DISAGGREGATE BEHAVIORAL MODEL OF AUTOMOBILE OWNERSHIP

Steven R. Lerman, Cambridge Systematics, Inc.; and
Moshe Ben-Akiva, Massachusetts Institute of Technology and Cambridge Systematics, Inc.

This paper describes a series of disaggregate behavioral models that forecast the probability that various combinations of automobile ownership and travel modes to work will be selected by households. The models assume that workplace and residential location are predetermined. The multinomial logit model is used in a joint structure that captures the complex interrelationship of automobile ownership and travel-to-work decisions. The paper describes the considerations in the choice of independent variables and the specification of the utility functions. The estimation results for each of 7 distinct socioeconomic groups, or market segments, with different behavioral characteristics are presented and analyzed. One of the models then is used to examine the shifts in automobile ownership for a suburban household resulting from alternative levels of transit service improvements.

•FORECASTING automobile ownership has always played an important role in the transportation planning process. The car ownership of a household is a major determinant of its trip-making behavior. For example, car ownership has been found to be the single most important variable in trip-generation models (10, 12) and a major determinant of modal choice (3, 5, 7). Thus, to predict trip-making behavior adequately, one must first model the process underlying car-ownership decisions.

In most major transportation studies, car ownership typically has bridged the gap between urban land use models, which focus on the spatial pattern of urban activities, and the traditional 4-step transportation planning process of trip generation, trip distribution, modal split, and traffic assignment. This relationship between car ownership and the traditional transportation forecasting cycle is shown in Figure 1. Note that, in this figure, the transportation level of service should enter into the factors determining car ownership. However, despite its fundamental importance as a determinant of how people use an urban transportation system, forecasting car ownership often has been treated outside the basic forecasting cycle. It has been relegated to a side calculation made with simple models that rely on trend extrapolations or correlations between 1 and 2 variables and car ownership rather than on a strong causal theory. Few studies have ever addressed the basic behavioral factors underlying the household's car-ownership decisions, and still fewer have attempted to embody a behavioral perspective in a valid econometric model. Furthermore, no modeling efforts have attempted to incorporate in a behaviorally consistent way the interaction of the way in which households choose the number of cars they own and the other transportation-related decisions they make. This paper describes a study that developed a series of models that represent car-ownership behavior in a way consistent with a credible theory of the choice process at the household level. This series therefore can be used with reasonable confidence in a broad range of policy-testing situations.

The basic objectives of the study were

1. To formulate and test behavioral hypotheses about the relationships between car ownership and the transportation system,
2. To develop and estimate models of car ownership that can be used as part of an

overall transportation planning process and that are behaviorally structured and statistically valid,

3. To provide a tool for transportation policymakers to assess the impacts of policies on car ownership and in particular to assess the role that transit level of service plays in determining car ownership, and
4. To develop models that allow policymakers to separate the impacts of various transportation policies on different socioeconomic groups.

ISSUES IN MODEL DEVELOPMENT

Car ownership is a household-level decision that is highly dependent on how workers in that household choose to travel to work. Previous models (4, 6, 11) have failed to treat this interaction in a credible way; they have either ignored it entirely, assumed some arbitrary sequence of decisions, or used other highly simplistic behavioral assumptions.

Each household makes its car-ownership decision as part of a larger range of transportation-related choices. How many cars one owns depends on where one lives and how one uses those cars. For this reason, considering car ownership as part of a complex group of decisions that are hierarchically structured is desirable; that is, car-ownership decisions are made conditional on the outcome of some household choices and are made before the outcome of other decision processes. Figure 2 shows the choice hierarchy on which this study is based. The choices of employment location, residential location, and housing are assumed to be made on the longest term basis. Car ownership and travel mode to work, the medium-term choices, are made conditionally on the results of the long-term decisions. The short-term travel decisions of trip frequency, destination, mode, and the like, for various non-work-trip purposes are made last conditionally on the locational, work-trip, and car-ownership decisions.

