due to the approximations and averages used to characterize the aggregated regional system. The important thing to note is that these adjustments do not change in any way the behavioral validity of the relative weights estimated statistically for the variables of the models. The advantages of disaggregate models in including more relevant variables than is possible in aggregate models, and in requiring fewer observations for model estimation, are also not affected by constants and the need to adjust them in aggregate applications.

TRIP LENGTH ADJUSTMENTS

Shunk and Kollo miss the importance of trip length adjustments when they state that these adjustments are applied more often to work trips than to nonwork trips. The magnitude of these corrections is more relevant than their frequency of application, and the relative magnitudes for work and nonwork purposes vary with trip length. For all trips less than 5 km (3 miles) in length, no correction is applied for either purpose. In the 5- to 24-km (3- to 15-mile) range, work corrections exceed those for nonwork travel. For trips longer than 24 km, the home-based shop corrections are the largest.

COST AND EFFECTIVENESS

Our paper mentions the expanded resource requirements, both in terms of staff understanding and in terms of analysis costs. Shunk and Kollo quote computer costs of $6000; we maintain that these compare favorably with the costs of traditional aggregate systems, which can be as high as $10 000 for a full analysis. In addition, it must be noted that these costs apply only to the full network analysis system, MTCFCAST. For many problems faced by MPO's, SRGP can provide the required information at costs per alternative in the $100-$200 range, after one-time costs of approximately $5000, to prepare a data base of household and level-of-service data. It is also worth noting that further work is being done to expand the SRGP approach to be compatible with network assignments. The computer costs of this approach fall in the $1500-$2000 range when an iterative procedure is used to predict both demand and network equilibrium, two aspects that cannot be addressed at all for the quoted $6000 cost.

Fred Reid raised another important question. He asked both Shunk and Ben-Akiva, "If you had the project to do over again, what would you do differently?" This is a question to which we have given considerable thought, because the technical quality and capability of the model system are not being taken full advantage of by the agency for which it has been developed.

One important aspect of the project that would be done differently is that less effort would be spent formulating and estimating additional model components; instead, more effort would be spent on thoroughly testing and validating the fewer model components estimated. This strategy is required to prevent the disillusionment likely to occur when, near the end of the model development process, some component produces unreasonable results under certain input assumptions.

Two other redirections of effort would have increased the usefulness of the modeling work done. First, rather than the almost exclusive emphasis, in the prediction testing and validation portions of the project, on the full network analysis system, MTCFCAST, more effort would have been devoted to demonstrating the value and usefulness of the SRGP program, which is potentially more cost effective for many of the policy questions addressed by an MPO. Second, more emphasis would be placed on ensuring, throughout the project, that the end product be precisely what is needed to meet the agency's planning needs and that the agency staff have full knowledge of the end product and complete facility in using it.

The problems of implementing and successfully using a major new model system require a large amount of cooperative effort by modelers and practitioners to be completely solved.

*Publication of this paper sponsored by Committee on Passenger Travel Demand Forecasting and Committee on Traveler Behavior and Values.*

# Effects of Transportation Service on Automobile Ownership in an Urban Area

Thomas F. Golob,* Consultant, Birmingham, Michigan
Lawrence D. Burns, Transportation and Traffic Science Department,** General Motors Research Laboratories, Warren, Michigan

**A disaggregate automobile ownership choice model is applied to estimating the elasticities of automobile ownership with respect to household income, fixed costs of automobiles, travel times on urban roadways, and public transit service in a case study urban area. Focus is on the aggregate stock of automobiles held by all households and on the distribution of households owning zero, one, two, and three or more autos. Automobile ownership behavior of sociodemographic segments in the total population is also compared. Results indicate that the total number of automobiles owned is approximately three times more sensitive to household income than to automobile travel times. Furthermore, automobile ownership is twice as sensitive to automobile travel times as it is to public transit travel times. Finally, the automobile ownership decisions of inner-city dwellers and older families are more sensitive to all of these factors than are the decisions of suburban dwellers and younger families. It is demonstrated that transportation policies affecting urban traffic efficiency and public transit service are likely to impact on automobile ownership and these impacts will vary with geographical location and population sociodemographic segment.**

The purpose of this research is to estimate the relative sensitivities of urban automobile ownership levels with respect to household income, automobile costs, efficiency of automobiles and public transit travel, and locations of residences and urban activities. Focus is on the aggregate stock of automobiles held by all households and on the distribution of households owning 0, 1, 2, and 3 or more automobiles.

The sensitivity estimates are generated by using a disaggregate automobile ownership model based on a theory proposed by Beckmann, Gustafson, and Golob (1). The theory postulates that a household trades off reduced consumption of goods and services other than transportation for increased accessibility to opportunities when deciding whether or not to own one or more automobiles. The dependent variables are the probabilities that a given household will choose to own a particular number of automobiles. The explanatory variables include those encompassed in the consumption component of the household trade-off function and those encompassed in the accessibility components. The former variables include household disposable income, fixed costs of automobile ownership, automobile operating costs, and public transit fares. The latter variables include travel times by automobile from the household's location to all possible trip destinations, travel times by public transit to those destinations accessible by transit, and the activity level or opportunities at each destination. Household sociodemographic characteristics are used as segmentation variables.

The Beckmann-Gustafson-Golob automobile ownership theory leads directly to a strict utility model of choice in the manner described by Georgescu-Roegen (2, 3) and Halldin (4). Strict utility models are referred to as Bradley-Terry-Luce models in psychology (5, 6) and are applications of the well-known first-choice axiom of Luce (6). As demonstrated by McFadden (7, 8) and Yellott (9), these models are expressed without loss of generality as multinomial logit models for parameter estimation purposes.

The initial logit parameter estimations of the Beckmann-Gustafson-Golob theory were accomplished by Burns, Golob, and Nicolaidis (10). Lerman and Ben-Akiva (11) independently proposed an alternative model that is less rigorous in its underlying choice theory, more restrictive in its assumptions of a hierarchy of travel choices, but able to estimate the effects of a far larger number of explanatory variables. The two models are excellent complements.

