APPLICATION OF DISAGGREGATE MODAL-CHOICE MODELS TO TRAVEL DEMAND FORECASTING FOR URBAN TRANSIT SYSTEMS

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This paper describes the development and application of disaggregate models to travel demand forecasting for transit systems in the Niagara Frontier region in western New York State. In this study, the disaggregate modal-choice models are developed from trip information from standard home-interview surveys. The data set used is a 12 percent subsample of the home interview conducted in 1962 in the Niagara Frontier. Binary logit models are calibrated for four types of trips, classified by trip purpose and automobile availability. For each model, the individual's probability of using transit is related to two system variables: the ratio of transit-to-automobile travel time and trip length. Aggregated transit-use proportions for the entire system are then obtained by combining the disaggregate probabilities with an approximation term, which reflects the within-zone variance of system characteristics. The prediction performance of the disaggregate modeling approach is compared to that of the conventional modal-split model. Results suggest that, by using the same type of information but only 12 percent of the sample, the disaggregate modal-choice method can produce at least as accurate modal-split predictions as the conventional method. The paper also describes the procedures necessary to integrate the disaggregate modal-choice method into typical urban transportation planning modeling systems.

•THE simulation package for conventional urban transportation planning is used primarily for forecasting demand for transportation facilities and systems in urban areas. This package has been applied by New York State Department of Transportation in the preparation of its long-range systems plans in upstate New York cities. The calibration process for several of the simulation package models is quite extensive and involves massive amounts of data. Accordingly, each of the urban studies in upstate New York conducted an extensive survey program as part of its initial activity. Between 13,000 and 20,000 households were interviewed in each area, and the resulting travel files contained more than 100,000 trip records.

There is a general feeling on the part of the profession, however, that the use of such data in these models is inefficient at best and that, as the transportation planning studies move into the continuing phase, the emphasis of systems planning has shifted from concentration on urban areawide system plans to more detailed analysis of corridor locations and questions of modal alternatives within corridors. Furthermore, a general tightening of the budget has made it infeasible to collect the same amount of information as was done in the first stages of these studies. These constraints require, therefore, that new modeling techniques be developed that are capable of operating at the corridor and systems level and that use much smaller data sets. The problem is how this may be done within the contexts of the simulation process described without unduly sacrificing the reliability of travel forecasts.

In the last 2 years, considerable research on disaggregate models has been undertaken. The most important characteristics of these procedures for our use are that (a) they operate on considerably fewer data than do conventional modeling procedures

and (b) they use specific mathematical functional forms from which estimates of travel demand elasticity may be obtained external to the model. These advantages are obtained by using calibration methods that operate on individual trip records and thereby use all of the information in travel data sets for model development. Conventional model calibrations, however, generally aggregate trip information before models are constructed and thereby lose much of the information.

Use of disaggregate models as part of the repertoire of transportation planning techniques, however, has not followed easily from their theoretical development. Most of the research on disaggregate models has been confined to the calibration of mathematical forms from small data sets and to the extension of mathematical model theory. Much less emphasis has been placed on the use of these tools in transportation system planning. This is because a typical disaggregate model ideally would require specially collected or augmented data information, and most state and regional transportation planning agencies have available to them only conventional home-interview (HI) survey information. Another problem is that aggregation is generally necessary if these tools are to be applied to aggregate zone-to-zone flows for computation of modal shares.

RESEARCH OBJECTIVES AND SCOPE

The primary objectives of this study of disaggregate models are

1. To develop and implement a small-sample modeling capability within the conventional technical simulation process used by New York State DOT;
2. To demonstrate, with readily obtainable data, the use of disaggregate models by applying them in real-world planning contexts and at a variety of scales and levels of detail.

It is hoped that this study may also serve as a link between the theoretical development of the disaggregate behavioral modeling technique and the conventional urban transportation planning simulation package currently being used.

This paper concentrates on the calibration and small-sample tests of disaggregate modal-choice models and on the demonstration of their application in a planning process for an urban transit system.

MODELS COMPARED

The conventional modal-split procedure used at New York State DOT determines the zonal percentage of transit use based on the transit-to-automobile service ratio and the air distance of each zone pair. Four trip categories (by purpose and automobile availability) are used in which the splits are performed within each category (4). Percentages of zone-to-zone transit use are multiplied by the volume of travel so that transit and automobile trip volumes can be obtained. Various post-split aggregations, such as the district-to-district summaries and other relevant information, are also provided as part of the model output (4, 6).