This general hierarchy of choice has important implications for the way in which car ownership decisions should be modeled. Car ownership and mode to work are closely related and, therefore, to model them as jointly determined is most appropriate. (For this study, only the mode of the primary worker was considered. The primary worker, also termed the breadwinner, was defined as the working member of the household with the highest socioeconomic status on a scale developed during the study.) The overall model structure representing this choice hierarchy can be termed block conditional. This means that a block of lower-level choices is made conditionally on higher-level choices but that the choices within each block are determined jointly.

Another hypothesis on which the study was based is that households have very different underlying behavior depending on both the stage of life that they are in and the occupation of the primary worker. For this reason, different models are estimated for different market segments. The empirical results indicate that such market segmentation isolates groups of households that make car-ownership decisions by using very different sets of values and that previous modeling efforts that pooled all households may be biased substantially when used in forecasting.

In the initial model development, 9 distinct market segments were considered. These consist of 4 life cycle groups:

1. Households consisting of single persons without children,
2. Households with a married couple both of whom were younger than 45 years without children,
3. Households with children, and
4. Households with a married couple 1 or more of whom were older than 45 years without children.

Two occupational groups were defined as

1. Occupation A, which was made up of the blue-collar primary workers; and
2. Occupation B, which was made up of the white-collar primary workers.

These provided 8 market segments each labeled by life cycle and occupation. A ninth segment consisting of households with no full-time workers also was defined and labeled life cycle 5. In addition, a random sample of households in life cycles 1 through 4 was used in model estimation for comparison with the separate market-segment models.

The models described in this paper use disaggregate data from the 1968 Washington, D.C., home-interview survey to estimate a series of multinomial logit models. Choice theory and the logit model are not reviewed in this paper. Excellent discussions of the theory and use of disaggregate choice models are available elsewhere (2, 3, 8, 9).

The models developed in this study predict the probability with which a household will select each of a number of available alternative car-ownership and travel-mode-to-work combinations. Thus, by the multinomial logit form, the probability of a household's choosing to own a given number of cars a and traveling to work by mode m is

$$P(a, m) = \frac{\exp(V_{am})}{\sum_a \sum_m \exp(V_{am})} \tag{1}$$

where V_{am} is the utility of a car-ownership and travel-mode-to-work combination.

Given the joint model for the probability $P(a, m)$, one can derive any desired conditional or marginal probabilities. For example, a simple car-ownership model with indeterminate modal choice will be

$$P(a) = \sum_m P(a, m) \tag{2}$$

and a model of modal choice given a car-ownership level will be

$$P(m \mid a) = \frac{P(a, m)}{P(a)} \tag{3}$$

The utility functions V_{am} are restricted to be linear in the coefficients.

CHOICE OF VARIABLES

There are 6 basic categories of variables that influence a household's car-ownership and travel-mode-to-work decision:

1. Transportation level of service to work,
2. Car-ownership costs,
3. Locational attributes,
4. Housing attributes,
5. Spatial opportunity variables, and
6. Socioeconomic variables.

Each of these categories represents important factors that determine car ownership and travel mode to work. Therefore, none should be ignored completely. However, the level of detail with which each category can be treated can vary widely. For example, housing can be treated as a 0-1 dummy variable to represent whether the household lives in a single-family dwelling, or it can be treated as a broad range of variables describing rent, type of tenure, years at residence, type of structure, age of structure,

and type of lot. The trade-off between level of detail and relative ease of use in forecasting was basic to the problem of variable selection, particularly when one of the objectives of the study was to capture as much of the behavioral process as possible.

Note that not all the variables appear directly in the utility functions. Some variables are combined in ways that reflect a theory about how they interact. Others enter into the utility functions of some car-ownership and travel-mode-to-work pairs and not others. Thus this section is not intended to be a discussion of the actual independent variables used for estimation, but rather it is a list of those variables that in some form affect the probability of a household's selecting any alternative. What follows is a discussion of each category of variables and the actual measures used in the models to represent it.

