sample (3). This regional estimate can then be used as a control, and individual travel components can be expressed as shares of regional vehicle kilometers of travel. A recommended refinement of the regional estimate would be an estimate of peak-hour or peak-period vehicle kilometers of travel since commuting accounts for such a large share of travel in that time period. Different regions may also wish to estimate vehicle travel separately for different jurisdictions, such as central city versus suburbs, or different development areas, such as CBD, high-density residential, and low-density residential.
2. Central-area cordon count—Because of the traditional importance and heavy travel demands of the central area, a special one-day cordon count would appear to be very useful, especially if it could be related to longer-term traffic counts on each of the routes of entry. This cordon count could estimate not only the mix of vehicles entering the central area but also automobile occupancy and transit ridership, which are highest in central areas. These data could then be related to the journey-to-work estimates for commuters employed in the central area.
3. On-board transit survey—In areas that exhibit significant transit ridership, an on-board transit survey would be a valuable complement to the journey-to-work data of the 1980 census. The work-trip data obtained in such a survey could be compared with the commuting data obtained in the census. Valuable supplemental data, such as mode of access, transit route, and walking distance at each end of the trip, could be obtained. Such a survey is probably the only feasible method of obtaining data on nonwork transit trips, especially for transit-dependent groups.
4. Parking inventories—Areas of high commuter parking demand will be readily identifiable through the 1980 census. A study of parking price and occupancy conducted during the same period will identify total parking demand, of which commuter parking is only a part. Comparing these data with the number of drivers commuting to the CBD, as identified in the census, could make it possible to identify imbalances between parking demand and supply at a fraction of the cost of a conventional parking survey.

CONTINUING DATA BASE ON COMMUTING

By the time the 1980 census results on the journey to work are available, it will have been 15 years or more since the previous regional travel surveys were conducted in most urban regions. In view of the extensive changes in urban growth patterns, costs of transportation, and attitudes toward the regulation of travel in metropolitan areas that have occurred during this period, it is amazing to consider that public policies have generally been formulated without hard data on current travel.

It appears that, although the Federal Highway Administration intended the studies of the 1960s to make the transition into continuing planning processes in the 1970s, the need for continuing travel data was not resolved. Several agencies saw the need to refresh their travel data base of the early 1960s with a small-scale, continuing effort that would not become outdated (4). However, the federal procedures did not specifically call for new travel data. Instead, they recommended monitoring the inputs to the travel demand process, running the models calibrated on the original survey, and attempting to simulate ground counts (5). Unfortunately, there are so many factors that can be adjusted to bring about such a simulation that important discrepancies can be masked.

It has become increasingly difficult to obtain approval for efforts to collect new travel data, especially with more priorities on planning funds including satisfying new federal requirements. At the same time that metropolitan planning organizations were struggling to keep their regions certified to do transportation planning without new data, there were increasing calls from the federal government for new data on components of the traveler market, such as the elderly, the handicapped, minorities, and low-income trip makers.

In my opinion, some of the plans for continuing home-interview surveys were overly optimistic. However, maintaining a continuing planning process without anticipating any new data is similarly unrealistic. The compromise recommended is a program of monitoring commuting patterns to new job locations. In fact, such an effort to detect change may prove to be more valuable than any supplemental data collection effort tied in with the census. It should be designed in such a way as to analyze the location of new jobs, identify the location of workers' residences and work schedules, and measure the relative use of at least the automobile, the carpool or vanpool, and transit modes.

New Job Locations

The recommended program provides extremely valuable data on two major travel determinants: job location and home location. These can be obtained directly from the employer without resorting to a personal survey. Measuring changing job locations will provide a direct comparison with the accuracy of small-area employment forecasts, probably the most important single factor influencing future travel demand. Tracking the residences of workers in new businesses will provide a check on the accuracy of local housing forecasts and also yield a valuable measure of the extent of in-commuting from exurban areas, a trend that seems to have been a major factor in declining growth rates within the statistical boundaries of many urban areas.

When the relations between new jobs and residences are established, it will be possible to add this matrix to data produced from the 1980 census to produce a quick estimate of current commuting patterns. It could be assumed that the distribution of trips by modes for trip interchanges that existed in 1980 would not change.

The next improvement in this process is a survey of commuting modes, perhaps stratified to concentrate on certain corridors. Having already established the distribution of trips, such a survey could be scientifically designed to produce accurate data, at relatively low cost, on actual travel modes as well as on alternatives, characteristics of the destination, and details on the routing of the trip. Such data would provide information on changes in the extent of carpooling and transit use in major commuting corridors. This would be an extremely valuable means of measuring the success of major transportation system improvements. This special survey could also be used to establish modal splits for patterns that were rare or nonexistent in 1980.

The data on commuting to new job sites would provide a means of establishing changes in commuting patterns at a very early stage. Rather than measuring changes by monitoring aggregate commuting patterns, the homes and travel modes of employees at new work places could be monitored. Such changes could also be simulated through the use of existing models to see whether they can be predicted accurately. In this way, major changes in commuting behavior can be identified soon after they happen rather than after they have become significant enough to affect aggregate commuting streams—a slow, evolutionary process.

Finally, the political value of such current data should not be underestimated. Although technicians may be convinced that models calibrated on 1960s data can simulate current travel in the 1980s, this strains the credibility of the planning process with nontechnicians. It is not necessary to have a great deal of data. A small survey will usually satisfy politicians and citizens who are supportive participants in the transportation planning process (especially if there is no other information). Antagonists will not be satisfied with any amount of data if they disagree with the results. However, friends of the transportation planning process will be a lot happier if they can be shown that this process is not completely detached from the world of hard data.

Conceptual Framework for Identifying Commuting Patterns

There is a great deal of flexibility in the manner of identifying "new" employment locations. The most rigorous method would be to identify jobs at any new office or industrial site as new jobs. An initial assumption would then be that existing buildings would continue to draw workers from approximately the same labor-market area as in 1980 and with similar work-schedule and mode-split characteristics. A much simpler assumption would be to classify new jobs according to whether they occur within existing or new employment districts. Jobs in employment districts that were relatively well developed in 1980 would be assumed to generate work-trip patterns similar to those identified in 1980 census data on the journey to work. A simple factor could update them. Newly developing employment districts would include new employment centers on the fringe of the downtown area as well as those in new suburban areas. Only jobs in these developing areas would be surveyed.

Once the method of identifying new jobsites is determined, a sample can be drawn for all new jobsites. This can either be a simple random sample or a stratified sample in which the sample rate is proportional to the size of the employer. Although a detailed design should be done, it is expected that a sample of about 10 percent would be appropriate.

The first stage of the survey would be to identify only work schedules and the locations of workers' residences. It should be possible to obtain this information through the employer. If additional data, such as mode split, are required, they must be obtained through direct survey. But the information already obtained should make it possible to select a highly structured sample. For example, if data are desired on carpooling to a new suburban plant adjacent to a freeway that has a reserved carpool lane, the sample could be designed to focus only on employees who reside in that particular corridor.

A final improvement on this process would be to resurvey employees who work in areas that were developed in 1980. This would be done where there was reason to believe major changes had been made in commuting patterns. In combination with the data on commuting to new work locations, this would then constitute a complete update of the journey-to-work data of the 1980 census.

Potential Data Sources

The key data resource in this proposal is a means of identifying new work sites. The greatest advantage of the technique is that it requires only a mechanism for monitoring change, not one that will establish a complete base-year situation. The base-year file would come from 1980 census commuting data. Two common sources of such data on change are employer files and building-permit files.