The model requires data of the sort typically collected in urban transportation planning system (UTPS) studies. The case study application presented here uses home interview, transportation network, and land-use data from the Detroit Transportation and Land Use Study (TALUS) (12). A maximum likelihood estimation technique was employed. Maximum likelihood estimations of multinomial logit parameters have been shown by McFadden (7, 8) to be statistically consistent, asymptotically efficient, and unique under very general conditions. The estimators are also asymptotically normal, which permits large sample applications of t-statistics and chi-square statistics in significance tests.

Model calibrations were performed by using random subsamples of households interviewed in the 1965 TALUS home interview survey. Since TALUS expended considerable effort to establish a probability sample of households and since large sample sizes were used in the present study, the random subsamples were judged to be representative cross-sections of 1965 Detroit area households. Separate subsamples were used for model calibration and for calculation of goodness of fit.

As a first step in calibrating the models, households were divided into choice-constraint segments based on the maximum feasible number of automobiles they were assumed to consider. This maximum feasible number of automobiles is generally equal to the number of driver-aged household members. However, for some low-income households, the maximum feasible number of automobiles is determined by a constraint on the amount of disposable income available to meet costs of automobile ownership. The rationale of separate calibrations for choice constraint segments has been proposed by Recker and Golob (13). It allows for the possibility that housholds faced with different choice sets weigh the costs and benefits associated with the choices differently in arriving at their final decisions.

In the course of calibrating the models, sensitivity analyses were conducted on several model parameters. These included automobile fixed costs, disposable income definitions, automobile operating costs, and definitions of activities at trip destinations.

Following calibration of the model for the total sample, the households were divided into segments that were homogeneous with respect to their demographic and socioeconomic characteristics. Separate calibrations were then performed for each demographic segment. As discussed by Lovelock (14), Louviere and others (15), and Nicolaidis, Wachs, and Golob (16), such a segmentation allows identification of different sensitivities in the choices of various readily identifiable groups in society.

To study the relative importance of factors affecting household consumption and those affecting household members' accessibilities in household automobile ownership decisions, the effects of changes in these factors must be examined. These effects are captured in a dimensionless measure commonly known as elasticity. Elasticity is a ratio of the resulting percentage change in a dependent variable to the corresponding change in an independent variable. The greater the absolute value of elasticity, the greater the sensitivity of the dependent variable to changes in the independent variable. Expressions were formulated for elasticities of (a) household choice probabilities, (b) expected household automobile ownership, (c) expected aggregate choice frequencies, and (d) expected aggregate automobile ownership with respect to (a) household income, (b) automobile fixed costs, (c) automobile travel times to all destinations, and (d) public transit travel times to destinations reachable by public transit.

These expressions are used in conjunction with results from the model calibrations to determine elasticity values. The values are then interpreted with respect to traffic efficiency and public transit service policies.

## MODEL CALIBRATION

### Total Sample

In the 1965 Transportation and Land Use Study (12) a total of 28 178 households that resided within the boundaries of the 1960 Detroit urban area were interviewed (17). These households were divided into three choice-constraint segments on the basis of the above criteria for determining the maximum feasible number of automobiles for each household.

This division is depicted in Figure 1, where 22.2 percent of the households were postulated to have choices between 0 and 1 automobile; 64.4 percent had choices among 0, 1, and 2 automobiles; and 13.4 percent had choices among 0, 1, 2, and 3 or more automobiles. Again, both number of driver-aged household members and household disposable income were used to segment these households.

Also shown in Figure 1 are the total numbers of households in each choice-constraint segment observed to choose each alternative number of automobiles. These distributions of actual choices affect choice model calibrations and must be taken into account when evaluating the goodness of fit of such models.

Multinomial logit parameter estimates for each choice-constraint segment are shown in Table 1. The sample size for each model is approximately 600. The first three rows in this table list the utility coefficients (the coefficients corresponding to the consumption term and transportation accessibility term are denoted $b_c$ and $b_t$ respectively) and their t-statistics (ratio of coefficient to standard error of coefficient) for the consumption term, transportation accessibility term, and constant. The asymptotic distribution of these t-statistics is Student's t, and therefore they are used to test the null hypotheses $b_c = 0$ or $b_t = 0$.

The 99 percent critical value of the t-distribution for approximately 600 degrees of freedom is 2.33; t-statistics greater than this value have a probability of less than 0.01 of being due to chance.

The consumption term is a function of disposable income and automobile fixed costs. The transportation accessibility term is a function of travel times by automobile from each household's location to all potential trip destinations, the population residing at each destination (a proxy for the attraction of destinations), and travel times by public transit to those destinations accessible by public transit. These terms are described by Burns and Golob (18).

The last row of Table 1 gives a chi-square statistic developed from the ratio of the logarithms of the initial and final likelihoods; it is used to test the joint null hypothesis that $b_c = b_t = 0$ and has three degrees of freedom in the present applications. It can be concluded from these results that, first, the probability that statistics supporting these models are due to chance is extremely low (less than 0.0001) and, second, the relationship between the number of automobiles households choose to own and both the consumption and accessibility variables defined in the present theory is highly statistically significant. Research by Burns and Golob (18) presents additional and encouraging model goodness-of-fit results from previous sensitivity analyses.

The predictive power of these three calibrated models

Figure 1. Choice-constraint segmentation for total sample.