Transportation Level of Service to Work

The variables for transportation level of service to work influence directly the primary-worker's choice of travel mode to work, and therefore influence car ownership through the interdependency of car ownership and travel mode to work represented by the joint structure of the model. It was decided to use the traditional level-of-service measures commonly included in modal-choice models: in-vehicle time, out-of-vehicle time, and out-of-pocket cost. Empirical tests indicated that the time spent out of vehicle apparently is perceived to be far more onerous for short trips than for longer ones. Hence the ratio of out-of-vehicle time to highway travel distance was used. The level-of-service measures of both the car and the transit mode appear in the model in their respective utility functions.

Even when these 3 types of level-of-service variables are used, certain effects that influence modal choice, such as the frustration of being in congested traffic and the high variance of peak-hour travel time in heavily used travel corridors, are not measured. It is these factors that typically cause modal choice for downtown-oriented trips to be different from non-central-business-district (non-CBD) trips (13). To capture this effect, we used a dummy variable for CBD-oriented work trips.

Car-Ownership Costs

Car-ownership costs are the primary deterrent to high car ownership for households with more than 1 driver. However, the cost of owning a car is highly dependent on the type of car owned. Small cars with their low purchase prices and good fuel economy are far cheaper to own on an annualized basis than are larger, less efficient cars. However, the focus of this study is on the total number of cars a household will own rather than on their type, age, or quality. Thus, some value representing the average cost of owning a specific number of cars must be used.

An average figure of $1,000 ownership cost/car/year was used in the models to be described under socioeconomic variables. However, because this figure was selected somewhat arbitrarily, tests were made to determine the sensitivity of the results to large changes in that cost. These results indicate that large variations in this assumed value do not substantially alter the parameter estimates.

Locational Attributes

The way in which locational attributes affect the car-ownership and travel-mode-to-work decision is far more subtle than the effects of the first 2 types of variables discussed. At the simplest level, differences in personal property taxes and insurance will add to the monetary cost of owning cars; however, these variations in the Washington, D.C., area were deemed too small to be relevant. What is more significant is that implicit in a household's location decision are important restrictions on the way in which households may travel to work or to shop. For this reason, no specific variables

were introduced into the utility functions to represent locational effects; instead, location was reflected in the other variables, such as those for spatial opportunity and level of service to work, and in restrictions on the alternatives available to each household as described under spatial opportunities.

Housing Attributes

Housing attributes can be represented by a large number of possible variables. However, on careful consideration of the way in which a household selects the number of cars it wishes to own, it was decided that only 1 major influence, whether the household resided in a single-family dwelling, merited consideration. Single-family houses typically have driveways and generally are located in areas that have readily available on-street parking; multiple-family dwellings generally are characterized by the reverse. Thus one would anticipate that, if all else is equal, the utility of multiple-car ownership would be substantially higher for those residing in single-family homes than for those residing in apartments.

Spatial Opportunities

Spatial opportunities make up perhaps the most difficult class of variables to represent and measure. These variables are a composite of the attributes of all nonwork trips, and some way of combining the characteristics of various possible trips with the relative likelihood of the household's making them must be found. The approach used in this study relies on a behavioral means of combining the level of service to different nonwork destinations. In the choice hierarchy shown in Figure 2, when a household selects its car ownership and mode to work, its actual pattern of nonwork travel is indeterminate. However, given any choice of car ownership and travel mode to work, the household then would be able to determine the probability with which it would travel to each destination. These probabilities depend on the transportation level of service and the attractiveness of each destination, but they also depend on the characteristics of the household. Therefore, it makes theoretical sense to use an estimate of the household-level probabilities to weight the level of service for nonwork travel. Expressed mathematically, this spatial opportunity measure is determined as follows [a more detailed discussion of this type of composite variable is available elsewhere (2, 3)]:

$$\text{Accessibility of a household in zone i by mode m} = \sum_{d} t_{idm} \cdot P(i, d, m) \qquad (4)$$

where

$P(i, d, m)$ = probability of the household's traveling from i to d by mode m, and
t_{idm} = some measure of the level of service from i to d by mode m.

