TEMPORAL STABILITY OF TRIP GENERATION RELATIONS

Edward J. Kannel, Purdue University; and
Kenneth W. Heathington, University of Tennessee

Trip generation models based on household data rather than zonal aggregate data are evaluated. It has been suggested that analysis of household travel characteristics should precede aggregation so that home-interview data can be used more efficiently. Relations identified at the decision level of travel should have greater causal validity and should be more temporally and spatially stable. The major objectives of this research are to examine the form of household travel relations, to determine the stability of these relations over time, and to evaluate the ability of household models to estimate future travel. The potentials for reduced sample sizes and greater applicability of disaggregate models in different urban areas are also examined. Household travel data were obtained from home-interview surveys in 1964 and 1971. Single-family households interviewed in the 1971 survey represented the identical families that were interviewed in 1964. This unique sampling design permitted the analysis of the effects that changes in the households' socioeconomic characteristics during the 7-year period had on trip production. The results indicated that the household models based on the 1964 data could successfully predict household travel reported by the same households in 1971. The household models from both time periods could be expanded to adequately estimate 1964 reported zonal area travel. Parameters of the disaggregate models also appear more consistent among geographical areas and could be developed with considerably fewer data than comparable zonal models.

•THE methodology of trip generation modeling used in most current urban transportation planning studies is referred to as a zonal analysis concept. The enormous body of data obtained in the home-interview portion of the origin-destination study is aggregated and summarized in larger units of the total study area, the traffic zone. These zones are the smallest areas considered in all further analyses and projections. The aggregated data are used to calibrate generation models that estimate trip production occurring under present economic, social, and physical conditions. Future travel is then estimated assuming that the true causal relations have been identified and that the model parameters will remain stable over time.

This traditional trip generation modeling approach, which is based on aggregated socioeconomic and land-use data, is subject to critical review. The modeling approach has been challenged from at least two major viewpoints:

1. The modeling approach does not allow full consideration of the continuous nature of the travel decision process. Trip generation is only the first stage in the total urban transportation planning process that also consists of trip distribution, modal split, and trip assignment. In current practice, each of the models is normally developed independently of the others. As a result, there is no general assurance that an internally consistent network equilibrium will be achieved. The modeling process acts as though there is a given level of demand irrespective of the transportation system that is available.
2. The use of spatially aggregated data assumes that the relations derived represent the true relations occurring in the units that compose the aggregate total. Further, the aggregate descriptions are assumed to remain stable temporally and thus serve as a basis for prediction of future travel.

Inconsistencies may arise because the transportation system is not explicitly allowed to affect all stages of the model development; therefore, attempts have been made to develop explicit demand models that combine the functions of generation, distribution, and modal split (2, 8, 11). Other research efforts have been directed to the development of a stochastic modeling approach that would retain the sequential nature of current planning models but would incorporate principles of economic utility theory to include more policy-sensitive variables in the model framework (12, 13, 15). These latter approaches also recognize the efficacy of using disaggregate data to estimate model parameters.

Research related to the second major point of discussion, data aggregation effects, has also shown the shortcomings in the aggregate planning model concept (1, 3, 6, 9, 10). Review of the assumptions of the aggregate models has shown that the zonal means are not adequately representative of the individual units composing the mean (9). The reasons for inadequate representation are that the zone sampling distributions are skewed rather than normal so that the sample mean is not the central value and considerable heterogeneity exists within zones with respect to household travel characteristics and socioeconomic traits.

Further, aggregation of the behavioral units to a zonal description "washes out" much of the total variation that exists in the data. The aggregate data may mask the true relations and the causal nature of the explanatory variables. Investigations have shown that aggregation changes the strength of the associations among variables, and that the model parameters are dependent on the size of the area unit selected in the analysis (1, 3, 9). As a result, the calibrated model is applicable only at the macrolevel of analysis and in the geographical area for which it was calibrated. This has further important implications in the continuing phase of the urban transportation planning study as one needs to be concerned with measurement of changing conditions. When the analyst is interested in measurement of changes, particular care must be exercised to carefully identify the explanatory variables to be used and the parameters associated with those variables. Because the aggregate models are based on large volumes of data that are averaged together, the models are not sensitive to subtle changes that occur at the basic decision level of travel. Further, the data measure habits for a single time frame. Because it is financially impractical to obtain the large quantities of data that would be necessary to revise the zonal estimates, the relations observed in the original time frame are generally assumed to be held constant throughout the planning period. Logic suggests that changes in social and cultural patterns and changes in the physical environment will have an effect on urban travel. To be sure, comparisons of aggregated relations within an urban area have been made for different time periods, but these aggregate relations are dependent on the type and level of activity within the area units. Because the size of some zones or the level of activity within the zones may change over the study period, it is difficult to separate the effect of changing area descriptions from the effect of changing relations of the variables in the model. The subtle changes in urban structure and the status and life-style of the individual cannot be detected at the macrolevel of analysis.