Employer files have been developed from state employment-security records in several areas. Such files not only list employment for all private and government employers at a given point in time but can also be linked for different years (6). Once an employer record has been put into a fixed format and coded to a small area, changes in employment for all future years can be obtained by a computer match. Moreover, since the proposed method requires only changes in employment since 1980, it is not necessary to do all the processing for a base-year file. All that is needed is a copy of the raw files for 1980, which can be matched to future-year files to identify new employers. However, many new-employer records will probably represent businesses moving into locations that existed in 1980 to take the place of other businesses that have moved out. Since the initial effort will concentrate only on new buildings, the files can be compressed to premise address so that turnover at existing addresses will not be surveyed.

A much simplified method involves identifying new employment sites rather than new firms. Such a data file could range in sophistication from a complex property identification system that identifies changes in building space to a simple inventory of all new nonresidential developments in a community. The latter list could be compiled by someone familiar with the area.

A middle-ground approach would be to use data on building permits. Although a considerable number of building permits can be issued yearly even in small regions, a recent study by the Baltimore Regional Planning Council showed that in 1975 commercial permits accounted for only 2 percent of all permits issued in Baltimore. Furthermore, since building permits are themselves measures of change, such a system could be initiated in 1980, just in time to identify buildings opened after the census. The 1980 base data would be assumed to be reflected in the census data.

SUMMARY

A census is a major undertaking. The collection of travel data planned for the 1980 census will require a monumental effort in data reporting, checking, coding, and processing in order to deliver a useful product to transportation planners. However, as discussed in this paper, even the highest-quality census output will fall short of the needs of transportation planners. Not only is the coverage restricted to commuting, which represents a minority of the daily trip making of households, but there are also gaps in the types of work-trip data commonly used by planners. Certain of these missing data items could be supplied by a limited survey of employers; others would require a direct survey of commuters. Nonwork travel data, if desired, must be obtained through locally sponsored surveys.

The main opportunity presented by the census seems to be that of establishing a foundation for a continuing data base on commuting. By using the 1980 census journey-to-work data to estimate home-to-work interchanges by mode for each zone in a region, the most expensive part of such a data base can be minimized. Identifying change in work locations after 1980 at the local level and surveying workers at these new sites can provide an affordable method of detecting change since 1980, which will make it possible to keep the census data up to date.

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Workplace Interviews as an Efficient Source of Travel Survey Data

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In recent years, personal surveys have become increasingly expensive. At the same time, doubt about their reliability has increased. In addition to cost increases, a problem shared by most other service industries, other problems in personal surveys include the increased difficulty of finding adults at home and higher nonresponse rates because of privacy and security problems. The results of two recent travel surveys conducted through employers in the Washington, D.C., area indicate that such a sampling frame may solve many of these problems. With the cooperation of slightly more than 400 employers, 10 000 questionnaires were distributed. The response rate compared quite favorably with that of personal surveys on similar subjects, and the costs were a mere fraction of the cost to conduct such a survey in person. The general applicability of this technique, as well as its potential application for private survey research firms rather than government agencies, is discussed.

The increased difficulties of obtaining survey data from individuals have become so widespread that they have now become a concern not only to survey researchers but also to the public at large (1). The two principal problems are a dramatic decrease in the probability of finding people at home during the day and a marked increase in the nonresponse rate. These two problems also contribute to excessive increases in the cost of surveys.

A possible solution in those surveys that collect information only on the employed labor force is to interview workers on the job rather than at home. This virtually ensures that a contact will be made with a respondent within a reasonable number of calls. It also makes it more likely that the survey will be completed by respondents, especially if the employer's approval is given, since the questionnaire can then be

Table 1. Sample design for travel survey.

Number of Employees	Establishments	Establishment Sample Rate (%)	Samples	Number of Employees[a]	Employee Sample Rate (%)	Employee Sample Yield
≥250	90	100	90	59 751	10	5 975
50-249	571	20	114	56 376	50	5 700
10-49	2 570	5	129	53 275	100	2 664
1-9	7 096	1	71	24 287	100	243
Total	10 327		404	193 689		14 582

[a]All firms.

Table 2. Rate of employer cooperation.

Type of Business	Number of Employers	Cooperating Employers by Number of Employees (%) 0-9	10-49	50-249	≥250	All
Service	167	45	85	95	84	78
Trade	83	31	50	50	71	46
Finance, insurance, real estate	38	60	92	100	86	84
Transportation, communication, utilities	30	100	100	75	100	93
Industrial	14	50	71	-	100	71
Total						
Before survey	332	43	76	81	88	72
After survey	315	64	70	81	89	72

completed in the employee's office or work station, which may be a more convenient environment than the chaos that occasionally exists in the home when the interviewer calls. Moreover, intrusions on the privacy of the office are not felt to be as much of an invasion as those on the privacy of the home. Finally, the ability to fill out the form on the employer's time rather than on one's own time is an extra incentive, especially for busy people.

All of these factors point to the desirability of a workplace survey. When the Metropolitan Washington Council of Governments (COG) was investigating alternatives for surveying commuters to measure the impact of the Metro rail rapid transit system, it was decided that a workplace survey was the only feasible means of collecting the information. The results described in this paper summarize COG's experience with two such surveys—one conducted in the early summer of 1977 and referred to as the "before" survey and one conducted during the fall of 1978 and referred to as the "after" survey. These results indicate that such a survey is a major improvement over more traditional techniques.

SAMPLING DESIGN

The three principal employment components in the central area of Washington, D.C., and adjacent northern Virginia are the private sector, the federal government, and the municipal (District of Columbia) government. In the surveys of the federal and municipal sectors, which were handled as separate surveys, a sample of employees was selected from an employee roster. Government workers received questionnaires through the normal distribution channels of their agencies. The private-sector survey required a distribution through each separate company location. Questionnaires were mailed back to COG in the before survey and collected by the survey staff in the after survey.

The most important advantage COG had in preparation for this survey was a file that represented a virtual census of employment for the metropolitan area. This file, the Regional Employment Census, is based on records from state employment security files (2). This made it possible to estimate the universe with greater accuracy, draw a random sample of employees, and expand the results to represent the universe.

The summary of the universe and the sample for the before survey given in Table 1 shows that, while the vast majority of the central-area establishments are small employers with fewer than 10 workers, most of the jobs are concentrated in a relatively few large firms. This suggests a stratified sampling plan that samples businesses in proportion to their number of employees. Such a plan also makes it possible to economize by yielding more responses per employer contact. It was decided to stratify private employers by four size groups as shown and use a declining sample rate from the largest to the smallest firms. Because of the number of employees involved in some of the larger businesses, it was decided to further sample a percentage of employees in these groups. Such a technique minimized the burden on large firms (those with more than 250 employees) by interviewing only 1 out of every 10 employees. In the next smaller size group, half of all employees were sampled. In groups below that size, questionnaires were distributed to all workers. In cases in which a sample of workers was required, the employer was given a procedure for selecting every "nth" employee from the roster after a random start.

The sampling plan for the after survey was similar except that large firms were given the option of selecting a sample of employees or distributing to everyone, which was sometimes easier.

EMPLOYER COOPERATION

The cooperation of employers in this survey was excellent. The definition of cooperation includes only employers who both agreed to participate in the survey and were able to elicit some response from their employees. As the data given in Table 2 show, almost three out of every four establishments that received questionnaires had at least some employees who responded. It is assumed that, in the remainder of the establishments, the employer either failed to distribute the questionnaires or did not sufficiently encourage employees to participate.

Table 3. Rate of employee response.