Actually measuring this type of accessibility gives rise to a number of practical issues such as what types of spatial opportunities should be used. It was decided that the most relevant nonwork travel purpose is shopping and that other spatial opportunities play a secondary role and reasonably can be ignored. This greatly reduced the computational problems of creating the accessibility measures without substantially sacrificing important car-ownership effects. Another practical issue concerns what measure of level of service is most appropriate. Although each travel-time and cost measure can be used separately, this gives rise to an unwieldy number of variables. Hence generalized prices that are a weighted linear function of in-vehicle time, out-of-vehicle time, and out-of-pocket cost were created. Furthermore, the value of time used in the weighting process was itself a function of income, reflecting the hypothesis

that high-income households would be willing to pay more to save time than low-income households would. Because all the level-of-service measures are for shopping trips, which typically are made in the off-peak hours, they are substantially different from the work-trip level-of-service measures.

The last practical issue that arises from the use of this type of accessibility measure is how the probabilities P(i, d, m) and the parameters of the generalized prices can be estimated. Because the underlying motivation for using this type of variable is its behavioral, disaggregate interpretation, it seems logical that a previously estimated disaggregate choice model should be used. This is precisely what was done in this study. By using a model developed by Ben-Akiva (2), we determined based on off-peak level-of-service data the probabilities of every household in the sample to select each shopping destination. Ben-Akiva's model (2) is in itself a simultaneous-choice model; in this case, choice of mode and destination for shopping trips are considered. By using the joint probability of mode and destination, P(d, m), we derived the conditional probabilities P(d|car) and P(d|transit). The weighting parameters of the generalized prices were taken from the utility function of this joint probability model. By using the forecasting probabilities, we determined the attributes for the expected shopping trip by both car and transit. These values are a function of both the home zone and the income of the household and hence are highly disaggregate measures of spatial opportunities.

Socioeconomic Variables

Socioeconomic variables are a special class of attributes in that they do not vary across car-ownership and travel-mode-to-work alternatives. For this reason, these variables must somehow be transformed in the utility function either by combining them with other variables or by making them alternative specific (including them in the utility function of some car-ownership and travel-mode-to-work combinations and not in others). These transformations of the actual measures will be considered in the next section of this paper.

Household income clearly plays an important role in determining automobile ownership. Simple tabulations of automobile ownership for different income groups indicate a strong and positive correlation. Higher income would increase the relative utility of the more expensive alternatives such as owning more than 1 car and taking a car to work.

Household size also should play a role in the car-ownership decision. Large households typically will require a greater portion of their available income for essentials such as food, housing, and clothing, thus leaving fewer family resources for expenditures on automobiles.

The number of licensed drivers represents the competition among household members for the use of cars. The greater the competition is, the more likely it should be that the household will own a greater number of automobiles and the more likely it should be for the primary worker to use transit to work. Furthermore, a household is extremely unlikely to own more cars than it has drivers in a household; this places an upper bound on car ownership. Table 1 gives a summary of the variable categories that are introduced into the joint car-ownership and modal-choice model.

SPECIFICATION OF THE JOINT UTILITY FUNCTIONS

The previous sections consider only the variables included in the model. This section will address the equally important question of how these variables are represented in the utility functions of each car-ownership and travel-mode-to-work combination. All of the models discussed in this section assume that a maximum of 5 alternatives are available to any household:

1. 0 cars owned and transit taken to work,

2. 1 car owned and car taken to work,
3. 1 car owned and transit taken to work,
4. 2 or more cars owned and car taken to work, and
5. 2 or more cars owned and transit taken to work.

For convenience, the alternatives in items 4 and 5 will be referred to as having 2 cars even though they consist of 2 or more cars. Thus 5 utility functions (1 for each possible alternative) are to be considered. However, not every household in the sample has every alternative available.