DISAGGREGATE TRIP GENERATION ANALYSIS

Although there is a recognized need for considering concepts that incorporate the interacting effects of the total travel decision process, in this paper attention is directed only toward obtaining a better understanding of travel behavior by evaluating trip generation relations at a disaggregate, behavioral level of analysis. The household is taken as the basic decision-making unit for evaluating travel behavior.

Other researchers have pointed out the shortcomings of models based on spatially aggregated data and have indicated the desirability of identifying the more basic relations between the socioeconomic and travel characteristics that occur at the household level of analysis. Analysis at the disaggregate level appears to provide a means of overcoming several of the shortcomings mentioned previously and provides several advantages to the transportation analyst. First, because the analysis is conducted at the household level, the basic relations are not averaged out by aggregation or clouded by the analyst's selection of the area boundaries. Because the parameters of the model are not tied to a particular aggregation scheme, the model can be developed and then applied to whatever aggregation scheme is necessary for the following series of models that are employed. This is of importance in the continuing phase of the transportation study as the size and shape of the planning area change. This greater flexibility in application would allow the analyst to more effectively use data from other public records (e.g., census data) that are summarized in area units that do not conform to the boundary scheme of the transportation study.

A second advantage proposed for the use of household level analysis is that the household provides a common base for comparing travel characteristics in different urban centers. Unlike the artificial aggregate unit such as the traffic zone, the household is basically of the same size and internal consistency in different geographical areas. Because of the common nature of the household unit, one might expect household model parameters to be more consistent from area to area.

A third advantage is that the household relations represent the basic relations at the decision level and therefore are assumed to possess greater causal validity. These causal relations are more likely to remain stable over time, thus forming a more valid basis for the prediction of future trip generations.

Finally, because all the data that are collected in the home-interview surveys are analyzed prior to aggregation, the data are used more completely and effectively. As a consequence, the possibility exists for using smaller sample surveys in the continuing study to measure the changes that occur in the basic relations.

The purposes of the research reported in this paper were to evaluate the form of the relations that occur in household trip generation models and to evaluate the stability of these relations. In addition, the ability of models based on reduced sample size to estimate total area travel is examined. The hypothesis that the parameters of disaggregate generation models are more consistent from one geographic area to another is studied.

STUDY DESIGN

The data used in this study to evaluate the causal validity and stability of household trip generation relations were obtained from home-interview surveys in Indianapolis, Indiana. In this metropolitan area of 800,000 population, a basic transportation study was conducted with the home-interview data collection taking place in 1964. The Indianapolis Regional Transportation and Development Study (IRTADS) is a typical example of a transportation study in which the trip generation formulations are based on aggregate zonal totals. A 5 percent home-interview sample was taken representing over 10,000 interviews. The data were aggregated into 395 zones defined for the study area and factored to represent total travel volumes for the area.