Type of Business	Number of Employees	Employer Response by Number of Employees (%)				
		0-9	10-49	50-249	≥250	All
Service	4877	55	40	36	43	40
Transportation, communication, utilities	1915	22	30	21	42	38
Trade	1555	29	19	26	26	25
Finance, insurance, real estate	989	43	44	46	54	48
Industrial	512	38	26	-	37	34
Total						
Before survey	9848	43	36	34	41	37
After survey		77	49	39	33	38

When employers in the before survey were classified by five major industry types, only the trade category showed a response that was below average—46 percent, or slightly less than a majority. The highest response rate—93 percent—occurred among transportation, communication, and utility (TCU) firms. TCU firms may feel obligated to cooperate because most of them are government regulated. The second highest rate of employer cooperation—84 percent—occurred in the finance, insurance, and real estate group. This group is also regulated by the government but not to the same extent as the TCU group. Seventy-eight percent of service establishments, which account for almost half of all private business locations in central Washington, cooperated in the survey. Finally, industrial employers, who are relatively rare in the central area, cooperated in the survey at about the same rate as that for all employers combined.

If these findings have general applicability, it appears that most establishments of the office type are very willing to cooperate in such a workplace survey. The lowest response rate was among retailers, whose employees do not have the same type of permanent work status as office workers. In addition, their salary scales are rather low, and they may employ illegal aliens or people who are not supposed to be working because they receive some form of government benefits. Finally, because of the number of business forms used in stores, retail employers may prefer not to have large numbers of survey forms circulating around.

Analysis of employer cooperation by size of establishment in the before survey showed a clear distinction between small firms (those with fewer than 10 employees) and larger firms. Although small firms had only a 43 percent rate of participation, more than 3 out of every 4 with 10 or more employees cooperated. Within this group of larger firms, there was a generally increasing participation rate as the size of firms increased; 88 percent of all the largest employers cooperated in the before survey and 89 percent in the after survey. The pattern of cooperation in the after survey was almost identical except for a significantly higher level of cooperation among small firms. Apparently, the fact that a member of the survey team scheduled an appointment to pick up the completed questionnaires was a subtle inducement to cooperate. In the before survey, questionnaires were returned directly to COG and no further visit was made to the site.

The relationship of participation rates by firm size within a given industry category (Table 2) confirms the patterns identified above for the before survey. Cooperation rates vary among industries, but within a given industry they are generally higher for larger businesses.

EMPLOYEE RESPONSE

After all employers from whom no response was received were eliminated, it was possible to calculate a true response rate as the ratio of questionnaires returned to questionnaires distributed to cooperating employers. The overall average in the before survey was 37 percent. Although this is only half the rate of employer cooperation, it is excellent for such a mail-back survey. The response rate in the after survey was an almost identical 38 percent. Like the rate of employer cooperation, the response rate in the before survey was lowest in trade establishments, where only one employee in four participated. In addition to the reasons for this cited above, many retail employees receive commissions, which means that spending time filling out forms could affect their wages. The highest response rate came from workers in the finance, insurance, and real estate sector, probably because these people are the most oriented to filling out forms. The other three industrial groups had response rates that were clustered in the 34-40 percent range.

Analysis of the response rate by size of establishment shows a different pattern from that described above (see Table 3). In fact, the highest rate of response was found among people who work for small businesses: Forty-three percent responded to the before survey and an impressive 77 percent to the after survey. This substantial increase in response appears to be the result of personal visits made to the site by the survey team in the after survey described above. In a small firm, a personal follow-up is very close to a personal survey since most employees are located in the same general work area. In fact, about half of the small firms in the after survey yielded a 100 percent response.

Response rates for larger firms dropped substantially in both surveys although they were consistently higher in the after survey for each firm size. Apparently, communications become somewhat more difficult in larger firms, which makes it more difficult to communicate survey goals effectively and thereby lowers the response. A possible solution would be to sample smaller operating units within large organizations.

The response rate for the next two largest categories dropped to 36 and 34 percent, respectively. It increased to 41 percent for large employers. The high response among people in small businesses may reflect the close proximity of the staff and, therefore, better communication of the survey goals. Although small firms may cooperate less frequently than larger firms, the actual response rate from the sampled employees is similar. This is a very important point because it has been indicated above that one of the goals of this technique was to minimize the types of selection bias frequently encountered in surveying private residences.

COSTS

One of the other major advantages claimed for this technique is the cost advantage over more traditional techniques. Since much of the cost of such a survey is borne by the cooperating employer and workers, the cost to COG was very low. The average employer distributed 35 questionnaires to employees, who on the average mailed back 11 completed forms. Because many of these employers were clustered within walking distance of each other, transportation costs were less than $0.50/site. More important, interviewer productivity was high: The initial employer contact could be completed in an hour, and frequently two businesses per hour could be visited. The salary cost per interview was about $1.25, an order of magnitude lower than the cost of obtaining the same data through personal interview.

SUMMARY

This paper has reported the experience from two large travel surveys of downtown workers conducted through the cooperation of employers. The results indicate that this technique has some major advantages over more traditional home-based interviews. Small businesses and retailers showed a lower rate of cooperation than other firms if there was no follow-up, but they were almost as cooperative as other businesses when they were told that a call-back visit would be made to pick up completed questionnaires. Once employers received the questionnaires, the response rate of workers in small businesses was actually much higher than that in larger firms. An important measure that seems to increase the response rate is to make the employer responsible for collecting completed questionnaires. This approach was not taken in the before survey because of the possibility that respondents would fear the disclosure of confidential information to their employer. However, use of this technique in the after survey caused no major problems. A similar survey conducted in the San Francisco area (which did not collect as much confidential household data) produced an excellent response rate of 58 percent by collecting the questionnaires through the employers (3). Finally, because much of the cost of this type of survey is absorbed by the employer, the survey cost to the sponsor is relatively low.

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Design of Small-Sample Home-Interview Travel Surveys

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Procedures for use in designing small-sample home-interview travel surveys are described. The following steps are addressed: (a) Decide on the purpose of the survey, (b) decide which variables should be measured to fulfill the purpose, (c) decide whether a home-interview travel survey can adequately measure the variables in question, (d) determine the coefficients of variation of the variables in question, (e) decide on a level of accuracy and a confidence limit, and (f) based on steps d and e, compute the sample size. Methods for using stratified sample frames are also discussed. The techniques are illustrated by using composite data from several urban areas. These data indicate that travel demand models can be developed from a survey of less than 1000 households.

The first step in any data collection is to decide on the purpose for collecting the data. If this decision is not made with the utmost care, there is a real danger that the survey will fail to produce the desired results. In the past, most origin-destination surveys of the home-interview type were conducted to replicate travel patterns in an urban area. Great care was taken to ensure that the survey instrument—i.e., the household questionnaire—was designed to extract just the right data. However, the sample sizes were not usually based on their ability to produce desired statistics within a specified accuracy. Usually 1 out of 10 or 1 out of 20 households was interviewed, on the basis of past experience or judgment, to duplicate travel patterns in the area (1). As a result, large sums of money were spent, and a large number of data were collected. The relations developed from these data have resulted in increased knowledge about the structure and interdependence of variables appropriate for travel demand forecasting. This increased knowledge should allow the development of procedures for determining sample-size requirements by statistical means.

The purpose of this paper is twofold: (a) to provide the transportation planner with a procedure that uses local data to estimate the required sample size for conducting a home-interview origin-destination (O-D) survey and (b) to provide the transportation planner whose local data are limited with typical data needed to determine sample sizes. These procedures are based on the sample sizes required to calibrate travel demand models rather than on sample sizes required to duplicate travel patterns. Therefore, in following the procedures described here the transportation planner will usually find that the sample size required for an O-D survey is smaller than conventionally thought. Thus, application of these procedures is likely to result in more cost-effective data collection and an overall savings of funds because fewer data need to be collected.

The methods described in this paper cannot be used to determine sample sizes for all kinds of transportation surveys, however. Only O-D surveys of the home-interview type are covered. Before consulting these methods, therefore, the planner must first decide whether such a survey is necessary. In general, a new O-D survey is needed if either of the following conditions exists:

1. There has never been an O-D survey in the area and models cannot be successfully borrowed from another area.
2. The previous O-D survey has been used to update old, unusable models, and the updated models yield unsatisfactory results. Normally, this occurs only when the previously collected data are fraught with errors or omissions or major land-use and growth changes have occurred that have significantly altered travel behavior in the area.