Even when the restriction that the utility function must be linear in its parameters is imposed, the number of ways in which variables can be formulated is virtually limitless. Variables can be multiplied, added, or divided, or their logarithms can be used. Some variables may appear in one utility function and not in others. Furthermore, socioeconomic variables, because their values do not vary across alternatives, must be transformed somehow either by combining them with other variables or by making them alternative specific.

The first group of variables selected represents a constant term added to each utility function. A different constant term can be introduced into all but 1 of the utilities. These constants measure pure alternative effects, that is, the attributes of the alternative relative to the one without a constant term that are not measured in all the other variables. A constant term was introduced into each utility except for the case of cars owned and transit taken to work. This choice of which utility should not have a constant term is completely arbitrary and has no effect on the probabilities of selecting each alternative.

The next variable used reflects the fact that the level of car availability a household would have if it chose any particular alternative affects its perception of the desirability of the alternative modes to work. The number of cars per licensed driver pertaining to each alternative was used to measure this effect. Because this variable was selected to measure the modal-choice aspect of the decision process, it was defined as follows:

$$\text{Cars per licensed driver} = \begin{cases} \dfrac{\text{number of cars in the alternative}}{\text{number of licensed drivers in the household}} & \text{for car-to-work alternative} \\ 0 \quad \text{otherwise} & \end{cases}$$

A variable of this type frequently appears in simple modal-choice models because of the presumed effect of car ownership on whether to take car or transit for a trip. As it is defined here, it plays precisely the same role, except that it now affects both modal choice (directly) and car ownership (through the simultaneity in the model structure). In addition, in modal-choice models, this variable reflects the chosen car ownership rather than the various levels that might have been selected. Thus an increase in the number of licensed drivers will cause a decrease in the value of the variable. One would expect that this should decrease the probability that the household will have its primary worker take the car mode to work; therefore, the coefficient of this variable should be positive.

The next variable requires some explanation. It arises from the fact that a large number of monetary measures are in the model, including household income, car-ownership costs, and out-of-pocket travel costs for the work trip. Furthermore, it was hypothesized that the way household size affects car ownership is by altering the amount of gross income available for nonessential expenditures. Clearly, one would like to avoid introducing a separate variable for each of these monetary factors. The question is how these attributes can be combined into a single variable representing the money that would be available to the household if it selected each alternative. This was

done by formulating a variable, termed for reference as the remaining income variable, as follows:

Remaining income = household annual income - 800 (household size)
- 1,000 (number of cars in the alternative)
- 250 (out-of-pocket cost of the work trip of the alternative)

Thus the value of this variable is an approximate measure of the amount of money a household has left over after expenditures on essential goods [assumed to be $800/household member/year based on work by Mudarri (11) and Hoxie (6)], car-ownership costs ($1,000/car owned), and work-trip cost (250 round-trip work trips/year). An alternative with 0-car ownership results in a high value of remaining income, representing the availability of income the household otherwise would have to allocate to the purchase, maintenance, and operation of a car if it had chosen to do so. The coefficient of this variable in the utility function always should be positive to reflect the fact that, if all else is equal, households would rather have more money than less money. The use of the remaining income variable is a classic case of the application of variable selection criteria based on deductive reasoning. Its justification is based on the theoretical considerations rather than empirical ones. However, the motivation for developing this variable in the first place was that reliable estimates of the coefficients of the separate cost components could not be obtained, and excellent estimates of the remaining income variable coefficient could. At first glance, this would seem to be contradictory. However, by collapsing all costs into a single variable, we have added an extra piece of information to the model formulation; the marginal utility of any cost component has been assumed to be the same, regardless of the type of expenditure considered. Stated more simply, the household has been assumed to view a dollar as having the same value regardless of where it is spent. It is this assumption that improved the estimate of the cost-term coefficient. To do this, a piece of deductive information has been used.