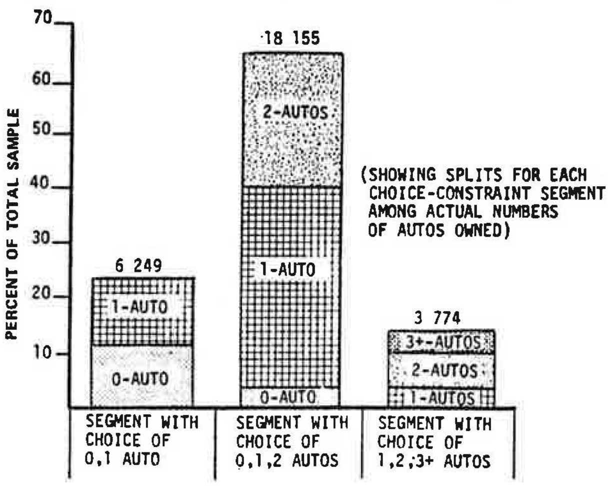



Table 1. Choice model results for total sample.

| | Choice-Constraint Segment | | |
|---|---|---|---|
| Model Parameter | 0, 1 Auto | 0, 1, 2 Autos | 1, 2, 3+ Autos |
| Coefficient on transportation accessibility term $b_t$ | 0.526 | 0.471 | 0.252 |
| t-Statistic | 13.60 | 22.60 | 16.90 |
| Coefficient on consumption term $b_c$ | 2.13 | 6.96 | 8.02 |
| t-Statistic | 11.60 | 11.40 | 11.70 |
| Constant | 0.598 | 1.43 | 0.816 |
| t-Statistic | 6.37 | 16.90 | 10.20 |
| Choice to which constant assigned | 0 autos | 1 auto | 2 autos |
| Chi-square statistic for likelihood explained by model relative to null hypothesis of choice shares | 127.0 | 116.0 | 96.4 |
| Degrees of freedom | 3 | 3 | 3 |

Table 2. Choice model tests for total sample hold outs.

| | Choice-Constraint Segment | | |
|---|---|---|---|
| Test Statistic | 0, 1 Auto | 0, 1, 2 Autos | 1, 2, 3+ Autos |
| Aggregate frequencies of households owning particular numbers of automobiles (computed/actual) | | | |
| 0 autos | 518/514 | 77/56 | - |
| 1 auto | 526/530 | 551/562 | 285/285 |
| 2 autos | - | 383/393 | 635/628 |
| 3+ autos | - | - | 339/346 |
| Individual households' choices classified correctly, % | 69 | 60 | 50 |
| Individual households' choices predicted correctly using choice share proportions as aid to random process, % | 50 | 46 | 38 |

Table 3. Choice model results for total equal-proportion sample.

| | Choice-Constraint Segment | | |
|---|---|---|---|
| Model Parameter | 0, 1 Auto | 0, 1, 2 Autos | 1, 2, 3+ Autos |
| Coefficient on transportation accessibility term $b_t$ | 0.526 | 0.448 | 0.207 |
| t-Statistic | 13.6 | 23.9 | 15.1 |
| Coefficient on consumption term $b_c$ | 2.13 | 10.6 | 7.56 |
| t-Statistic | 11.6 | 17.6 | 11.9 |
| Constant | 0.598 | 0.404 | (constant insignificant) |
| t-Statistic | 6.37 | 4.10 | |
| Choice to which constant assigned | 0 autos | 1 auto | |
| Chi-square statistic for likelihood explained by model relative to null hypothesis of choice shares | 127.0 | 279.0 | 90.7 |
| Degrees of freedom | 3 | 3 | 3 |

Table 4. Sociodemographic factors.

| Factor No. | Percentage of Variance Explained | Component Variables | Correlation Between Factor and Variable |
|---|---|---|---|
| 1 | 25.4 | Marital status of head of household | 0.86 |
| | | Sex of head of household | 0.78 |
| | | No. of licensed drivers | 0.77 |
| | | No. of household members | 0.66 |
| 2 | 19.0 | Age of head of household | 0.83 |
| | | Tenure at address | 0.81 |
| | | Rent or own home | -0.52 |
| | | Education of head of household | -0.49 |
| 3 | 18.0 | Population density of zone of residence | 0.81 |
| | | Race of head of household | 0.80 |
| | | Rent or own home | 0.48 |
| | | Education of head of household | -0.44 |

was next tested on hold-out samples. Probabilities were calculated by using the parameter values calibrated on the original sample and the observed independent variable values for each household in a segment hold-out sample. The aggregate frequencies of households owning each particular number of automobiles were then computed by adding the probabilities for each choice state. In addition, each household was assigned to the choice state with highest calculated probability, and the percentages correctly assigned were tabulated. Results are shown in Table 2.

The descriptive power of each of the models is good. With regard to the less stringent aggregate frequencies test, all computed frequencies were within 2.5 percent of the actual, with the exception of the relatively rare case of the households with choices of 0, 1, and 2 automobiles who chose to own 0 automobiles; these households were over-predicted by 37.5 percent. With regard to the very stringent percent correct classification test, the models each improved classification accuracy by approximately one-third over the best achievable using a priori probabilities based upon the proportions of households choosing to own various numbers of automobiles (i.e., using a random process aided by market share proportions).

The results of the total sample model calibrations are partially dependent on degrees of inequality in choice share proportions. Constants in multinomial logit models adjust for inequalities in choice shares, but, in general, utility coefficients are also affected. Consequently, in order to investigate the relative contributions of the consumption and transportation accessibility terms in explaining the choices of each of the three choice-constraint segments, models were calibrated for samples chosen with equal proportions of each chosen alternative. Results are shown in Table 3. The segment with choice between 0 and 1 automobile had approximately equal choice shares for the total sample, and thus model results are the same as in Table 1.

The presence of constants in a logit model estimated on equal proportion samples indicates that there is a bias in choice toward one or more alternatives not explained by the model variables. The failure to find a constant significantly different from zero is a necessary but not sufficient condition for the full explanatory power of model variables in light of random disturbances. Thus, there is justification in interpreting the results of Table 3 to mean that the choices of households among 1, 2, and 3+ automobiles are more fully explained in terms of the present theory than are the choices of households between 0 and 1 automobile, and among 0, 1, and 2 automobiles. In other words, choices involving the alternative of 0 automobiles are more difficult to explain than choices involving only how many automobiles are to be owned. This conclusion is further strengthened by comparing the chi-square statistics, where degrees of freedom correspond, and t-statistics listed in Table 3.