Statistically, sample sizes can be computed if the following information is known: (a) the variable to be estimated; (b) the coefficient of variation or, alternatively, the mean and standard deviation of the variable; and (c) the desired accuracy level and confidence limits. Each of these three components has often been ignored in the past.

The first component is basic. Before any survey is begun, one should know what the survey is going to measure. However, this requirement has often been forgotten. Most O-D surveys in the past were ostensibly designed to reproduce "travel patterns". Travel patterns may mean desire lines or entries in an O-D table. Not only is the definition of travel patterns vague but, with either definition, travel patterns are also impossible to measure with any reasonable degree of accuracy by using any reasonably sized O-D survey.

The second component is knowledge of the coefficient of variation (CV) of the variable being measured. When earlier surveys were taken, there was no such knowledge. Now, however, CVs of all kinds of variables related to transportation planning can be derived from past surveys in the same or similar areas. The procedures outlined in this paper assume such knowledge. If these data are unavailable in a particular area, the CVs shown in the examples in this paper can be used.

When the value of a particular variable is to be measured by a survey, the desired level of accuracy and confidence limit should be selected beforehand. An accuracy level is the percentage of sampling error that is acceptable to the analyst. For example, it may be decided that enough samples should be collected to estimate the average household trip rate to within ±10 percent. That is, if a trip rate of 8.0 trips/household is measured, the analyst wants to be reasonably sure that the true trip rate is between 7.2 and 8.8. Just how reasonably sure the analyst can be is determined by the confidence limit. Suppose a confidence limit of 90 percent is specified. The analyst would then be 90 percent sure that the true trip rate actually was between 7.2 and 8.8.

Any sample size can be made arbitrarily large by specifying a strict level of accuracy and a high confidence limit. Conversely, any sample can be made arbitrarily small by specifying a loose level of accuracy and a low confidence limit. Thus, substantial judgment is required in selecting the level of accuracy and the confidence limit. This is the art of statistically based sample-size determination. The important point is that selection of these figures quantifies the sampling accuracy of the survey.

Once the three elements of statistically based sample design have been determined, the sample size can be computed. The remainder of this paper is devoted to determining these three elements for each of the four steps in the traditional process of travel demand forecasting: trip generation, trip distribution, mode choice, and traffic assignment. The numbers used are composites taken from data collected in several urban areas. If the reader has no similar data for his or her area, these composites can be used.

In computing sample sizes, the formula used is

$$n = C^2Z^2/E^2 \qquad (1)$$

where

- C = coefficient of variation,
- E = accuracy level expressed as a proportion rather than a percentage,
- n = number of samples, and
- Z = normal variate.

The normal variate depends on the confidence limit selected. Knowing the confidence limit, the analyst can find the value of Z by using standard statistical tables. Equation 1 will be referred to throughout this paper as the sampling equation.

TRIP GENERATION

Trip generation is dealt with in two phases: trip production and trip attraction. Forecasts of total trip attractions are adjusted to agree with trip productions because the latter are considered more accurate. Therefore, sample sizes for creating accurate estimates of trip-production parameters are discussed here.

Since trip production occurs, by definition, at the household level, the appropriate variable to measure is trips per household. To measure trips per household to a desired level of accuracy, the CV of the variable must be known. Usually, the CV can be computed from previously collected local data. If local data are unavailable, a CV from a similar area, or an overall average of CVs from other areas, can be borrowed. To aid the planner who has no local data to use in computing a CV, an average CV from several areas is used here. A generalized sample size is then computed to illustrate the procedures of sample-size calculation. The table below gives some of the CVs that have been reported or computed:

CV	Variable	Source
0.28	For single-family homes only	Arizona Department of Transportation (2)
0.87	For all households	Nationwide Personal Transportation Survey (3)

CV	Variable	Source
0.86	For all households	Southwestern Pennsylvania Regional Planning Commission
1.07	For all households	Manchester, New Hampshire, 1964 O-D survey
1.05	For all households	Baltimore 1962 O-D survey

As can be seen, the computation of a generalized sample size is confounded by the variety of CVs available (2, 3). Except for the first CV, which is for single-family homes, all the CVs are close to 1. So, from this point on, sample sizes needed to compute trip rates will be based on a CV of 1.

The next step in computing a sample size to measure trip production is to decide on a level of accuracy and a confidence limit. This is the most difficult step in the process. These two parameters must be specified subjectively. To do this, the precise meaning and effect of each term need to be fully understood.

Level of accuracy has already been described and needs no further amplification. If a confidence limit of 50 percent is specified, half of the samples drawn will yield a statistic within the desired level of accuracy. This is the same confidence that would be generated by flipping a coin. Therefore, a stricter confidence limit is usually set. Confidence limits of 90, 95, and 99 percent are most often used. At a 90 percent confidence limit, 9 out of 10 sample groups will yield statistics within the desired level of accuracy; at 95 percent, the ratio is 19 out of 20; and at 99 percent, the ratio is 99 out of 100. Since sample size increases exponentially as the 100 percent confidence limit is approached, very strict confidence limits are seldom used; they are simply not worth the extra effort. For illustration, the 90 percent confidence limit is used in this paper for all sample-size calculations.

In computing a trip rate, high levels of accuracy should be set because the entire model sequence is driven by the number of trips generated. Accurate trip-generation rates do not, however, guarantee the production of a good set of models. For purposes of analysis in this paper, an accuracy level of 5 percent was chosen. Coupling this figure with a 90 percent confidence limit and a CV of 1, the sample size is computed by using Equation 1, where C = 1.00, Z (which depends on confidence limit α) = 1.645 (for α = 90 percent), and E = accuracy level as proportion = 0.05, or $n = (1.0)^2 (1.645)^2/(0.05)^2 = 1084$. So about 1000 samples will produce a trip-rate estimate to a tolerance of ±5 percent 90 percent of the time.

This procedure is fine if only a current estimate of the total number of trips per day in a given area is needed. However, a forecast of travel is usually desired. Therefore, the base-year trip rate is usually related to some of the other variables collected in the survey. These variables most commonly include automobile ownership, household income, and family size. If trip rates are cross-classified by automobile ownership and income, as in the table below, an estimate of each trip rate is desired:

	Automobiles Owned		
Income	0	1	≥2
Low	1.20	4.42	8.50
Medium	2.62	6.57	9.69
High	2.97	7.79	11.21

Each trip rate, however, does not have to conform to the same strict level of accuracy as the overall trip rate. Instead, a statistical technique for calculating sample sizes based on a stratified sample (in this case, stratified by income and automobile ownership) can be used. To use this technique, an overall level of accuracy is first selected. In this case, as before, it is assumed that the overall trip rate must be known to within 5 percent.

The next step is to compute a set of modified CVs, one for each cell. These CVs are modified in that they are computed by dividing each cell standard deviation not by each cell mean but by the overall mean. In conducting the background research for this paper, it was found that the set of modified CVs for trip rates cross-classified by income and automobile ownership were very similar for each urbanized area tested. A matrix of the average modified CVs computed is given below:

	Automobiles Owned		
Income	0	1	≥2
Low	0.31	0.72	1.02
Medium	0.40	0.92	1.26
High	0.45	0.99	1.24

After the matrix of modified CVs is obtained, an estimate of cell frequencies is needed. This requirement is based on the idea that cells that contain few households (such as the high-income, zero-automobiles cell) will not require estimates as stringent as those for more frequent cells. A realistic example of cell frequencies (i.e., an average of several areas) is given below:

	Automobiles Owned		
Income	0	1	≥2
Low	0.124	0.124	0.023
Medium	0.026	0.266	0.125
High	0.010	0.150	0.152

Use of Equation 1 requires a single CV, designated by C in the formula. In this case, however, many coefficients of variation are available. To get a single measure, each modified CV is multiplied by the corresponding cell frequency. The sum of the products is then the measure desired.