It was decided that this variable should not enter the utility functions linearly; the utility a poor family derives from an extra dollar is probably much greater than that which a wealthy family derives. Thus the marginal utility of money should decrease as the value of remaining income increases. This hypothesis was reflected by using the natural log of remaining income as an independent variable rather than by using simply the value itself.

The next variable is the type-of-housing dummy variable. This was defined to be equal to 1 only in the 2-car alternatives for households residing in single-family dwellings. Thus the coefficient of the single-family-housing dummy represents an added utility to the multiple-car options for a specific group of households and leaves the utility of the remaining options unaffected. Presumably, the coefficient of this dummy variable should be positive.

The next variable is the in-vehicle travel time in minutes for the round-trip work trip. This variable reflects the disutility of travel time, and hence should have a negative coefficient. Note that this variable has the same value for all alternatives with the same mode to work for the primary worker and is independent of the car ownership associated with the alternative.

The other time variable, out-of-vehicle time, is measured with respect to the distance of the work trip. This variable is defined as follows:

$$\text{Excess time/distance ratio} = \frac{\text{out-of-vehicle time for round-trip work trip in minutes}}{\text{1-way travel distance in miles (kilometers)}}$$

This choice of an out-of-vehicle time measure was made largely on empirically based criteria. Other forms of the variable typically produced results that were less satisfactory, and no strong theoretical reason existed for selecting one over the other. Travel distance was measured along the highway network. As with in-vehicle time, the value of this variable is invariant among car-ownership levels.

The next variable was designed to reflect another effect of the number of licensed drivers within a household. Although number of licensed drivers affects choice of mode to work through the cars-per-licensed-driver variable, it also should affect the level of car ownership directly. The more licensed drivers there are in a household, the more likely it should be to select a high car-ownership level independently of the travel mode to work taken by the primary worker. This effect was measured by introducing a variable that reflects the number of licensed drivers into each utility function with a different coefficient for each car-ownership level. These variables were defined for 1-car alternatives as follows:

$$\text{Inverse licensed drivers}_1 = \begin{cases} \dfrac{1}{\text{number of licensed drivers in the household}} & \text{for 1-car alternatives} \\ 0 \text{ otherwise} & \end{cases}$$

$$\text{Inverse licensed drivers}_2 = \begin{cases} \dfrac{1}{\text{number of licensed drivers in the household}} & \text{for 2-car alternatives} \\ 0 \text{ otherwise} & \end{cases}$$

When these variables originally were introduced into the model, it was hypothesized that the effect for the 2-car alternatives (as measured by the coefficient value) would be twice as great as the effect for the 1-car alternatives. Statistical tests indicated that this was indeed the case, and, for the models ultimately selected, the 2 licensed driver variables were combined into a single variable, defined as follows:

$$\text{Inverse licensed drivers} = \begin{cases} 0 \text{ for the 0-car and transit-to-work alternative} \\ \text{inverse licensed drivers}_1 \text{ for the 1-car alternatives} \\ 2\ (\text{inverse licensed drivers}_1) \text{ for the 2-car alternatives} \end{cases}$$

The use of the inverse of the number of drivers rather than simply the number of drivers reflects the hypothesis that, as the number of drivers increases, the marginal effect of an additional driver on the need for automobiles decreases. Clearly, the coefficient of the inverse licensed drivers variable should be less than 0.

The next 2 variables represent the spatial opportunities for nonwork travel. In the household's selection of car ownership, the absolute level of shopping accessibility is of little importance. What is actually relevant is whether the household will typically use car or transit for shopping trips; therefore, the cost of using a car relative to the cost of using transit influences car ownership. For this reason, the following variable was developed.

$$\text{Generalized price ratio} = \frac{\text{expected generalized car cost for shopping travel}}{\text{expected generalized transit cost for shopping travel}}$$