Response Surface Technique

Currently, to obtain the zonal transit use percentage, New York State DOT works with a table "look-up" (e.g., a response surface) that arrays the transit trip percentage by the air distance and the transit-to-automobile travel-time ratio. Figure 1 shows the response surfaces for each trip category: long trip, automobile available (LAA); long trip, no automobile available (LNAA); short trip, automobile available (SAA); and short trip, no automobile available (SNAA). Long trips are basically work trips, and short trips are basically shopping, social, and recreational trips. A more detailed definition of these trip categories is documented in (6).

Figure 1. Response surfaces.

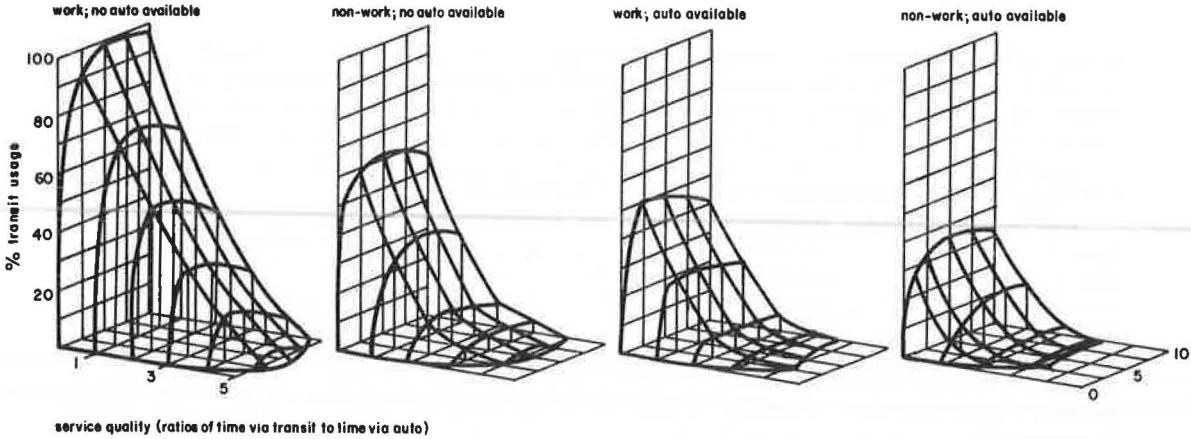


Figure 2. Niagara Frontier region.

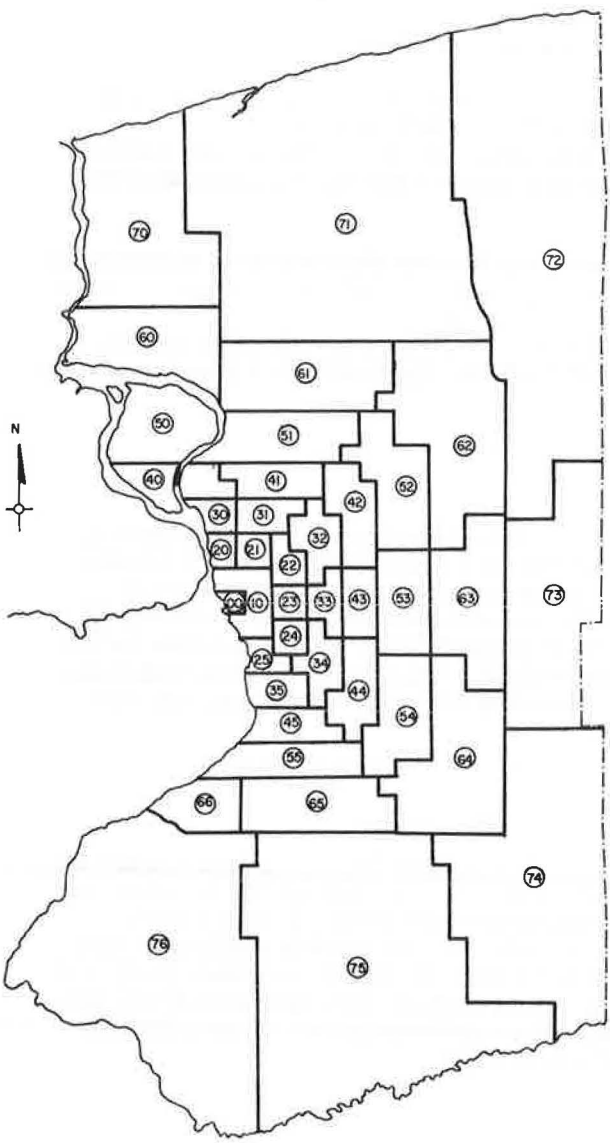


Table 1. Subsample distribution.