In this research, a second home interview was conducted in 1971 to study changes in household socioeconomic characteristics and travel behavior and to evaluate the stability of household trip generation models over a 7-year period. The latter survey obtained measures of the socioeconomic and travel characteristics of some of the identical families that were interviewed in 1964. Earlier research had suggested several variables that could be evaluated at the household level including family size, automobile ownership, stage in the family life cycle, occupational status, income, type of dwelling unit, and location within the urban structure (7, 10, 16). Although simultaneous evaluation of all levels of all factors would have been desirable, such a design would have required a prohibitively large sample to obtain a sufficient number of cases for statistical stability in all possible levels and combinations of the variables. Instead, a sample was selected that represented all levels of three principal socioeconomic variables: family size, automobile ownership, and income. In the experimental design, the confounding influence of other variables was controlled to the greatest possible extent by careful selection of the 1971 sample. Differences in travel behavior that were caused by differences in life-style of families living in different types of dwelling units (and not by changes in the principal variables being considered) were controlled in the 1971 study by selecting only single-family homeowners. The 1971 survey interviewed the identical families that were interviewed in 1964. Further, only those families were selected that remained at the same dwelling unit from 1964 to 1971. In this way, differences in travel behavior that may have been caused by changes in the living environment could be controlled to a greater degree. Finally, travel variation that may be attributed to seasonal or daily variation was controlled by obtaining both data sets in the fall of the year and by scheduling the 1971 interview schedule such that each household recorded travel in 1971 on the same day of the week as in 1964.

Elimination of all families who were not single-family homeowners or who did not provide complete information in 1964 provided a final list of 4,300 households from which the 1971 sample was selected. Table 1 gives a list of average household and travel characteristics of the 4,300 households and of the 357 households from which completed interviews were obtained in 1971.

HOUSEHOLD TRAVEL CHARACTERISTICS

Several household variables such as family size, automobile ownership, income, labor force, and occupational status were examined to determine their effect on household trip generation rates. All of the variables showed a statistically significant effect when considered alone; however, because of the large intercorrelation among the variables, the effect of any one variable is not independent of the others. For example, although income would be a significant explanatory variable for estimating trip production, the research indicated that income had a greater effect on automobile ownership, which in turn affects household travel (5). Because automobile ownership appeared as a more direct cause of travel, it was selected for use in the prediction models along with the family size variable.

Graphical summaries of the relations between family size and automobile ownership and household travel are shown in Figure 1 and Figure 2 respectively. Figure 1 shows that the relation between family size and home-based trip production is nearly linear for family sizes of four or less, but, as family size increases, the rate of trip production increases at a decreasing rate. This overall nonlinear trend agrees with the findings reported by Oi and Shuldiner (10). Because trip generation models generally assume linear relations, large departures from linearity could have important effects on these prediction models. The analyst must recognize where the assumptions of the model are not met and the consequences of using the variable or model formulation in spite of these irregularities. This will be examined later in connection with evaluation of the predictive ability of the models.

The other significant observation to be made from Figure 1 is the relatively good agreement of the curves for the two data sets. Although changes in the family composition and age structure have occurred over the years, the average trip production for families of similar size for the two periods is relatively stable. This again has important implications in developing models of travel behavior. The stability of the form of the relation indicates that the variable should be useful in forecasting models.

Figure 2 shows the corresponding curve for automobile ownership. The curve exhibits strong linear trends with greater fluctuation from linearity exhibited in the 1971 data. However, the slope and intercept (and thus the effect of automobile ownership on trip production) appear to have shifted in these households over the years. Such a shift in the relations could again have special significance in the planning study. Unless a shift in the value of model parameters is detected by observation at intervals less than the planning period for which forecasts are made, the final estimate could yield considerable error. Because the disaggregate modeling approach is able to detect the subtle changes that occur, it is felt that these relations could be monitored with smaller sample sizes and perhaps with greater frequency to detect these changes.

MODEL DEVELOPMENT

Stability of the disaggregate trip generation relations was evaluated in three stages. First, standard linear regression models were developed from the 1964 and 1971 data sets, and the parameters of these models were compared. Next, the 1964 model was used to predict the volume of travel that should be expected in 1971 if the model relations are sufficiently stable to predict future travel in the households. The regular planning process was then essentially reversed in that the 1971 model was taken back in time to estimate the total zonal movement reported by the 4,300 single-family households in 1964. The 1964 and 1971 models were compared as to their ability to measure the 1964 aggregate home-based trip production. Finally, a disaggregate model from all types of dwelling units was used to estimate total area travel. The consequences of using data that do not appear to meet the theoretical requirements of the model formulation are discussed.