A second conclusion is that transportation accessibility is more important relative to consumption (disposable income and fixed automobile costs) for households choosing between 0 and 1 automobile than it is for households in the other two choice-constraint segments. This conclusion is based on comparisons of utility coefficients and is only ordinal.

## Sociodemographic Segments

The total sample of Detroit urban area households was segmented on the basis of similarities in patterns of sociodemographic characteristics. The available characteristics measured in the TALUS home interview are listed below.

| Characteristic | Coding |
|---|---|
| Number of household members | Absolute number |
| Number of licensed drivers | Absolute number |
| Rent or own house | 1 = own, 2 = rent |
| Tenure at address | 1 = 7 weeks or less, 2 = 8-51 weeks, 3 = 1-4 years, 4 = 5-10 years, 5 = over 10 years |
| Education of head of household | 1 = 8 years or less, 2 = 9-11 years, 3 = high school, 4 = college |
| Sex of head of household | 1 = female, 2 = male |
| Race of head of household | 1 = white, 2 = nonwhite |
| Age of head of household | Absolute number |
| Marital status of head of household | 1 = unmarried, 2 = married |
| Population density of traffic analysis zone of residence | Persons per hectare |

The segmentation methodology is similar to that described by Golob and Nicolaidis (19). It involves factor analysis and cluster analysis. The factor analysis is used to summarize the interrelationships among the sociodemographic variables by creating linear combinations of the variables (factors) that are independent of one another. Clustering individual households into homogeneous groups is then conducted in the multidimensional space of the factors; this eliminates redundancies in demographic measures and simplifies interpretation of the resulting segments. A random sample of 935 households was used in the factor and cluster analyses. The total sample of 28 178 households were then assigned to the resulting segments by using multiple discriminant analysis classification procedures.

Three sociodemographic factors were found to account for 62.4 percent of the variance in the original ten variables, and additional factors were judged not to add sufficient descriptive power to warrant the loss in efficiency. The factors are described in Table 4, where the percentage of variance accounted for by each factor and the variables that have high correlations (factor loadings) with each factor are listed.

The selection of an appropriate number of segments is accomplished in a fashion similar to the selection of the number of factors: a cut-off point is located in a clustering "compactness" index (i.e., an index simultaneously measuring within-segment homogeneity and between-segment heterogeneity). A good compactness index is judged to be the Wilks $\lambda$-criterion, the ratio of the determinant of the pooled within-segment scatter matrix to the determinant of the total scatter matrix. In this way four sociodemographic segments were found.

The four sociodemographic segments were next plotted in the space of the three factors to facilitate interpretation. The segments were labeled so as to best represent their positions in the factor space. These labels and the proportions of the total sample in each segment are given below. Essentially, there are two large segments, and two segments that are approximately one-half the size of the large segments.

| No. | Label | Percentage of Total Sample |
|---|---|---|
| 1 | Single-person households | 15.7 |
| 2 | Younger families | 39.8 |
| 3 | Inner-city dwellers | 15.2 |
| 4 | Older families | 29.3 |

Division of each of the four segments into choice-constraint segments led to the aggregate splits depicted in Figures 2 through 5. These figures are analogous to Figure 1 for the total sample. However, some choice-

Figure 2. Choice-constraint segmentation for demographic segment 1.

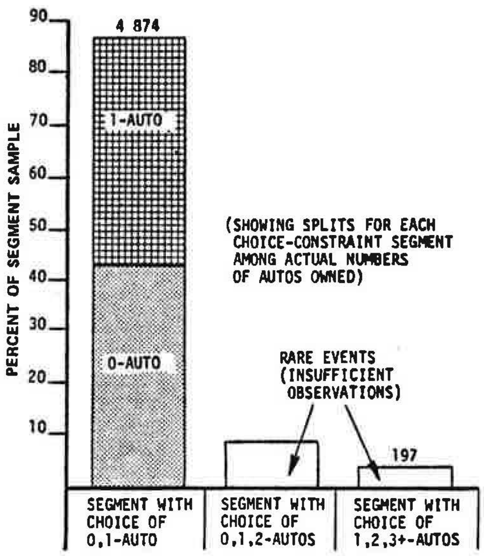



Figure 3. Choice-constraint segmentation for demographic segment 2.

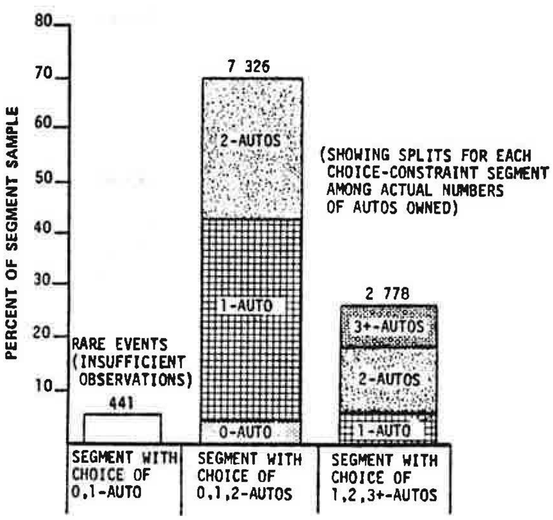
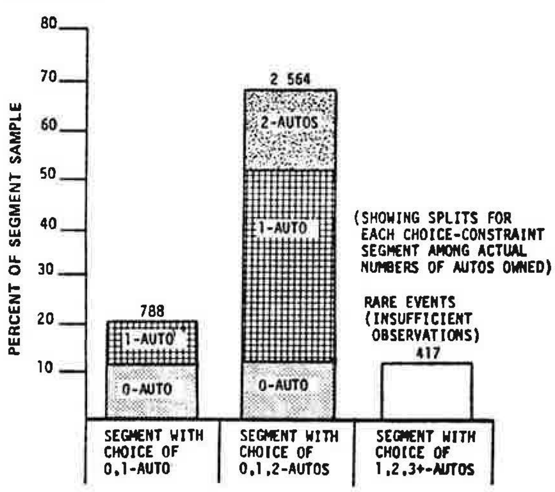



Figure 4. Choice-constraint segmentation for demographic segment 3.




constraint segments essentially did not exist for some sociodemographic segments, because there were insufficient observations to permit choice models to be calibrated for these cases. They are indicated as rare events in Figures 2 through 5.