As defined, this variable does not change value for different alternatives and therefore must be introduced into the utility function as alternative specific. (This would not have been true had the shopping-trip model used car ownership as an explicit dependent variable. However, it still might have been desirable to capture differences in the way accessibility is perceived for different car-ownership levels.) Thus the following 2 variables appear in the model.

$$\text{Generalized price ratio}_1 = \begin{cases} \text{generalized price ratio for 1-car alternatives} \\ 0 \text{ otherwise} \end{cases}$$

$$\text{Generalized price ratio}_2 = \begin{cases} \text{generalized price ratio for 2-car alternatives} \\ 0 \text{ otherwise} \end{cases}$$

Note that the cost of taking transit when transit is not available (as in many suburban zones) is for practical purposes infinite; in such cases, the value of the generalized price ratio is 0. As generalized shopping travel cost by car increases, the value of the generalized price ratio increases. One would anticipate that this increase in car cost would result in greater use of transit. Consequently, the likelihood of high car ownership should decrease. To reflect this hypothesis, the coefficient of both these variables should be negative because they both measure the effect of shopping accessibility relative to the 0-car and transit-to-work alternative. Furthermore, the effect should be greater for the 2-car alternatives than for the 1-car options. This should result in a larger coefficient for the 2-car alternative than for the 1-car alternative.

The last variable used in the models is the work-trip-destination dummy variable, which is used to reflect the added disutility of traveling downtown by car not entirely captured by the level-of-service measures. This variable is defined as follows:

$$\text{CBD work-place dummy} = \begin{cases} 1 \text{ if work place is in CBD for car-to-work alternatives} \\ 0 \text{ otherwise} \end{cases}$$

Note that this variable is defined as specific to the car mode. Therefore, the coefficient reflects the difference in utility between car and transit for downtown work trips if all else is equal, and it should be negative.

Table 2 gives a summary of the variables and their definitions. However, the precise structure of each utility function is not clear and can best be illustrated by writing out the utility functions with the variables that are always 0 eliminated. For example, if the coefficients of the 13 variables are denoted B_1, B_2, and so on, the utility of variable 2 is as follows:

$$V_2 = \beta_2 + \beta_6 + \beta_8 + \beta_9 + \beta_{10} + \beta_{11}$$

The remaining 7 coefficients do not appear in the utility because the value of the variable with which they are multiplied is by definition 0. A more complicated utility function is that of variable 3 and is given in the following equation:

$$V_3 = \beta_3 + \beta_5 + \beta_6 + \beta_7 + \beta_8 + \beta_9 + \beta_{10} + \beta_{12} + \beta_{13}$$

Figure 1. Relationship of car-ownership model to conventional transportation forecasting cycle.

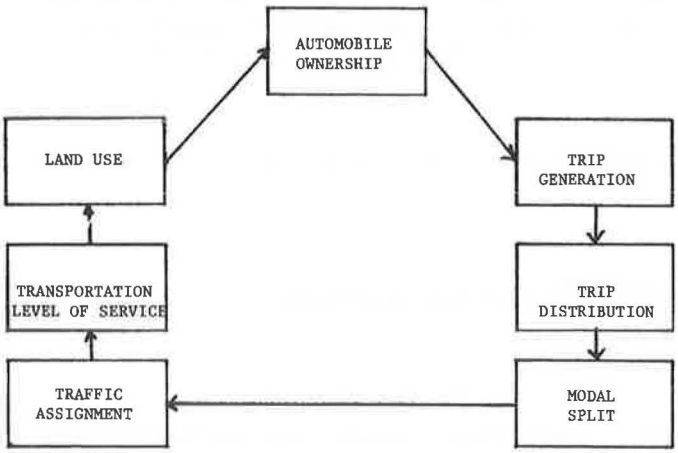

Figure 2. Choice hierarchy.