Thus, $C^* = \Sigma f_i C_i$, where i = cell index, f_i = frequency of cell i, and C_i = modified CV for cell i. C^* is then used in the sampling equation: $n = C^{*2} Z^2/E^2$, or $n = F C^{*2}$, where $F = (Z/E)^2$. The table below gives values of F:

Level of Accuracy (%)	Sample-Size Factors by Confidence Limit: 99 Percent	95 Percent	90 Percent	68 Percent
1	66 306	38 416	27 060	10 000
5	2 652	1 537	1 082	400
10	663.1	384.2	270.6	100
25	106.1	61.5	43.3	16

The application of these procedures is illustrated by the following step-by-step example, in which the data given in the second, third, and fourth tables above are used:

1. Enter the modified CVs (C_i) for each cell of the cross-classification matrix into column 3 of the worksheet given in Table 1. This worksheet is designed for analysis of a nine-cell matrix; for larger matrices, a larger worksheet would be used. The cell number that has the largest CV should be entered in the "critical cell" line.

Table 1. Worksheet for computing sample size.

Cell	Standard Deviation	Modified CV(C_i)	Frequency (f_i)	Factor (f_iC_i)[a]	Weight (W_i)[b]	Optimal Allocation[c]	Expected Frequency[d]	Full Random Sample[e]
1		0.31	0.124	0.038	0.042	37	110	154
2		0.72	0.124	0.089	0.098	87	110	154
3		1.02	0.023	0.023	0.025	23	20	28
4		0.40	0.026	0.010	0.011	10	23	32
5		0.92	0.266	0.246	0.271	240	236	329
6		1.26	0.125	0.158	0.175	155	111	155
7		0.45	0.010	0.005	0.006	5	9	12
8		0.99	0.150	0.149	0.165	146	133	186
9		1.24	0.152	0.188	0.208	184	135	189
Sum				0.905	1.000	887	887	1239
Critical cell		6						

[a]Column 3 × column 4. [b]Column 5/Σf_iC_i. [c](Column 5)xn. [d](Column 4)xn. [e](Column 4)xe.

2. Enter the cell frequencies (f_i) in column 4.

3. Multiply each CV in column 2 by the corresponding frequency in column 3. Record each product in column 5. Sum the entries in column 5, and record the sum at the bottom of the column. This sum is C*.

4. Choose a desired level of accuracy and confidence limit. In this case, ±5 percent level of accuracy and a confidence limit of 90 percent have been chosen.

5. Find the sample-size factor F (from the table in the text above) given the accuracy level and confidence limit. In this case, F = 1082.

6. Multiply F by the square of C*. The result is the sample size, i.e., $n = FC^{*2} = (1082)(0.905)^2 = 887$.

The resulting sample size of 887 is smaller than the 1084 computed for the simple, unclassified sample. There is a price that must be paid for this reduction, however. The sample size of 887 is for an optimally allocated sample; that is, the sample units must be selected in such a way that each cell in the cross-classification matrix contains an optimal number of samples. To determine this allocation, first divide each f_iC_i by the sum Σf_iC_i. The resulting weights W_i, when multiplied by the total number of samples (887 in this case), will yield the optimal allocation of samples. How to compute the optimal allocation of the sample and analyze the results is shown in the following continuation of the step-by-step example:

7. Divide each f_iC_i by the sum of the f_iC_i entries. Record the answers in column 6 of the worksheet, labeled W_i. For example, $W = (f_1C_1/\Sigma f_iC_i) = (0.038/0.905) = 0.042$. As a check, the sum of the W_i's should be 1.0.

8. Multiply each W_i by 887 (total samples from step 6), and round it off to the nearest integer. Record each product in column 7 of the worksheet. This is the number of samples required for each cell. As a check, the sum of the cell samples should be equal to the total number of samples (in this case, 887).

9. Multiply each f_i (see column 4 of the worksheet in Table 1) by the total sample size from step 6 above (in this case, 887). Record each product in column 7. This is the number of households that could be expected to fall in the various categories if a random sample of 887 households were drawn. So, if 887 households are drawn at random, 135 of them will be expected to fall in cell 9. But 184 samples are needed in this cell (see column 7 of the worksheet). Other cells will also be short of samples if a random sample of 887 is drawn.

10. The cell in which the shortfall of samples is most critical needs to be identified. In column 3 of Table 1, cell 6 was found to have the largest modified CV (see step 4). This is the critical cell.

11. The next step is to determine how much of a shortfall exists in the critical cell. To find out, divide the samples required (column 7) by the expected frequency (column 8) for the critical cell. In this case, the shortfall ratio is 155/111 = 1.396. Thus, the expected frequency for cell 6 falls short of the required number of samples by 39.6 percent.

12. Multiply each expected frequency in column 8 of the worksheet by the shortfall ratio found in step 11 above. Record the results for each cell in column 9. Sum the results. This sum represents the total number of random samples required to obtain sufficient samples in the critical cell. In this case, 1239 samples are required.

The number of samples required, computed by the above steps, is somewhat misleading. Although 1239 random samples are needed to produce the correct number of households in the critical cell, all other cells will have more samples than are needed to produce the overall trip rate within the desired accuracy and confidence limits. For example, 330 of the 1239 samples will fall in cell 5, but only 240 samples are required in that cell.

This excess can be handled in two ways. The first way is to conduct interviews at all 1239 households. Although more than the minimal data are collected, the data are at least sufficient to produce the desired statistic within the desired confidence and accuracy limits. But conducting complete interviews at all 1239 households may not be cost effective. A multistage sample design may be a better choice.

A multistage sample design consists of the following stages:

1. Collect a small amount of information from a large sample.

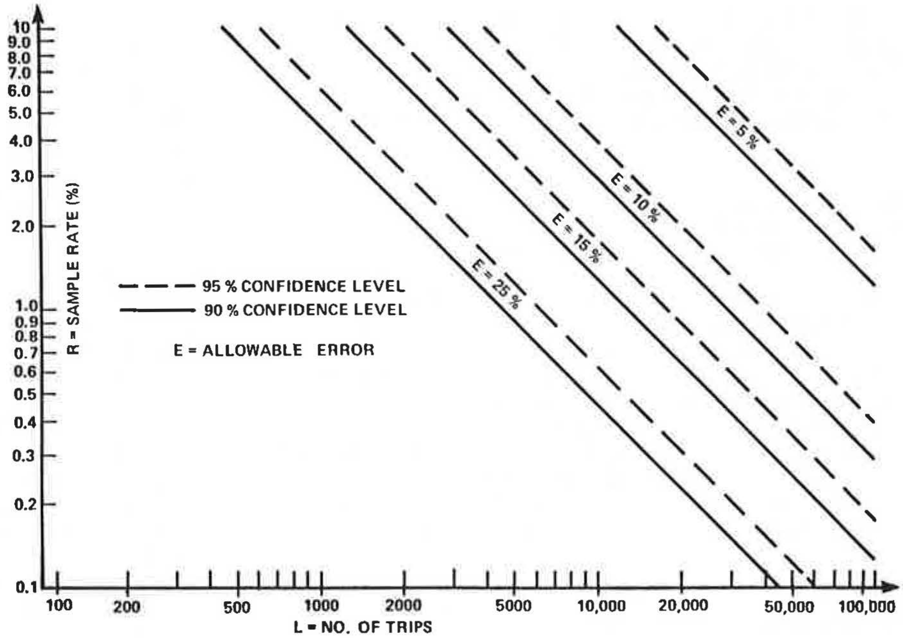
2. Stratify the households interviewed in stage 1 by the variables collected.