As indicated, the relation between family size and trip production did not appear to be linear through the entire range of the independent variable. Preliminary investigations also showed heteroscedasticity of household trip production variances for all levels of the family size and automobile ownership variables. Further, the sampling distribution of the dependent variable is not a true normal distribution. Although this does not preclude the use of linear regression analysis to estimate parameters for the model, one may not be able to make probabilistic statements about the accuracy of the model parameters with the degree of confidence that is usually associated with the statistical model. Because of these limitations, linear regression techniques were used to evaluate the disaggregate models.

Table 2 gives the results of the linear models for estimating home-based trip productions. As was expected, the parameters of the model have shifted somewhat over time. The degree of change is in agreement with observations made from Figures 1 and 2. That is, the parameter for family size is very similar over the period, whereas automobile ownership has greater variability. Two-way analysis of variance models (ANOVA) with unequal cell sizes were evaluated to test the stability of the relation over time (17). The time factor may be labeled simply as a years' effect, but years is considered only as a surrogate for the effect of changes in other possible pertinent variables such as income and stage in the family life cycle. The statistical analysis indicated that there was not a significant change in the effect of family size over the time period, but the effect of automobile ownership had changed. From Figure 2, one could speculate that the change occurred in the zero- and three-car families. Indeed, when only one- and two-car households were considered, there was not a significant variation due to time changes.

The coefficient of determination, R^2, and the standard error of the estimate provide other measures for comparing the two models. Both models give similar statistics for these measures, but, for the analyst who is accustomed to observing R^2 values of about 0.90 for zonal data, they are unimpressive. However, these values were not unexpected because the models are attempting to explain all of the variation in trip production—not just the variation between zones. Within any household, the number of trips reported may be two to three times the average rate of trip production of all households with similar characteristics. The household model formulated here cannot hope to predict these large variations for each household. The measure of usefulness of the household model for forecasting trip production must be based on its ability to predict average travel for some higher level of aggregation. If the model is successful in accomplishing this task, then model development at the disaggregate level would be of value to the researcher as a means of evaluating causal relations at a behavioral level and to the practitioner for developing area travel forecasts.

Estimation of 1971 Household Travel

The 1964 trip generation model given in Table 2 was first used to estimate home-based trips for the 357 families in 1971. The total estimated home-based travel was 2,542 trips compared to the survey total of 2,498 trips, i.e., an error of less than 2 percent.

Sufficient data were available in one- and two-car households and all family size levels to statistically evaluate discrepancies in the estimated and observed trips using a chi-square contingency analysis (14). The null hypothesis of no difference between the estimated and surveyed trips could not be rejected at the 0.01 significance level. Visual inspection of zero- and three-car families also did not show any major discrepancies.

The household equation was remarkably successful in estimating trip production for these households. Of course the independent variables for the prediction of 1971 trips were known exactly at each household. This is a luxury that is not available in the operational study, but it does exhibit the faithfulness of the model for estimation even though all theoretical considerations of linear regression were not met. In particular, the nonlinear trend for the family size variable did not significantly reduce the effectiveness of the linear model to estimate future travel from the surveyed households.

Estimation of 1964 Single-Family Zonal Trips

Because the independent variables of the household model are linear in form, zonal area trips may be efficiently estimated from the following relation:

$$Y_j = na + b_1X_{1j} + b_2X_{2j} + \ldots + b_mX_{mj}$$

where

Y_j = the number of trips in zone j,
X_{kj} = the zonal total of variable k in zone j,
n_j = the number of households in zone j,
a = the regression constant, and
b_k = the regression parameter for variable k.

Table 3 gives the results of expanding the 1964 and 1971 household equations to obtain estimates of the home-based trips reported by the 4,300 single-family households. Two prominent elements of these statistics deserve attention here. First, when the household equations are expanded to obtain zonal estimates, the percentage of variation is increased from about 35 (Table 2) to 96, whereas the percentage of standard error of the mean is reduced from approximately 60 to 20. The adjusted values are similar to values observed in zonal regression analyses.

The second and most important point to be drawn from the data in Table 3 is the comparability of estimates obtained from the two data sets. The 1971 model estimated the zonal trip productions reported in 1964 with the same statistical efficiency as was possible with the 1964 household data sets. This supports the basic hypothesis of this research; i.e., analysis at the household level should provide relations that are more meaningful, and these relations should remain stable over time. In this study, the disaggregate analysis did detect a shift in the effect of automobile ownership for the families selected, but the overall relation was sufficiently accurate for estimating zonal travel at a second point in time.