Trip Type	Trip Records	Transit Trips	Transit (percent)
LAA	2,576	160	6.21
LNAA	686	311	45.34
SAA	6,721	128	1.90
SNAA	2,933	311	11.29
Total	12,916	910	7.04

The main shortcoming of the response surface method is that a large data set is required to assure sufficiently stable estimates of the transit proportion in each cell, especially those near the edges of the surface. The set of response surfaces for the Niagara Frontier, for instance, were constructed from over 100,000 individual trip records.

Disaggregate Model Technique

The disaggregate modeling technique has two advantages. First, it requires a much smaller sample size than aggregated methods. Because the data are treated at the individual or household level, all of the information contained in each trip record is fully used when the models are calibrated. Consequently, the disaggregated models can be estimated on the basis of a small sample and are not restricted to zoning.

The second advantage is that the method deals with the most basic travel unit: the individual or the household. In other words, although the aggregate method searches for the associative relationships between travel demand and the various explanatory variables, the disaggregate method attempts to extract the traveler behavioral pattern associated with making a trip. Therefore, the resulting models promise transferability, temporally as well as spatially.

This particular study aims to capitalize mainly on the first advantage of the disaggregate modeling approach, the savings in data requirements. (Because of the peculiar data information used in this paper for model estimation, the estimated models are not believed to be truly behavioral, and therefore their transferability is questionable.) It is intended that, instead of relying on the response surfaces that require a large amount of sample data, we can compute the percentage of zonal transit use by applying a set of disaggregate modal-choice models, which can be estimated on a much smaller sample.

The disaggregate model form used in this study is the binary logit model; i.e.,

$$P_k = \frac{1}{1 + e^{G(X)}} \tag{1}$$

where P_k is the probability that a certain travel mode is chosen by an individual and G(X) is usually a linear combination of transportation level of service and individual socioeconomic characteristics.

DATA

The 1962 HI survey for the Buffalo region (Fig. 2) contains 103,328 individual trip records. Inasmuch as one of the objectives of this study is to determine if one can feasibly apply disaggregate techniques to the relatively small 1973 update travel survey collected in the Niagara Frontier, this study uses, as a data base, a subsample of the 1962 HI survey that has a sample size comparable to that anticipated in the 1973 survey. Accordingly, trip records in the quasirandom 12 percent subsample, containing 12,916 records (Table 1), were drawn from the original file. [A detailed description of the original sample and the subsample is discussed elsewhere (5).]

APPROACH

For each category of trips, binary logit models (Eq. 1) were developed. So that an exact comparison between the response surface method and the disaggregate approach could be made, only two variables, air distance and service ratio, were used in constructing the modal-choice models.

As a typical, conventional travel survey, the 1962 HI file contains zone information

on trip characteristics. Each traffic zone is represented by a single zonal loading point, which is usually a major bus terminal in the zone. Consequently, all individuals who travel between a certain zone pair are assigned to the same transportation level of service. The actual modal choice of an individual traveler is reported in the survey, and the dependent variable is 1 if the automobile mode is chosen and zero if otherwise. Model coefficients are estimated by maximum likelihood estimation. (The computer program used for model estimation is the PROLO program originally prepared by Stopher at Northwestern University.)

An important issue is the use of the disaggregate modeling technique as a tool to predict zone-to-zone modal shares, V_k. Of course, V_k can always be obtained by summing the individual modal-choice probabilities obtained from the model, i.e., $V_k = \sum_{\text{all } k} P_{ik}$, where P_{ik} is the probability that individual i will choose mode k (9). This procedure becomes cumbersome when a large population is involved. Another suggested method is that V_k be obtained by first estimating the proportion of population that chooses mode k and then by multiplying this proportion and the total population in the market segment, i.e., $V_k = E(P_k) \cdot V$, where $E(P_k)$, the expected value of the probability of choosing mode k, is the proportion of population that chooses mode k.