3. Identify a subset of households for an in-depth-interview stage based on the stratification made in stage 2.

In this case, 1239 first-stage interviews would be conducted. In each of the first-stage interviews, only enough information would be collected to assign the household to an income versus automobile ownership cross-classification matrix. After all 1239 households were so assigned, 887 of them would be selected for the in-depth interview. The number of households to be reinterviewed in each cell would be determined by the optimal allocation of households shown in column 7 of Table 1.

Alternatively, a multistage sample design can be performed by using a branched questionnaire. The interviewer asks enough questions to determine the category to which the household belongs. If the quota established

Figure 1. Sample rates for trip distribution.



for households in that category has been filled, the interviewer stops there and goes on to the next sample.

To determine which alternative—the full set of interviews or the multistage design—is the more cost effective, the following continuation of the step-by-step procedure is used:

13. The shortfall ratio computed in step 11 can be thought of as an expansion factor e inasmuch as it was used to expand the original sample size. The cost-effectiveness of the multistage procedure depends on e according to the following formula: $r = [e/(e - 1)]$ $[1.396/(1.396 - 1)] = 3.53$, where r is the cost-effectiveness ratio.

14. Divide the actual cost of an in-depth survey by the actual cost of a first-stage survey to yield the survey cost ratio R. In this case, assume a first-stage survey costs $10 and an in-depth survey costs $33. Then, $R = 33/10 = 3.3$.

15. If R is greater than the cost-effectiveness ratio r, conduct the survey according to a multistage sample design. Since in this case $R < r$, a multistage sample design would not be used. Instead, in-depth interviews would be conducted at all 1239 households. It should be noted, however, that the difference between R and r is very small in this case. Since the procedure for computing R and r used estimated figures, the analyst may, in this case, want to consider other, more subjective criteria before making a decision on which sampling method to use.

TRIP DISTRIBUTION

One way to approach sample-size determination for estimating patterns of trip distribution is to presume that the number of trips in each cell of the O-D matrix is to be determined within an acceptable degree of precision. Figure 1 shows the sample size required in making such an estimation. In the graph, L represents the number of trips expected for a given interchange. Thus, if an interchange that is expected to have a volume of about 1000 trips is to be measured to within 25 percent at 90 percent confidence, an R of 4.3 percent is required. The sampling rate is based on randomly selected trips rather than randomly selected households. If households are used as the primary sampling units, trip clusters will be measured; therefore, some of the variance will not be accounted for, and the sample size required will be greater.

The preceding argument shows that, even for very large interchange volumes, a high sampling rate is required to produce acceptable volume estimates. For ordinary volumes on the order of 20-30 per cell, the required sampling rate approaches 100 percent. It is not feasible, therefore, to produce an accurate O-D trip table from any reasonably sized home-interview survey. Even the large surveys conducted in the past had no hope of reproducing interchange volumes at the zonal level within a reasonable degree of accuracy.

How, then, are trip interchanges to be measured? Since they cannot be measured directly, they must be simulated. The most commonly used method of simulating travel patterns is the gravity model. Since calibration of the gravity model depends on the trip-length frequency distribution (TLFD), an accurate measurement of TLFD should provide the tool required to produce a reasonably accurate O-D trip table.

The problem with measuring a TLFD to within a given level of accuracy is in trying to designate one specific variable to measure. A TLFD is, by definition, a distribution of numbers rather than one single number. If, however, one single number can be found from which the entire TLFD can be derived, the task of sample-size determination will be much easier.

Fortunately, TLFDs can be derived from a single measure. Pearson and others (4) have shown that reasonable estimates of TLFDs, by trip purpose, can be derived from the mean trip length for each purpose.

Now that the variable to be measured is known, the coefficient of variation must be calculated. In their research, Pearson and others (4) created a standard TLFD for each trip purpose. In the process, they also created an implied CV of trip length for each trip purpose.

Given that the mean trip length, by trip purpose, is the variable to measure and given the CVs for each purpose, the only remaining task before computing the sample size required is to select a level of accuracy and a confidence limit. In keeping with the precedent established for trip generation, 5 percent accuracy at 90 percent confidence is used here for purposes of analysis.

When all three elements of the procedure for determining sample size are identified, the sample size can be determined by using the simple sampling equation, Equation 1. In this case, Z = 1.645 and E = 0.05; C and the resulting sample sizes are given in the table below:

Trip Purpose	C	Sample Size
Home-based work	0.53	574
Home-based nonwork	0.58	628
Non-home-based	0.63	682

The sample sizes are in trips rather than households. In conducting the background research for this report, it was found that urban households report an average of about 7 trips/day—25 percent being home-based work trips, 50 percent being home-based other trips, and 25 percent being non-home-based trips. By using these assumptions, the number of trips by purpose that would be generated from the 887 households selected to determine trip rates can be computed. The number of trips computed in this way are given below:

Trip Purpose	Trips
Home-based work	1552
Home-based nonwork	3104
Non-home-based	1552
Total	6209

As the numbers given above show, far more trips will be samples than the number necessary to compute a TLFD for each trip purpose. Therefore, if the number of trips per household, or the assumptions about the purpose split of trips, is changed slightly, the sample size will still be sufficient. In addition, sampling households to get a sample of trips introduces a clustering bias that increases the required sample size. Fortunately, this bias is small for computing mean trip length (5). Therefore, the excess samples shown should be more than sufficient to cover the bias.

The above analysis shows that a relatively small sample can be used to calibrate a gravity model. The analysis was based on the estimation, by statistical means, of the same sizes required to compute specific quantities. Other research performed by Ben and others (6) shows empirically that even samples as small as 600 trips can adequately reproduce a trip-length frequency distribution (6).

MODE CHOICE

There are three approaches to estimating the sample sizes required to measure mode choice:

1. Measure the number of automobile trips as well as the number of transit trips to within a few percent.
2. In highway planning, measure the percentage of transit to within a few percentage points to account for the number of automobile trips that the transit system is taking off the road. This measurement must be followed by a measurement of automobile occupancy. This option is particularly useful in smaller urban areas.
3. Calibrate a model for predicting mode-choice percentages under various future transportation options.

Option 1 is difficult with a home-interview survey. In most urban areas, a transit ride is a statistically rare event and therefore hard to measure in a home-interview survey. Data collected in the Nationwide Personal Transportation Survey indicate that the average of transit trips per household was 0.183 and the standard deviation was 0.752. Using these figures, an accuracy level of 5 percent, and a confidence limit of 90 percent yields a sample size of 18 278. Because such large sample sizes are required, home-interview surveys are seldom used to estimate transit demand. Therefore, measurement of transit ridership by a home-interview survey should not be attempted unless (a) because of a very high number of transit trips the CV is much lower than that indicated above or (b) the very large survey required is considered worth the effort.

Pursuing option 2 above requires an estimate of transit share (not transit ridership). For example, suppose it is known that transit captures about 20 percent of all trips. The rest of the trips, or about 80 percent, go by private vehicle (assume that taxis and other paratransit modes carry an insignificant share of the trips). The requirement is to estimate the number of private vehicle trips to within ±5 percent. This requires the range in the estimate of percentage of automobile trips to be 76-84 percent because 4 percent ÷ 80 percent = 0.05. So the percentage of automobile trips must be estimated to within four percentage points. Therefore, the transit share must also be estimated to within four percentage points. Since this is an absolute rather than relative level of accuracy, a slight modification to the sample-size formula is required. The formula to use is

$$n = Z^2 S^2 / d^2 \quad (2)$$

where S = standard deviation and d = absolute accuracy level/100 percent.

Applying Equation 2 to the present situation requires an estimation of the standard deviation. This estimate is given by the formula $S = \sqrt{p^*(1 - p)}$, where p is the estimated percentage of transit (note that, as p decreases, so does S and, therefore, n). In this case, $S = \sqrt{(0.2) * (0.8)} = 0.4$. In addition, d = 0.04 and Z = 1.645 (for 90 percent confidence). Therefore, $n = (1.645)^2 (0.04)^2/(0.04)^2 = 271$ trips.