GENERATION MODELS FOR ALL TYPES OF DWELLING UNITS

It is recognized that the 357 single-family units selected for the first part of this research represent a limited inference space in that they represent only a portion of the total population. The models developed for this sample can be expanded to give acceptable estimates of travel for the households from which they were selected. Would the same be true if one were to use a sample of all household and family characteristics? Further, these models have been expanded to obtain estimates of reported trips of the households from which the sample was drawn. Can these models be expanded to determine the factored trip volumes that represent the trips of the total population in the study area?

These questions are evaluated here by developing a household travel model using the entire 1964 IRTADS interview data set. In addition, the models based on all types of dwelling units are used to examine the possibility of data reduction in the continuing study and the geographical transferability of the model relations.

Estimation of IRTADS Total Urban Travel

The variables used in the home-based trip production model developed by IRTADS were total zonal population and total automobiles in the zone. The household model developed in this study used household family size and total automobiles in the household

Table 1. Average household socioeconomic and trip production characteristics.

Characteristic	1964, 4,300 Single-Family Households Mean	Standard Deviation	1964, 357 Households Sampled Mean	Standard Deviation	1971, 357 Households Sampled Mean	Standard Deviation
Family size	3.63	1.83	3.64	1.78	3.18	1.60
Persons age 5 and over	3.23	1.58	3.32	1.62	3.09	1.51
Labor force	1.31	0.73	1.39	0.71	1.26	0.79
Automobiles owned	1.39	0.73	1.48	0.75	1.67	0.88
Total trips	9.16	7.47	9.80	7.03	9.31	7.10
Home-based trips	6.98	5.38	7.49	5.24	7.00	5.18
Home-based work	2.00	1.49	2.12	1.34	1.99	1.51
Home-based shop	1.33	2.03	1.43	2.13	1.04	1.73
Home-based school	1.03	1.97	1.08	1.97	0.97	1.08
Home-based other	2.62	3.46	2.85	3.38	2.99	3.31
Mean income (dollars)	8,000	3,900	8,400	4,000	13,000	6,800
Median income (dollars)	7,300	–	7,200	–	14,000	–

Figure 1. Household travel rates for varying levels of family size.

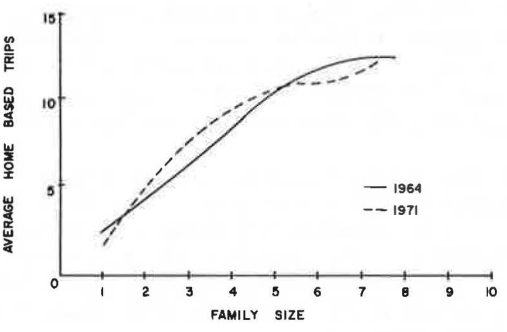

Figure 2. Household travel rates for varying levels of automobile ownership.

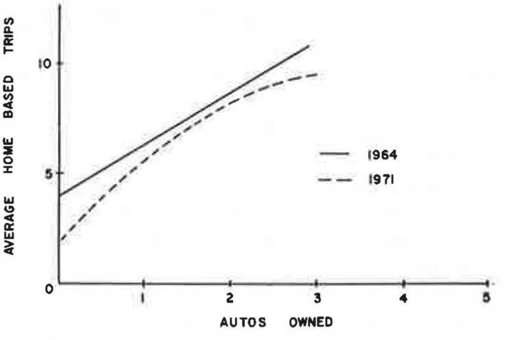

Table 2. Household prediction equations for home-based trips.

Variable	1964[a] Regression Coefficient	Standard Error	1971[b] Regression Coefficient	Standard Error
Constant	-0.45	–	-0.19	–
Family size	1.40	0.13	1.46	0.15
Automobiles	1.92	0.31	1.52	0.27

[a] R^2 = 0.34, standard error of estimate = 4.31, and $\overline{Y}$ = 7.46.
[b] R^2 = 0.36, standard error of estimate = 4.20, and $\overline{Y}$ = 7.00.

Table 3. Summary statistics of single-family household equations expanded to obtain zonal travel estimates.