Interpretation of the figures leads to the conclusion that, for each of the four sociodemographic segments, the distribution of the segment sample into choice-constraint segments is intuitively satisfying, including

Figure 5. Choice-constraint segmentation for demographic segment 4.

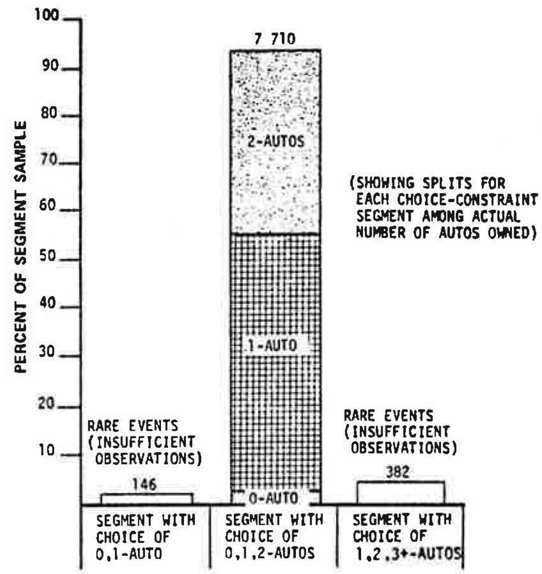



Table 5. Choice model results for sociodemographic segment 1.

| Model Parameter | Choice-Constraint Segment: 0, 1 Auto | 0, 1, 2 Autos | 1, 2, 3+ Autos |
|---|---|---|---|
| Coefficient on transportation accessibility term $b_t$ | 0.526 | No model | No model |
| t-Statistic | 11.7 | | |
| Coefficient on consumption term $b_c$ | 2.61 | | |
| t-Statistic | 9.99 | | |
| Constant | 0.615 | | |
| t-Statistic | 5.38 | | |
| Choice to which constant assigned | 0 autos | | |
| Chi-square statistic for likelihood explained by model relative to null hypothesis of choice shares | 109 | | |
| Degrees of freedom | 3 | | |

Table 6. Choice model results for sociodemographic segment 2.

| Model Parameter | Choice-Constraint Segment: 0, 1 Auto | 0, 1, 2 Autos | 1, 2, 3+ Autos |
|---|---|---|---|
| Coefficient on transportation accessibility term $b_t$ | No model | 0.433 | 0.215 |
| t-Statistic | | 24.8 | 13.9 |
| Coefficient on consumption term $b_c$ | | 10.9 | 7.80 |
| t-Statistic | | 18.4 | 10.6 |
| Constant | | | |
| t-Statistic | | 0.484 | |
| Choice to which constant | | 5.14 | (constant in- |
| assigned | | 1 auto | significant) |
| Chi-square statistic for likelihood explained by model relative to null hypothesis of choice shares | | 329 | 70.8 |
| Degrees of freedom | | 3 | 3 |

the occurrence of the rare events.

Choice model results for the sociodemographic segments are given in Tables 5 through 8. The format of these tables is identical to that of Table 3 for the total equal proportion sample. Comparisons among the results shown in Tables 5 through 8 lead to the following conclusions (sizes of the random samples chosen for model calibrations are approximately equal).

First, with regard to choices between 0 automobiles and 1 automobile, significance levels of constants indicate that errors in model specification are expected to be less for demographic segment 3 than for demographic segment 1. That is, choices of inner-city dwellers are more readily explained in terms of the accessibility and consumption variables of the present theory than are the choices of single-person households.

Second, with regard to choices among 0 automobiles, 1 automobile, and 2 automobiles, chi-square statistics and t-statistics indicate that choices of younger families are most effectively explained, then come choices of older families, and finally are choices of inner-city dwellers. In addition, the relative utility weights indicate that accessibility is a more important consideration relative to consumption for inner-city dwellers, which corresponds to an expected higher average level of public transit service for these people.

Comparisons involving choices among 1 automobile, 2 automobiles, and 3+ automobiles were not possible because only one sociodemographic segment had a choice model calibrated for this choice-constraint segment.

Table 7. Choice model results for sociodemographic segment 3.

| Model Parameter | Choice-Constraint Segment: 0, 1 Auto | 0, 1, 2 Autos | 1, 2, 3+ Autos |
|---|---|---|---|
| Coefficient on transportation accessibility term $b_t$ | 0.390 | 0.509 | No model |
| t-Statistic | 8.62 | 17.3 | |
| Coefficient on consumption term $b_c$ | 1.87 | 9.81 | |
| t-Statistic | 8.04 | 18.1 | |
| Constant | (constant | | |
| t-Statistic | insig- | -0.338 | |
| Choice to which constant assigned | nificant) | -2.94 | |
| Chi-square statistic for likelihood explained by model relative to null hypothesis of choice shares | 41.2 | 167.0 | |
| Degrees of freedom | 2 | 3 | |

Table 8. Choice model results for sociodemographic segment 4.

| Model Parameter | Choice-Constraint Segment: 0, 1 Auto | 0, 1, 2 Autos | 1, 2, 3+ Autos |
|---|---|---|---|
| Coefficient on transportation accessibility term $b_t$ | No model | 0.457 | No model |
| t-Statistic | | 27.5 | |
| Coefficient on consumption term $b_c$ | | 14.2 | |
| t-Statistic | | 20.0 | |
| Constant | | | |
| t-Statistic | | 0.371 | |
| Choice to which constant | | 3.83 | |
| assigned | | 1 auto | |
| Chi-square statistic for likelihood explained by model relative to null hypothesis of choice shares | | 278 | |
| Degrees of freedom | | 3 | |

## ELASTICITY CALCULATIONS

### Total Sample

Elasticities of automobile ownership in the Detroit metropolitan area in 1965 with respect to certain important model explanatory variables are shown in Table 9. These include elasticities for the expected number of households owning alternative numbers of automobiles and the overall elasticity for the aggregate stock of automobiles held by all households.