It is apparent that the number of trips to be sampled is far fewer than the number of trips that would be generated, for any given purpose, by the 887 households identified in the trip-generation section. An adequate estimate of transit share can thus be made from a small-sample home-interview survey as long as the percentage of transit trips is relatively low.

The next step in option 2 is to measure automobile occupancy. According to Nationwide Personal Transportation Survey data on the frequency of various automobile-occupancy figures (7), the CV of this variable is 0.69. If Z = 1.645 and E = 0.05, the required sample size is 725 trips. Again, the 887-household samples for trip production should provide more than enough data.

Thus, it is possible to measure the impact of mode choice on the highway system by using a home-interview survey of reasonable size. Usually, however, a forecast of mode choice under various policy alternatives is required, and this brings us to a discussion of sample-size requirements for option 3.

Usually, a separate mode-choice model is calibrated for each trip purpose. Unlike gravity models, mode-choice models do not have an easily measurable statistic on which they are calibrated. The most popular mode-choice model available is the logit model, which is calibrated on the basis of the maximum likelihood (ML) statistic. Since an ML statistic requires a calibrated logit model for computation, it is not possible to decide beforehand how many samples to collect to estimate the statistic.

Although the required sample size for logit modeling is difficult to derive theoretically, a reasonable range of required samples can be determined from past research in model calibration. In mode-choice modeling with data bases that contain trips (rather than households) as the primary observation unit, about 100-400 samples have been used to calibrate adequate models (8-10). Other logit models have been successfully calibrated by using data from about 500-1300 households (11, 12). Thus, it seems reasonable to be able to produce an adequate model by using the 887 households required to develop production models.

TRAFFIC ASSIGNMENT

The process of traffic assignment starts with a trip table. Since it has been determined that an accurate trip table cannot be produced directly from an O-D survey (unless a sample size approaching 100 percent is used), it follows that route assignments cannot be accurately determined directly from a reasonably sized O-D survey. Further support for this conclusion is available from a set of curves developed by Sosslau and Brokke (13). These curves show that estimating a volume of 1000 vehicles/day to within ±10 percent requires a sample of at least 20 percent of the dwelling units in the area.

Since it is not possible to develop accurate link volumes from a reasonably sized O-D survey of the home-interview type, the sample required to measure variables used in assigning traffic from a simulated trip table needs to be determined. The variables used are, however, system variables—usually travel time. Since traffic assignments are done on the basis of travel times taken from the coded network, data collected in the home interview do not affect the accuracy of traffic assignment as long as an accurate trip table can be synthesized from the data.

CONCLUSIONS

It has been determined that 900-1200 home-interview samples are sufficient to develop a cross-classification model for trip generation based on automobile ownership and income, depending on whether a simple random sample or a multistage sample is taken. It has also been shown that, for the purpose of travel demand forecasting, this sample size is sufficient for calibrating trip-distribution and mode-choice models. For traffic assignment modeling, the size of the home-interview survey is relevant only to the extent that an accurate trip table can be simulated. Computation of the sample sizes required is based on average measures of variability taken from several areas around the country. If variability (CV) is greater in the particular area where these procedures are being applied, a larger sample size will be required; if variability is less, the sample size required will be smaller.

If an O-D survey of the home-interview type is intended for more than or other than the purpose of calibrating travel demand models, other constraints need to be considered. For example, if the overall trip rate is being monitored, about 1100 samples are sufficient. But, if a trip rate for each of several jurisdictions is to be monitored, 1100 samples in each jurisdiction are required.

There are some transportation questions that cannot be cost effectively answered by using an O-D survey of the home-interview type. For example, vehicle kilometers of travel is most effectively measured where it occurs—on the street. Other methods of sample-size determination are applicable in that case. A complete discussion of street sampling to determine vehicle travel is presented elsewhere (14).

Clearly, several things must be done before the procedures in this report can be applied. The planner must first decide on the purpose of the survey and must then determine what variable(s) to measure to respond to that purpose. If it is then determined that the variables in question are amenable to an O-D survey of the home-interview type, the procedures in this report are applicable. But to apply these procedures, the analyst must develop an estimate of the variability in the quantity being measured.

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Abridgment

Use of Travel Diaries in Collection of Travel Data on the Elderly and the Handicapped

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Recently, there have been important policy developments regarding the planning and provision of transportation services for the elderly and the handicapped. Numerous experiments, notably the Service and Methods Demonstrations projects of the Urban Mass Transportation Administration (UMTA), have tested the worth of special transportation services for the elderly and the handicapped. Despite significant work in this area, much remains to be learned about the travel demand characteristics—i.e., the mobility—of such persons. This information is needed to design transportation systems that will enhance travel mobility. Improved mobility means not only more travel but also increased travel options, such as using preferred or more dependable modes, traveling to more attractive destinations, making more trips for certain purposes, and making trips at more convenient times of the day or week.

Measuring changes in travel mobility with statistical reliability depends heavily on the quality of the data. The quality of data is important because the changes being monitored are subtle in relation to background factors. Methods generally used for collecting travel data to assess changes in mobility have consisted of "retrospective" travel surveys and, of lesser relevance, on-board user surveys. Because these methods have not provided statistically reliable estimates of improvements in mobility, the evaluation of alternative service concepts has been limited.

The retrospective technique produces a high level of variability among individuals and their trip rates. In addition, when individuals are asked to recall travel behavior from a past period, memory lapse becomes a factor; if this problem is attacked by reducing the reporting period to shorter intervals, the problem of measurement is exacerbated by increased time-of-month variability (1).

This paper proposes a potential improvement in the data collection method to overcome these problems: recording travel data in a travel diary. A travel diary is a log in which the individual traveler records each trip made over a specified period of time. Because trips are recorded at or near the time they are made, the diary produces an accurate description of actual trip-making behavior. In addition, because the diary is typically compiled over an extended period of time, random variations in travel over time are greatly reduced.

The applicability of travel diaries to the analysis of the mobility of the elderly and the handicapped has been discussed by Kirby and McGillivray (2) and Crain and Associates (3). This paper reports on the planning and implementation of a before-and-after survey that incorporated diary techniques as part of the evaluation of a user-side-subsidy demonstration project in Lawrence, Massachusetts, under the UMTA Service and Methods Demonstrations Program (4). The study plan called for the diary survey to be administered once before the start of the project and again a year after the project had been in operation so that changes in travel behavior as a result of the demonstration project could be evaluated.

PREVIOUS USE OF TRAVEL DIARIES

There are, of course, practical reasons why diaries have not enjoyed more widespread use, such as the difficulties in identifying an appropriate and willing sample, the risk of dissolution of the sample before the end of the survey period, and the potentially high costs of administration, quality control, and respondent incentives. Our research uncovered few previous attempts to use travel diaries in surveys, particularly for periods of a week or more. Three noteworthy attempts were reviewed: the disaggregate data set pilot test by the State University of New York at Buffalo, the London Transport Survey (LTS) (5), and the 1966 Skokie travel survey (6).

The Buffalo pilot survey experimented with 7-day and 24-h trip logs. A substantial number of data items were requested for each trip. No incentives for participation were offered, and no surveillance was maintained during the survey. The LTS requested only transit trip data; it experimented with two different instrument formats and two incentive schemes but maintained no surveillance over respondents. In Skokie, the effects of different instrument formats, incentive plans, and levels of surveillance were measured, and survey forms in open-ended and categorical response format were tested. Three levels of economic incentive—from $3.50 to $11.50 (total compensation)—as well as a no-incentive strategy were tested. The highest level of incentive was provided to only 8 percent of the sample; the average incentive received by participants was $5.18, and the median was $3.50. Different levels of surveillance of respondents were also examined: Households were visited one, two, or three times a week for inspection and collection of forms.