Because of the nonlinearity of the logit model, the expected value of the probability is not equal to the probability of the zonal averages, i.e., $E(P_k) \neq P_k(\overline{X})$. Talvitie (8) has shown mathematically that the value of $E(P_k)$ may be approximated as

$$E(P_k) = P_k(\overline{X}) + \text{Var}\,[G(X)] \cdot P_k(\overline{X})\,[P_k(\overline{X}) - 1] \cdot [P_k(\overline{X}) - \tfrac{1}{2}] \qquad (2)$$

where Var [G(X)] is the within-zone (or within-interchange) variance of G(X), and its value depends on the variances and covariances of modal attributes. [Another method of binary-choice model aggregation is found elsewhere (10).]

The need to aggregate the estimated choice models has been questioned because zonal values will be used for the explanatory variables and, therefore, the estimated models will not be disaggregate at the individual level. Instead they will be zonal models and will not require aggregation for zonal prediction. The other interpretation is that, even though the individuals are assigned to zonal service levels, the models will still be estimated on individual records by individually observed modal choices. Therefore, the models will still be disaggregate at the individual level and, thus, will require aggregation for zonal prediction. Recent research results indicate that disaggregate models may be obtained from a combination of disaggregate and aggregated data if the variables are not correlated (7). This seems to support the latter interpretation. In this study, both of these interpretations are considered empirically. Prediction results based on both the nonaggregated and the aggregated estimates are compared.

EVALUATION CRITERIA

The choice models in this study are evaluated on reasonableness, statistical indicators, and performance prediction for transit systems. This will be done by inserting the models (i.e., calibrated equations) and other related information into the modal-model program, by replacing the response surfaces, and by applying the program to zone-to-zone flows in the Niagara Frontier. Model performance will be tested by the following methods:

1. Proportion of area-wide transit use.
2. Sum of absolute differences in districts, i.e.,

$$\Sigma D \equiv \sum_{\substack{\text{all}\\ \text{districts}}} \left| T_{predicted} - T_{observed\,(1962)} \right| \tag{3}$$

where T is the number of transit trips originating from a certain district.

3. Root deviation square (RDS),

$$RDS \equiv \left[\frac{\sum_{\substack{\text{all}\\ \text{districts}}} (T_{predicted} - T_{observed})^2}{\sum_{\substack{\text{all}\\ \text{districts}}} T^2} \right]^{1/2} \tag{4}$$

This also reflects the smoothness of the deviation fluctuation from district to district over the entire study area.

4. Comparison of predicted and observed transit trips in districts.

RESULTS

The disaggregate method for modal-split prediction is developed over a number of modeling and trial stages. In each stage, the prediction results were evaluated according to the set of criteria established earlier. Logical improvements in the modeling approach were made after each stage, and the revised method was investigated in the next stage. This process was continued until a method was derived that was able to predict as accurately as the existing response surface technique and that, at the same time, was based on sound theory. The approaches taken at the various modeling stages and their prediction performances are described in the following.

12 Percent Method

An initial approach was taken to estimate logit models based on 12,916 trip records. The coefficients of the four models are given in Table 2.

The coefficients of the service-ratio variable in these models have positive signs, which are consistent with intuitive reasoning. The model constant is largest for SAA and smallest for LNAA. This indicates that the travelers are most inclined to use an automobile for SAA trips and least inclined for LNAA trips. The model constant and the service-ratio variable are statistically significant at 0.95 level of confidence in all four models; however, the air-distance variable is not significant in the LAA and LNAA models.

These models were inserted into the on-line modal model, which was then applied

Table 2. Logit models for 12 percent of sample.

	Constant		Air Distance		Service Ratio		
Trip Type	LC	t-Ratio	LC	t-Ratio	LC	t-Ratio	Pseudo R^2
LAA	1.655	11.06	-0.077	-0.30	0.548	9.11	0.006
LNAA	-0.807	-4.71	-0.005	-0.14	0.647	7.76	0.107
SAA	3.549	25.94	-0.042	-1.95	0.206	4.7	0.003
SNAA	1.452	16.56	-0.038	-2.07	0.302	10.17	0.030

Note: LC = logit coefficient.

to the Niagara Frontier Transportation Study (NFTS) regional data. [It is assumed for this test that the probability of transit use for a zone or zone pair is also the proportion of transit use for the zone pair, (e.g., no aggregation bias).] Whereas the response surface method overpredicts the number of transit trips by 0.17 percent of the total person trips, the 12 percent method underpredicts the number of transit trips by 1.35 percent of the total person trips (Table 3).