Statistic	1964	1971
Adjusted R^2	0.96	0.96
Adjusted standard error of estimate	18.4	19.0
Mean of zonal trips[a]	95.8	95.8
Mean of residuals	-4.1	-4.1
Slope ($Y_{actual}/Y_{predicted}$)	0.98	0.98

[a] Dependent variable is 1964 zonal home-based trips, number of zones = 313, and household models based on 357 observations.

to define the equivalent relations. The relations obtained for each of the models were as follows:

1. IRTADS model (4)—Home-based trips/zone = 10.776 + 0.149 (population) + 1.257 (automobiles), and
2. Household model—Home-based trips/HH = -0.232 + 1.015 (family size) + 2.148 (automobiles).

The household equation was expanded and compared with the zonal estimates made by IRTADS. The statistics for the two models are given in Table 4. A special comment is necessary when comparing the data given in Table 4. The IRTADS model is based on data from 389 zones, whereas the household equation is expanded to represent travel from only 326 zones. As a consequence, the mean number of zonal trips is not identical for each model. The reduction in the number of zones is due to elimination in this study of all zones in which there were no reported dwelling units or labor force.

The ability of household equations to estimate zonal travel is shown in Figure 3. This is a plot of predicted home-based trips against factored zonal trip estimates provided by IRTADS. If the model predicted perfectly, all points should fit a 45-deg line passing through the origin. The actual regression line exhibited a slope coefficient of 1.00 and a constant term of -45. This constant is only 1 percent of the mean zonal trips; therefore, the model was accepted as a good fit of the data.

The residuals were examined by plotting the travel volumes against the residuals. This plot exhibited a random scatter of points. Further, Figure 4 shows a histogram of the residual distribution. This plot closely approximates the ideal normal distribution with a mean value of zero. Thus, in this study, it was found that, even though the household data did not meet all the assumptions for linear regression at the household level, residuals from the expanded equation did meet the criteria of independence and normality.

Comparison of the predictive ability of the zonal totals model and the household model indicates that the latter produces estimates with somewhat greater variation. It must be noted, however, that parameters of the IRTADS zonal equations are estimated to produce the minimum error in the zonal productions. By definition, the sum of the residuals must be zero. On the other hand, the parameters of the household model are estimated to produce minimum error at the household level. The mean of the residuals at the household level must be zero, but generally there can be no assurance that the residual sum will be zero when the model is used to estimate larger area travel. The degree to which the mean residual approaches zero provides another measure of the applicability of the expanded equation. The mean residual represents less than 1 percent of the zonal mean.

Potential for Data Reduction in Continuing Study

It was demonstrated previously that the disaggregate household model could be expanded to produce total area travel. However, because the aggregate and disaggregate models were both formulated from a data base that includes more than 10,000 home interviews, there has been no indication that the household modeling approach would save data collection expenditures. It would be necessary to conduct a full-scale analysis of sampling variability and expected errors to estimate potential savings. From this analysis, the ideal sample size necessary to obtain estimates within desired confidence limits could be determined. In this research, a single subsample was drawn to determine the order of magnitude of sample size reduction that might be possible. This subsample was equivalent to a 1 percent sampling rate, whereas the IRTADS sample was designed as a 5 percent sample. Table 5 gives the adjusted household equations given in Table 4 for the 5 percent sample and provides the comparable statistics for the 1 percent sample (2,240 cases). The ability of the two household equations to predict total travel is very similar. The standard error of the estimate is actually somewhat smaller for the smaller sample size, but, on the other hand, the mean residual is larger. Additional research is required to obtain more complete knowledge concerning the full extent of possible data reductions for trip generation as well as the other

Figure 3. Estimated and actual trip productions.

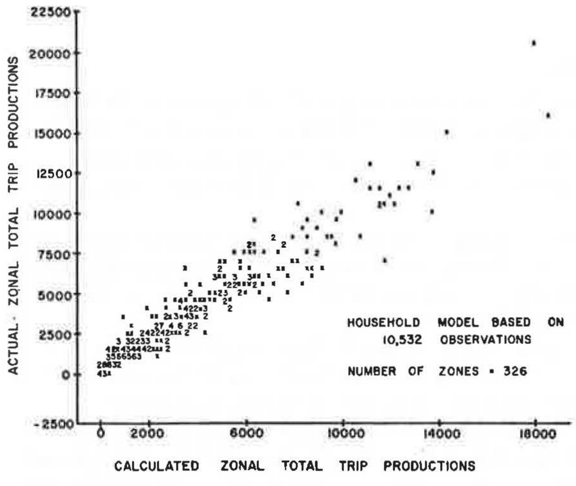

Figure 4. Frequency distribution of zonal residuals determined from expanded household equations.