Several lessons emerged from these surveys. The Buffalo survey had the lowest success rate of those studied, presumably because of the amount of data requested and the absence of surveillance or incentives. The LTS had the highest success rate, perhaps because of the public spirit of transit riders and the limited data requested in the survey. Of all individuals contacted in the London survey, 98 percent accepted the travel diaries and 81.5 percent completed the survey. The Skokie survey (in a relatively affluent suburb) had a scope and organization closest to those planned for use in Lawrence. About half of all the people initially contacted (56.7 percent) agreed to participate, and 50.8 percent of these eventually completed the survey.

SURVEY DESIGN

In designing the diary survey in Lawrence—an older, low-income city—we first assumed that some kind of compensation was essential, since the Buffalo survey produced virtually no response and a very poor response resulted in the zero-compensation group in the Skokie survey. It also appeared that higher incentives improved response and that payment schemes that offered a completion "bonus" were more effective in sustaining participation. Consequently, a total compensation of $20, divided into a $5 beginning payment and a $15 completion bonus, was offered. This amount was much higher than the average participant's compensation in Skokie, even after adjusting for inflation.

The Skokie survey concluded that surveillance was a very important factor in completion of the survey. However, since the city of Lawrence could more easily provide cash incentives than it could provide the personnel that were necessary for Skokie's higher levels of surveillance, a somewhat higher level of incentive was provided. Surveillance was limited to once-a-week visits to each household.

The final lesson learned from previous efforts was that survey forms should be kept as concise as possible. The Buffalo experience did not support the use of detailed travel logs, whereas the LTS achieved high reporting rates with simple forms. The Skokie experiment encountered problems with more ambitious data elements, such as route description and start-end times. In addition, the categorical response format (multiple choice) was not as effective as an "open-ended" approach.

SURVEY MATERIALS

As a result of the above considerations, the diary log for the Lawrence survey was designed to be as concise and simple as possible. The trip information requested included origin, destination, travel mode, trip purpose, and start time. Travel time could be calculated from external sources at some later time if desired. For trip purpose and travel mode, respondents were permitted to word responses freely rather than select from categories. Descriptions of origin and destination were to give just enough detail so that the location could be found on the map or in the city directory. A unique predated and prenumbered log sheet was supplied for each day of travel reporting. Sheets were printed on paper of different colors for each of the four weeks of the survey to facilitate identification when the forms were detached from the diary booklet and turned in at the end of each week's reporting.

Before the travel diary was filled out, each survey participant was administered a background questionnaire that collected data on age, sex, income, employment, handicaps, driver status, and the location, composition, automobile ownership, and income characteristics of the respondent's household. The questionnaire also recorded information on the individual's past travel behavior by means of a retrospective log that summarized all travel over the previous 3- or 7-day period. This was done to allow comparison between the reporting accuracy of diaries and that of retrospective logs.

SAMPLE REQUIREMENTS

Sample size was calculated to enable statistical testing of changes in travel behavior as a result of the user-side-subsidy project. Sample size was based on the number of individuals needed to measure a change in total monthly trip generation from the diary results for the entire sample on the order of a 5 percent increase by using a t-test and a 95 percent level of confidence. It was determined that, if a before-and-after paired sample could be "empaneled", complete records from 180 individuals would be needed; for independent samples, 240 individuals were necessary. Given the planned levels of incentive and reimbursement, a 20 percent drop-out rate and 10 percent unusable returns during the course of the survey were assumed. Thus, it was necessary to have a starting population of 320 for the independent sample. A 15 percent before-and-after attrition rate was assumed for the panel, which brought the required starting size to 260. The figure of 320 was selected as the design sample size given the uncertainties with the panel. The sample was to be stratified to include approximately two-thirds elderly and one-third nonelderly handicapped, roughly the ratio in the general population.

IMPLEMENTATION

The survey field plan had four stages: preliminary screening, field contact and training for the pilot test, conduct and review of the pilot test, and conduct of the main survey. Separate processes were used to identify the elderly and the nonelderly handicapped portions of the sample.

The sample of elderly individuals was selected from the names of persons 65 years of age or over in the Lawrence city directory by using a random start and skip interval technique. Of 714 names drawn from the directory, 485 resided in households with telephones and 229 did not. Each of the 485 persons with telephones were contacted for a 2-min screening interview. Of these, 321 of the telephone contacts agreed to accept a home visit from an interviewer and 194 subsequently entered into the pilot test. Of the 229 households without telephones, 106 were contacted in person and 28 entered into the pilot test.

Nonelderly handicapped participants were located through agency channels, civic organizations, nursing homes, and other contacts. A sample of 93 nonelderly handicapped persons was obtained. Individuals in wheelchairs and with hearing or sight impediments may have been underrepresented because of difficulties in locating such individuals. The pilot test was not administered to the handicapped sample because of delays in sample identification.

The pilot test was conducted during the two-week period before the main survey. Ten interviewers were needed to administer the pilot survey to the sample of 222 elderly individuals. This required an initial 1-h contact and a subsequent 1-h revisit, review, and action to prepare the individual for the main survey. Of the 222 persons sampled, 196 successfully completed the one-week pilot test and entered the main survey along with the 93 nonelderly handicapped. No major flaws were observed in the survey materials or approach as a result of the pilot test; thus, the main survey proceeded without any change in plans.

The main survey took place over the entire month of May 1978. The staff of interviewers was reduced to six during this period. Interviewers were assigned to a geographic sector and maintained contact with the same individuals throughout the survey (continuing contact was later judged to be a very important factor). Participants were visited once a week, when forms were reviewed and collected. Major literacy or comprehension problems were not encountered in the main survey; persons who could not meet survey requirements or obtain help within the household were eliminated at the pilot stage. The survey did retain a sample of approximately 10 percent of individuals who needed daily assistance. Ultimately, 195 of the 196 elderly and 90 of the 93 nonelderly handicapped completed the main survey. No diary was rejected because of unusable results or sloppy or suspicious reporting.

RESULTS

Only preliminary analysis of the diary data has been carried out to date. Tabulations of average daily trip rate by household income and automobile ownership have shown the expected relations. Weekly tabulations show the decline in the rate of travel from the beginning to the end of the month that is typical of travel among the elderly and the handicapped. The entire sample of elderly and handicapped travelers averaged 99 total monthly (one-way) trips with a mode of 60. An initial estimate of the standard deviation in total trips is 60, or about 60 percent of the mean. Although the mean trip rate for our sample, using the one-month diary, is as high as or higher than that in other reported surveys of the elderly and the handicapped, the variation is less than that reported elsewhere. Crain and Associates (3) describe a standard error in excess of the mean trip rate when the three-day-recall log method was used.

Two other initial findings are worth summarizing:

1. Only 38 percent of all trips were "return to home". This implies that 24 percent of trips were links in a travel chain, and at least 30 percent of all round trips had multiple destinations. The diary method of data collection is particularly effective in capturing this characteristic of travel behavior.
2. Although not all respondents to this "before" diary survey have joined the user-side-subsidy project, the same proportion have registered as in the population at large, or about 25 percent (the survey was conducted before demonstration project enrollment efforts began).

The total cost of the diary survey was $24 000, and this was broken down as follows:

Item	Cost ($)
Telephone screening	2 100
Initial household visit	3 750
Return visit after pilot test	2 100
Main survey surveillance and quality control	6 800
Incentives	5 250
Other direct costs including data coding	4 000
Total	24 000

For the 285 completed one-month diary surveys and the 315 sociodemographic and retrospective travel questionnaires, these costs represent approximately $77/usable diary and $6/usable survey questionnaire.

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**J.R. Kuzmyak was with Charles River Associates when this research was performed.*