Automobile ownership was found to be three times more sensitive to changes in disposable income or automobile fixed costs than to uniform percentage changes in automobile travel times throughout the metropolitan area: a 10 percent increase in all incomes would lead to a 3 percent increase in the aggregate stock of automobiles, while a 10 percent increase in automobile travel times would lead to a 1 percent decrease in aggregate stock. Travel time by public transit has one-half the effect of travel time by automobile and almost the same effect as travel time by automobile to destinations located within the city of Detroit.

The net number of households owning 1 automobile is relatively insensitive to changes in disposable income, fixed costs of automobiles, or any travel times. This is because about the same number of households move from 0 automobile to 1 automobile states as move from 2 automobiles to 1 automobile for opposite types of changes. With respect to the relative effects of the consumption term versus the transportation accessibility term, the number of households owning 0 automobiles and the number of households owning 3+ automobiles are most sensitive to income and automobile fixed costs. However, the number of households owning 0 automobiles also has the highest sensitivity to transportation accessiblity variables; the number of households owning 3+ automobiles, together with the number owning 2 automobiles, has only modest sensitivity to transportation accessibility variables.

The results in Table 9 were developed through aggregation of results for each of the three total sample choice-constraint segments. Tables 10 through 12 list these more detailed results for comparison purposes.

Table 9. Elasticities of total sample.

| Variable | Elasticity of Expected No. of Households: Owning 0 Auto | Owning 1 Auto | Owning 2 Autos | Owning 3 Autos | Elasticity of Aggregate Stock of Autos Held by All Households |
|---|---|---|---|---|---|
| Consumption term: | | | | | |
| Disposable income (= negative of fixed costs of all autos) | -0.94 | -0.08 | 0.49 | 0.89 | 0.29 |
| Transportation accessibility term: | | | | | |
| Travel by auto to all destinations | 0.30 | 0.05 | -0.21 | -0.21 | -0.10 |
| Travel by auto to destinations in city of Detroit (only) | 0.11 | 0.02 | -0.08 | -0.08 | -0.04 |
| Travel by public transit to all destinations | -0.17 | -0.01 | 0.10 | 0.09 | 0.05 |
| Travel by public transit to destinations in city of Detroit (only) | -0.10 | -0.01 | 0.06 | 0.06 | 0.03 |

Households faced with choices between 0 and 1 automobile (Table 10) are most sensitive to changes in both consumption and accessibility term variables; households faced with choices among 1, 2, and 3 or more automobiles are least sensitive to such changes. Since households in the latter choice-constraint segment generally have higher incomes, the difference in consumption term elasticities is consistent with traditional economic theories. Households in the latter segment in general are also more suburbanized, so the difference in accessibility term elasticities can be interpreted to reflect the relative unavailability of alternatives to travel by automobile outside the city of Detroit. Many such relationships between elasticities and socioeconomic and location patterns are explored later in this report.

A final issue in this section is the effect of automobile fixed costs. Because of the assumptions underlying the utility theory model, treating automobiles as homogeneous economic goods equates the absolute value of the effect of disposable income and automobile fixed costs. It is beyond the scope of the present theory to distinguish between new and used automobiles. If, however, second and third automobiles held by households are postulated to be affected by exogenous inputs (such as insurance costs) to a different extent than first automobiles are, differences in sensitivities to income and automobile fixed costs can be investigated in terms of the present theory.

Assume that changes in fixed costs of second and third automobiles are less than changes in fixed costs of first automobiles by a fixed percentage. For example, if costs of the first or primary automobile held by households increase by 10 percent, the costs of second and third automobiles increase by 7.5 percent (i.e., fixed cost increases for additional automobiles are 75 percent of fixed cost increases for primary automobiles). Fixed automobile cost elasticities for the total sample have been estimated under such an assumption, and results are graphed as a function of percentage difference between primary and second and third automobile cost differences in Figure 6. Fixed automobile cost elasticities range linearly from on the order of one-half the income elasticity to the income elasticity over the entire domain of possible percentage differences. These results are

Table 10. Elasticities of choice-constraint segment with choice of 0 or 1 auto.

| Variable | Elasticity of Expected No. of Households in the Choice-Constraint Segment: Owning 0 Auto | Owning 1 Auto | Elasticity of Aggregate Stock of Autos Held by Segment Households |
|---|---|---|---|
| Consumption term: | | | |
| Disposable income (= negative of fixed costs of all autos) | -0.72 | 0.72 | 0.72 |
| Transportation accessibility term: | | | |
| Travel by auto to all destinations | 0.21 | -0.21 | -0.21 |
| Travel by auto to destinations in city of Detroit (only) | 0.08 | -0.08 | -0.08 |
| Travel by public transit to all destinations | -0.12 | 0.12 | 0.12 |
| Travel by public transit to destinations in city of Detroit (only) | -0.07 | 0.07 | 0.07 |

Table 11. Elasticities of choice-constraint segment with choice of 0, 1, or 2 autos.