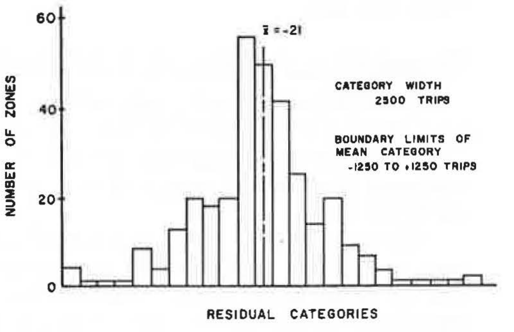

Table 4. Trip generation model statistics for estimation of total home-based trip productions.

Statistic	IRTADS Zonal Model	Household Model
R^2[a]	0.97	0.92
Standard error of estimate	597	948
Mean of zonal trips	3,287	3,947
Number of zones	389	326
Percent standard error	18.2	24.0
Mean of residuals	0	-21
Slope ($Y_{actual}/Y_{predicted}$)		1.00

[a]Adjusted statistics given for household model. Original household model based on 10,532 observations.

Table 5. Predictive ability of models.

Statistic	Sample Size: 10,532 Households	Sample Size: 2,240 Households
Adjusted R^2	0.92	0.92
Adjusted standard error of the estimate	948	922
Mean of zonal trips	3,947	3,947
Mean residual	-21	+56
Slope ($Y_{actual}/Y_{predicted}$)	1.00	1.02

Note: Household equations expanded to estimate home-based travel in 326 zones.

Table 6. Aggregation effects on trip generation model parameters for two urban areas.

Level of Analysis	Dependent Variable (Y)	Independent Variable (X_i)	Indianapolis: Number of Observations	Indianapolis: Model Parameters	Tri-State Area: Number of Observations	Tri-State Area: Model Parameters
Household	Trips per household	X_1 = persons per household; X_2 = automobiles per household	10,532	$Y = 1.146 X_1 + 3.169 X_2 - 0.192$	5,032	$Y = 1.064 X_1 + 3.169 X_2 + 0.292$
Zone	Average trips per household per zone	X_1 = average persons per household per zone; X_2 = average automobiles per household per zone	299	$Y = 1.092 X_1 + 5.139 X_2 - 2.37$	305	$Y = 2.054 X_1 + 3.458 X_2 - 2.94$

phases of travel forecasting. Certainly though, the contention that sample size requirements may be reduced for estimation of household trip generation appears to be substantiated.

Geographical Variation in Model Parameters

The final advantage proposed for disaggregate analysis was that observed relations should be more consistent from area to area because the analysis unit is not tied to an artificial area description, and the household unit is of the same basic internal consistency in different geographical areas. A limited examination of this aspect is given in Table 6.

The parameters given in Table 6 provide a measure of the degree to which household and zonal model parameters are comparable for two study areas, i.e., Indianapolis and the tri-state area, which includes New York City. The tri-state area equations were developed in the research by Kassoff and Deutschman (6).

The magnitudes of the household model parameters for the independent variables are strikingly similar for the two study areas, even though the areas themselves would not be considered as comparable in nature. The largest variation is in the magnitude of the constant term. One might reflect that the constant term of the model is the geographic factor that explains differences in household travel in the two areas. Of course, other differences in average trip rates in the areas would be reflected by differences in the average value of the independent variables.

On the other hand, there are substantial differences in the parameters of the zonal-based models. Although this comparison is only for two study areas, the basic premise that household parameters measure a more stable, basic relation appears to be substantiated.