This is a considerable discrepancy, considering that the total number of person trips in this region is in excess of 2 million. The sum of deviations and the RDS also reveal the relatively poorer prediction performance of the 12 percent method.

The cause of such undesirable performance is that there are interzonal and intrazonal groups of trips in this region, and over 8 percent (or ≈1,800) of the trips of the 12 percent sample are intrazonal. For these trips, the values of the air-distance and service-ratio variables are both assigned values of zero.

Because the response surface method only deals with the average values within each cell, intrazonal trips do not materially affect its predictive performance. However, inasmuch as the disaggregate method takes into account each trip record, these trips must be eliminated before reasonable models can be calibrated.

Disaggregated Interzonal Models

As an extension of these models, the interzonal and intrazonal trips were separated from the set of trip records of 12 percent of the sample. Furthermore, among the interzonal trips, those that had a service-ratio index greater than 6.0 were also sorted out. This is because a relevant choice situation between the two alternative travel modes is not expected to exist when the transit travel time is more than six times as much as the automobile travel time.

The remaining 10,004 trips were categorized according to their trip classifications, and a logit model was estimated for each trip type. The air-distance variable turned out to be insignificant in all the estimated models. Therefore, a set of models were reestimated by using only the service-ratio variable. The coefficients of these models and the statistical indicators are given in Table 4.

The coefficients of the service-ratio variable in these models also have positive signs. The model constants indicate the same rank order toward choosing the transit mode as that indicated by the previous models. However, the values of the coefficients are significantly different in the two sets of models. In particular, the values of the coefficients of the service-ratio variable are 1.2 to 3.3 times greater than the corresponding coefficients in the previous models.

For the intrazonal trips, two constants were used to represent the transit proportion. For zones in the inner urban area contained within the first four traffic rings, the transit proportion is 3.5 percent. For zones in the outer urban area where there is little transit service, the transit proportion is 0.73 percent. These proportions are empirically derived from the 1962 data.

The interzonal models and the constants for intrazonal transit use were inserted into the modal model, which was again applied to the NFTS regional data. The prediction is given in Table 3.

The predictive performance of the disaggregated approach is improved considerably over the 12 percent approach. For the area-wide transit use, this method underestimates the transit usage by 0.84 percent, as compared to an underestimation of 1.35 percent by the previous approach. Nevertheless, its predictive ability is still not satisfactory when compared with

Table 3. Model performance for response surface, 12 percent, disaggregated, and aggregated methods.

Prediction Method	Transit (percent)	Absolute Error[a] (percent)	Sum of Deviation	RDS
Response surface	7.59	+0.17	24.1×10^3	0.131
12 percent of sample	6.07	-1.35	63.3×10^3	0.344
Disaggregated	6.58	-0.84	31.8×10^3	0.166
Aggregated	7.53	+0.11	26.2×10^3	0.128

[a]Observed area-wide transit use is 7.42 percent.

Table 4. Coefficients for interzonal logit models.

Trip Type	Constant LC	Constant t-Ratio	Service Ratio LC	Service Ratio t-Ratio	Pseudo R^2
LAA	0.887	5.30	1.000	9.95	0.052
LNAA	-1.161	-6.95	0.817	8.31	0.128
SAA	2.140	12.79	0.683	9.17	0.014
SNAA	-0.235	-1.72	0.907	14.16	0.112

Note: LC = logit coefficient.

Figure 3. Approach applied to district transit trips.