| Variable | Elasticity of Expected No. of Households in the Choice-Constraint Segment: Owning 0 Auto | Owning 1 Auto | Owning 2 Autos | Elasticity of Aggregate Stock of Autos Held by Segment Households |
|---|---|---|---|---|
| Consumption term: | | | | |
| Disposable income (= negative of fixed costs of all autos) | -1.44 | -0.22 | 0.61 | 0.26 |
| Transportation accessibility term: | | | | |
| Travel by auto to all destinations | 0.47 | 0.12 | -0.26 | -0.10 |
| Travel by auto to destinations in city of Detroit (only) | 0.17 | 0.04 | -0.10 | -0.04 |
| Travel by public transit to all destinations | -0.27 | -0.04 | 0.12 | 0.05 |
| Travel by public transit to destinations in city of Detroit (only) | -0.16 | -0.03 | 0.07 | 0.03 |

Table 12. Elasticities of choice-constraint segment with choice of 1, 2, or 3+ autos.

| Variable | Elasticity of Expected No. of Households in the Choice-Constraint Segment: Owning 1 Auto | Owning 2 Autos | Owning 3+ Autos | Elasticity of Aggregate Stock of Autos Held by Segment Households |
|---|---|---|---|---|
| Consumption term: | | | | |
| Disposable income (= negative of fixed costs of all autos) | -1.07 | 0.01 | 0.87 | 0.23 |
| Transportation accessibility term: | | | | |
| Travel by auto to all destinations | 0.22 | -0.01 | -0.21 | -0.05 |
| Travel by auto to destinations in city of Detroit (only) | 0.08 | 0.00 | -0.08 | -0.02 |
| Travel by public transit to all destinations | -0.12 | 0.00 | 0.10 | 0.03 |
| Travel by public transit to destinations in city of Detroit (only) | -0.07 | 0.00 | 0.06 | 0.02 |

Figure 6. Implied elasticity of aggregate stock of automobiles versus change in costs of automobiles.

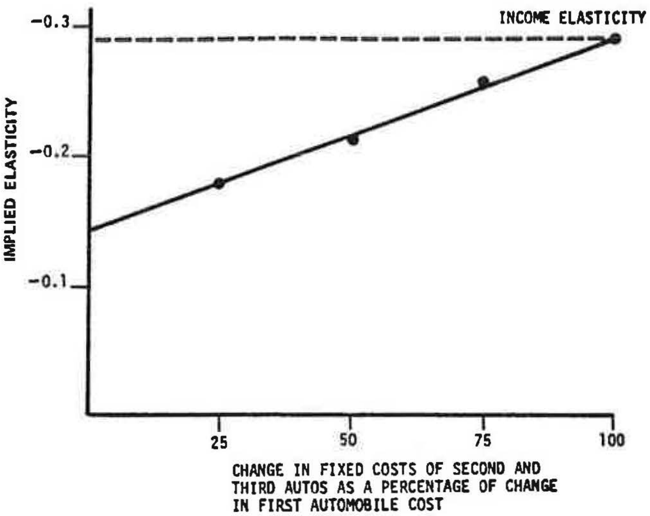



Table 13. Elasticities of aggregate stock of autos.

| Sociodemographic Segments No. | Type | Percentage of Sample | Disposable Income | Areawide Auto Travel Time | Areawide Transit Travel Time |
|---|---|---|---|---|---|
| 1 | Single-person households | 16 | 0.68 | -0.19 | 0.11 |
| 2 | Younger families | 40 | 0.48 | -0.12 | 0.06 |
| 3 | Inner-city residents | 15 | 0.77 | -0.20 | 0.13 |
| 4 | Older families | 29 | 0.66 | -0.16 | 0.07 |
| Total | | 100 | 0.51 | -0.14 | 0.07 |

interpreted to be evidence that the true automobile fixed-cost elasticity lies within this range.

## Sociodemographic Segments

Elasticities of the aggregate stock of automobiles owned by all households in a sociodemographic segment with respect to selected variables are shown for each of the four demographic segments in Table 13. The three variables are disposable income, automobile travel time to all destinations, and public transit travel time to all destinations. Results for the total sample are shown for comparative purposes. These total sample results are different from those listed in Table 9, since they are generated by using equal proportional sampling choice model parameters (Table 3), as opposed to random sampling (Table 1). This is necessary in order to match the sampling underlying the results for the sociodemographic segments.

The choices of inner-city residents are most sensitive to changes in disposable income and both automobile and transit travel times. The choices of younger families are least sensitive to changes in these variables explaining automobile ownership behavior. The effects of the two variables representing the transportation accessibility term are greatest relative to the effect of income for single-person households.

With regard to the two accessibility variables, the choices of inner-city residents and single-person households are most sensitive to public transit travel time relative to automobile travel time. Since these two segments are the least suburbanized, this result is consistent with the conclusion that public transit is a more significant factor in automobile ownership decisions in higher density areas where its service level is higher.

## CONCLUSIONS

The aggregate stock of automobiles held by urban households (all automobiles owned, both new and used) is sensitive to transportation accessibility factors—travel times by automobile and by public transit—as well as to income and automobile ownership cost. Using the Detroit area as a case study, the following sensitivities were found from 1965 cross-sectional data:

1. The elasticity of automobile ownership with respect to automobile travel times is 0.1. It may therefore be inferred that a 10 percent decrease in automobile travel times experienced by all households, as a result perhaps of road or traffic efficiency improvements, would cause a 1 percent increase in automobile ownership, all else being held constant. The elasticity of automobile ownership with respect to public transit travel times is 0.05, or one-half that of automobile travel times.
2. The automobile ownership decisions of inner-city dwellers are more sensitive to travel time accessibility factors (and income) than are those of suburban dwellers. The ownership decisions of young families are less sensitive to these same factors than are those of older families.
3. The elasticity of automobile ownership with respect to disposable income is 0.3, or three times that of automobile travel times and six times that of public transit travel times.

These conclusions are derived from elasticity calculations using cross-sectional data at one point in time. While such calculations are conceptually different from elasticity calculations that use time-series data, they do provide a basis on which to compare relative effects of different variables.