SUMMARY AND CONCLUSIONS

Analysis of travel behavior using the household as the basic unit provides a method of evaluating the changing relations that occur over time. A disaggregate trip generation model developed from data obtained from 357 single-family households in 1964 was able to predict the home-based trips produced by the same families in 1971 with an average error of less than 2 percent. The household models from 1964 and 1971 also exhibited the same degree of statistical efficiency when expanded to estimate total zonal trips reported in 1964 by the single-family households from which the 1971 sample was selected.

The disaggregate model for estimating total home-based travel from all dwelling units was judged to be nearly comparable with the zonal model for estimating present travel. However, because the disaggregate model is sensitive to measurement of change in the behavioral unit, the household model is preferred. Indications are that the data set may be reduced by as much as 80 percent for estimating trip generation parameters at the disaggregate analysis level. Further, because the household is the basic unit in all urban areas, analysis at the household level can help the planner understand true travel variation among geographical areas rather than apparent differences that are a function of the size of area unit selected within the study area.

Certainly, additional research is required to determine the limits of the sample size necessary for estimating travel and the degree of geographical biases that exist. Also, consideration must be given to the data requirements of other aspects of travel forecasting, i.e., trip attraction, distribution, modal split, and assignment. In the continuing study, the analyst must determine the degree to which the existing calibrated models can simulate changing travel patterns. Will the sample size that provides adequate information about changes in trip generation rates also provide sufficient data to evaluate changing attitudes and patterns of spatial distribution? Behavioral model research for the other planning models may also indicate increased efficiency. Careful planning of the survey design may provide information adequate for development of all disaggregate models. If knowledge of the complexities of travel behavior can be attained at this disaggregate level, the analysis could be conducted at this level, and then aggregation may proceed to whatever level is necessary. The important item to emphasize is that the disaggregate model approach is sensitive to changes that occur at the behavioral level and, therefore, provides a means to measure changes. This is an essential consideration as the transportation analyst considers the changing conditions that occur during the continuing planning process. After evaluation of these changes at the behavioral level, aggregation may proceed to whatever analysis unit is necessary.

REFERENCES

1. Bureau of Public Roads. Guidelines for Trip Generation Analysis. U. S. Government Printing Office, 1967.
2. Domencich, T. A., Kraft, G., and Valette, J. P. Estimation of Urban Passenger Travel Behavior: An Economic Demand Model. Highway Research Record 238, 1968.
3. Fleet, C. R., and Robertson, S. R. Trip Generation in the Transportation Planning Process. Highway Research Record 240, 1968.
4. Trip Generation Analysis. Indianapolis Regional Transportation and Development Study, 1966.
5. Kannel, E. J. A Disaggregate Analysis of Urban Travel Behavior. Purdue Univ., PhD dissertation, June 1972.
6. Kassoff, H., and Deutschman, H. Trip Generation: A Critical Appraisal. Highway Research Record 297, 1969.
7. Lansing, J. B., and Hendricks, G. Automobile Ownership and Residential Density. Institute for Social Research, Univ. of Michigan, Ann Arbor, 1967.
8. Manheim, M. Practical Implications of Some Fundamental Properties of Travel Demand Models. Presented at HRB 51st Annual Meeting, January 1972.
9. McCarthy, G. M. Multiple Regression Analysis of Household Trip Generation—A Critique. Highway Research Record 297, 1969.
10. Oi, W., and Shuldiner, P. Analysis of Urban Travel Demand. Northwestern Univ. Press, 1962.
11. Quandt, R. E., and Baumol, W. Abstract Mode Model: Theory and Measurement. Journal of Regional Science, Vol. 6, No. 2, 1966.
12. Reichman, S., and Stopher, P. Disaggregate Stochastic Models of Travel Mode Choice. Highway Research Record 369, 1971.
13. A Disaggregate Behavioral Model of Urban Travel Demand. Charles River Associates, Inc., March 1972.
14. Siegel, S. Nonparametric Statistics for the Behavioral Sciences. McGraw-Hill, New York, 1956.
15. Stopher, P. R., and Lisco, T. Modelling Travel Demand: A Disaggregate Behavioral Approach—Issues and Applications. Transportation Research Forum, 1970.
16. Stowers, J., and Kanwit, E. The Use of Behavioral Surveys in Forecasting Transportation Requirements. Highway Research Record 106, 1966.
17. UNEQUAL. Purdue Univ., Computer Library, 1970.