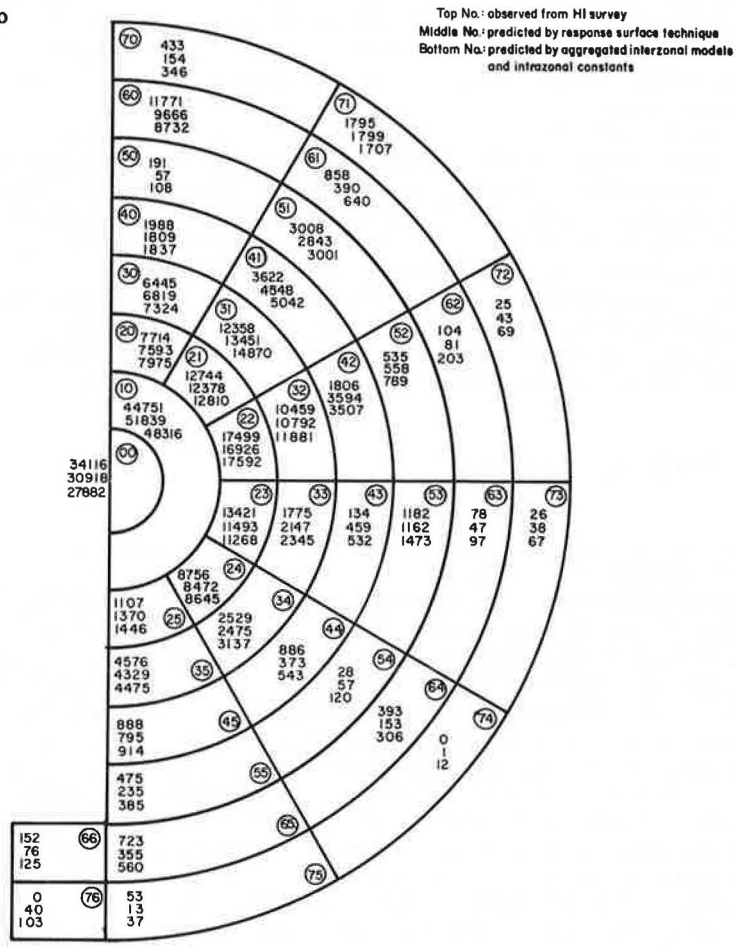
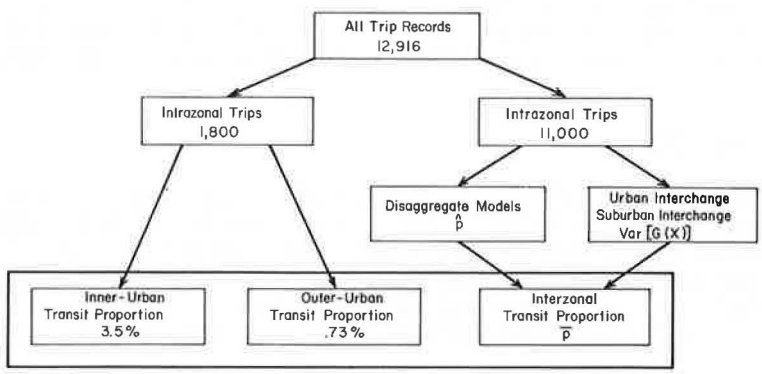


Figure 4. Disaggregate method procedure.



that of the response surface method. Further attempts to stratify trips by characteristics of the trip ends, e.g., urban interchange (trips with one end in Buffalo or Niagara Falls) and suburban interchanges (the rest of the interzonal trips), yielded, at best, predictive accuracy similar to that of this approach.

Aggregated Interzonal Models

For the various approaches investigated up to this point, it has been assumed that the choice models are applicable directly to the zones. Therefore, proportion of transit use for a certain zone is the same as the disaggregate transit probability at its zonal means, $P_k(\overline{X})$. Results of these attempts show an underestimation of transit use over the entire region.

As mentioned earlier, another interpretation of these choice models is that they are disaggregate at the individual level and therefore require aggregation for zonal predictions. In the following tests, an aggregation term is added to the disaggregate probabilities as shown in Eq. 2. The a priori knowledge of this aggregation term is that, for noncorrelated explanatory variables, it has a positive value if $P_k(\overline{X})$ is less than 0.5. The magnitude of this term depends on Var [G(X)].

The procedures taken in this stage were almost identical to those taken in the last stage, except that information about Var [G(X)] and the aggregation term was also inserted into the modal model. Because the set of estimated choice models contain only the service-ratio variable, the value of Var [G(X)] is

$$\text{Var}\,[G(X)] = \beta_{sr}^2 \cdot \text{Var}\,(X_{sr}) \tag{5}$$

where Var (X_{sr}) is the within-interchange variance of the service-ratio variable, and β_{sr} is its model coefficient.

Two assumptions (or approximations) are made in computing the values of Var (X_{sr}). The first is that the within-interchange variance of the service-ratio variable is similar to the between-interchange variance of this variable. Although previous studies (3) indicate that the within-zone variance is greater than the between-zone variance, this assumption is necessary because the Niagara Frontier data in zone-to-zone form do not contain any within-interchange information. The second assumption is that many zonal interchanges have approximately the same Var (X_{sr}). This assumption simplifies the prediction process because it would be infeasible, in practice, to compute the variance for each zone pair. Intuitively, the validity of these two assumptions may be justified if a single Var [G(X)] is computed for trips of similar service characteristics.