Implications of these results are twofold. First, transportation policies aimed at improving traffic efficiency within urban areas can be expected to increase automobile ownership levels. Second, policies aimed at improving public transit service can be expected to decrease automobile ownership levels, but the absolute value of this effect will be approximately one-half that of the traffic efficiency effect (for an equal percentage change in overall automobile or bus trip time). These effects should not be ignored when assessing the costs and benefits associated with plans affecting traffic efficiency or public transit service.

## ACKNOWLEDGMENTS

Martin J. Beckmann of Brown University and the Technical University of Munich, and a consultant to General Motors Research Laboratories, provided invaluable inputs to the development of the theory underlying this research. Richard L. Gustafson, now at Portland State University, and Gregory C. Nicolaidis, General Motors Research Laboratories, co-authored earlier reports on the project. Ellen M. Racusin, also of General Motors Research Laboratories, prepared much of the data for analyses. We gratefully acknowledge these contributions.

## REFERENCES

1. M. J. Beckmann, R. L. Gustafson, and T. F. Golob. Locational Factors in Automobile Owner-

ship Decisions. Annals of Regional Science, Vol. 7, 1973, pp. 1-12.
2. N. Georgescu-Roegen. Threshold in Choice and the Theory of Demand. Econometrica, Vol. 26, 1958, pp. 157-168.
3. N. Georgescu-Roegen. The Relation Between Binary and Multiple Choices: Some Comments and Further Results. Econometrica, Vol. 37, 1969, pp. 728-730.
4. C. Halldin. The Choice Axiom, Revealed Preferences, and the Theory of Demand. Theory and Decision, Vol. 5, 1974, pp. 139-160.
5. R. A. Bradley and M. E. Terry. Rank Analysis of Incomplete Block Designs: I. The Method of Paired Comparisons. Biometrika, Vol. 39, 1952, 324-345.
6. R. D. Luce. Individual Choice Behavior. Wiley, New York, 1959.
7. D. McFadden. The Revealed Preferences of a Government Bureaucracy. Project for the Evaluation and Optimization of Economic Growth, Institute of International Studies, Univ. of California, Berkeley, Technical Rept. No. 17, 1968.
8. D. McFadden. Conditional Logit Analysis of Qualitative Choice Behavior. In Frontiers in Econometrics (P. Zaremka, ed.), Academic Press, New York, 1974.
9. J. I. Yellot. The Relationship Between Luce's Choice Axiom, Thurstone's Theory of Comparative Judgment, and the Double Exponential Distribution. Journal of Mathematical Psychology, Vol. 15, 1977, pp. 109-144.
10. L. D. Burns, T. F. Golob, and G. C. Nicolaidis. A Theory of Urban Households' Automobile Ownership Decisions. TRB, Transportation Research Record 569, 1975, pp. 56-74.
11. S. R. Lerman and M. Ben-Akiva. Disaggregate Behavioral Model of Automobile Ownership. TRB, Transportation Research Record 569, 1976, pp. 34-55.
12. Growth, Change, and a Choice for 1990: Preliminary Plan, Southeast Michigan, Detroit. Detroit Regional Transportation and Land Use Study, 1965.
13. W. Recker and T. F. Golob. A Behavior Travel Demand Model Incorporating Choice Constraints. Advances in Consumer Research, Vol. 3, 1976, pp. 416-425.
14. H. Lovelock. A Market Segmentation Approach to Transit Planning. Proc., Transportation Research Forum, Vol. 16, 1975, pp. 247-258.
15. J. J. Louviere, L. M. Ostresh, D. H. Henley, and R. J. Meyer. Travel-Demand Segmentation: Some Theoretical Considerations Related to Behavioral Modeling. In Behavioral Travel-Demand Modeling (P. R. Stopher and A. H. Meyburg, eds.), Heath, Lexington, MA, 1976.
16. G. C. Nicolaidis, M. Wachs, and T. F. Golob. Evaluation of Alternative Market Segmentations for Transportation Planning. TRB, Transportation Research Record 649, 1977, pp. 23-31.
17. U.S. Census of Housing: 1960. Bureau of the Census, U.S. Department of Commerce, Vol. 1, States and Small Areas: Michigan, Final Rept. HC(1)-24, 1962.
18. L. D. Burns and T. F. Golob. The Role of Accessibility in Basic Transportation Choice Behavior. Transportation, Vol. 5, 1976, pp. 175-198.
19. T. F. Golob and G. C. Nicolaidis. Comparison of Segmentations for Modeling Consumers' Preferences for Transportation Modes. Paper presented at the American Institute for Decision Sciences Annual National Conference, San Francisco Nov. 10-13, 1976.

*Publication of this paper sponsored by Committee on Passenger Travel Demand Forecasting and Committee on Traveler Behavior and Values.*

**Mr. Golob was with General Motors Research Laboratories when this paper was written.*

***On January 1, 1979, the Transportation and Urban Analysis Department became the Transportation and Traffic Science Department.*

# Perceptual Market Segmentation Technique for Transportation Analysis

Ricardo Dobson*, Charles River Associates, Inc., Cambridge, Massachusetts
Mary Lynn Tischer, Federal Highway Administration

**A primary aim of this research is to illustrate a relatively uncomplicated and effective perceptual market segmentation procedure for transportation policy analysis. This illustration is achieved through a flowchart describing the technique, an empirical application, and tests of the reliability of the derived market segmentation structures across split halves of a data set. The procedure was calibrated on a sample of Los Angeles central business district workers. The segmentation structure, which was derived for the full sample, readily distinguished the perceptual groups and correlated highly with appropriate mode-choice patterns. It was also observed that perceptual segmentation membership was a stronger determinant of mode choice than zone network times and costs. The split sample analyses showed reliable relationships across halves and confirmed the mode-choice linkage of perceptual segments relative to network times and costs. Among the practical implications of the segmentation procedure are its use in developing short-range forecasting models and its potential for developing information aids to target groups of travelers.**

The concept of market segmentation for consumer re-