On examination, the urban interchanges (e.g., trips with either origin or destination in Buffalo or Niagara Falls) and the suburban interchanges (e.g., the rest of the interzonal trips) appeared to be the two trip groups within which trip characteristics are similar. The means and variances of the service-ratio variable are respectively 1.870 and 1.076 for urban trips and 3.523 and 1.196 for suburban trips.

Consequently, two values of Var [G(X)] are computed, one for urban interchanges and the other for suburban interchanges. This information and the choice models were inserted into the modal model. Results of this prediction approach are given in Table 3.

CONCLUSION

The predictive ability of the aggregated approach compares closely with that of the response surface method. The response surface method overpredicts areawide transit use by 0.17 percent; this method overpredicts it by 0.11 percent. The sum of deviation and the RDS indicators also show the predictive accuracy of this method to be as good as that of the response surface method.

A comparison of transit trips by origin district is shown in Figure 3. These results

show that the disaggregate method of approach can indeed produce, by using the same type of information, as plausible predictive results as the response surface method, but it uses only 12 percent of the original sample. Furthermore, the empirical results of this study suggest that such modal-choice models require aggregation corrections for application to the zonal level.

USE IN PRACTICE

A number of modeling approaches have been investigated in developing an accurate and workable disaggregate method for modal-split prediction. The best approach involved the following procedures:

1. Separate the regional trip records into interzonal trips and intrazonal trips;
2. Use constants to represent proportions of intrazonal transit use for intrazonal trips;
3. Eliminate those interzonal trips with service ratios greater than 6.0 and develop logit models by trip classification;
4. Separate the interzonal flows into urban interchanges and suburban interchanges and compute the variance of the logit model index, G(X), for each type of interchange; and
5. Insert the constants for intrazonal transit use, the interzonal logit models, and the values of urban or suburban interchange into the on-line modal model and apply it to regional flows.

A flow chart of the above disaggregate modeling procedures is shown in Figure 4. The information in the boxes is the input for the modal model.

OTHER NEEDED RESEARCH

It has been demonstrated that, based on the Niagara Frontier travel data, the disaggregate technique can be implemented, by using a limited amount of conventional survey data, to predict modal split at a regional level. Some rough approximations are adopted through the various parts of this analysis. For instance, during the aggregation of the zonal disaggregate probabilities, values of the within-interchange variances are approximated by values of the between-interchange variances, and only constants are used to represent the transit use of intrazonal trips. Therefore, further research is necessary to determine the true effects of these impurities in the process. Some of these questions will be answered when the disaggregate method developed in this study is applied to the data collected from the 1973 HI update survey in the Niagara Frontier. It is hoped that with the more complete and detailed information in the new survey better and truly behavioral models will result that are able to address other transportation service problems such as travel costs, conveniences, and other policy issues.

In the meantime, the immediate concern for transportation planning is whether or not this disaggregate method can be applied to another urban area or region that has a different transportation system. Because this method incorporates constants for interzonal trips and because the estimated disaggregate models are not believed to be genuinely behavioral, it is doubtful that the constants and the choice models obtained from the Niagara Frontier data could be directly applied to another location. However, the methodology developed in this study is expected to be valid for other areas. This, of course, remains speculative until empirical tests on other data sets are carried out.

The application of the disaggregate modeling technique is by no means limited to only modal-split forecasting. Recently, multinomial extensions of the logit model have been applied to directly compute the choice probabilities of other trip decisions such as destination, travel mode, time of day, and frequency (1, 2). However, demand forecasting by the disaggregate method for transportation systems has not been applied in other planning contexts at this point, to our knowledge. Although much has yet to be

explored and studied, the current application appears to offer a valid and efficient way to approach travel demand forecasting for large urban areas.

ACKNOWLEDGMENTS

We wish to thank Antti Talvitie of the University of Oklahoma, Richard Westin of Northwestern University, and Patricia L. Milic for their valuable comments. Special thanks are extended to James McDermott and his staff whose continuous assistance in data processing is greatly appreciated. The authors alone remain responsible for errors of fact, concept, or opinion. This research was supported by the Highway Planning and Research Program of the Federal Highway Administration.

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