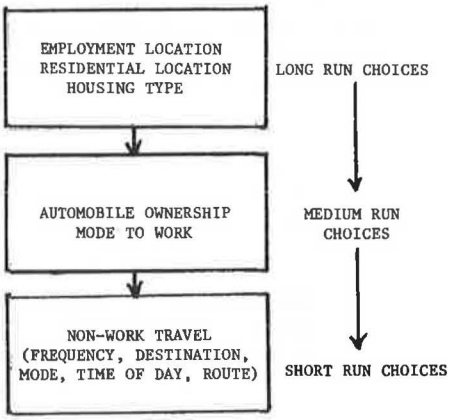

Table 1. Variables used in the model.

Category	Variables Used in Model
Level of service to work	In-vehicle time, out-of-vehicle time, and out-of-pocket cost by both car and transit Dummy variable representing downtown destination
Car-ownership costs	Cost of $1,000/car assumed
Locational attributes	Not explicitly introduced into model (level of service, traveling distances, and spatial opportunities are for residential and job locations)
Housing attributes	Dummy variable indicating single-family dwelling
Spatial opportunities	Expected generalized prices for shopping trips by both car and transit
Socioeconomic variables	Income, household size, and number of licensed drivers (life cycle and occupation are used for market segmentation)

Table 2. Variables and constants denoted by coefficient.

No.	Variable	Definition
1	1 car and car taken to work (constant)	1 for 1 car and car taken to work; 0 otherwise
2	1 car and transit taken to work (constant)	1 for 1 car and transit taken to work; 0 otherwise
3	2 cars and car taken to work (constant)	1 for 2 cars and car taken to work; 0 otherwise
4	2 cars and transit taken to work (constant)	1 for 2 cars and transit taken to work; 0 otherwise
5	Cars per licensed driver	Number of cars per licensed driver for car taken to work; 0 otherwise
6	$\ln$ (remaining income)	Household annual income - (800 × number of persons in household) - (1,000 × number of cars) - cost of 250 daily round trips
7	Single-family dwelling dummy	1 if household lives in single-family dwelling for 2 cars; 0 otherwise
8	In-vehicle time	Daily round-trip in-vehicle commuting time in minutes
9	Excess time/distance ratio	Daily round-trip out-of-vehicle commuting time in minutes/1-way distance of work trip in miles (kilometers)
10	Inverse licensed drivers	Number of cars/number of licensed drivers
11	Generalized price ratio_1	Generalized travel cost of shopping by car/generalized travel cost of shopping by transit for 1 car; 0 otherwise
12	Generalized price ratio_2	Generalized travel cost of shopping by car/generalized travel cost of shopping by transit for 2 cars; 0 otherwise
13	CBD workplace dummy	1 if work trip is CBD oriented for car taken to work; 0 otherwise

Table 3 gives a summary of the structure of all the utility functions. Each type of variable is given, and the coefficient with which this measure is multiplied appears for each alternative. Zeros appear where the variable has no effect on the utility of the alternative.

SET OF AVAILABLE ALTERNATIVES

The underlying choice theory of the logit model requires that the choice set consist only of feasible alternatives. This implies that, to properly estimate a joint car-ownership and modal-choice model, one must know which of the possible set of 5 alternatives is actually available to every household. However, data on the available alternatives were not included in the survey, and even if data had been included, they would have limited usefulness because of various reporting biases (14). This does not mean that the issue of available alternatives can be ignored. Even without data on reported choice set, it is possible to state with fairly high reliability that some households will not consider some alternatives as being available. For example, households without drivers only have the 0-car-ownership and transit-to-work alternative. Thus, no model need be estimated for them at all because they will always select the 0-car option with probability 1. A more interesting possible restriction of available options is that households living in fringe suburban areas do not have a transit-to-work option. These households would have only 2 alternatives: 1 car and car to work and 2 or more cars and car to work.

By using a series of rules such as these, one can approximate the set of feasible alternatives fairly well. This process has been termed screening the alternative set, and is an important part of the modeling process. Failure to do this will result in estimates that are biased and inconsistent, and, therefore, will result in unreliable forecasts of future conditions.

ESTIMATION RESULTS

By using the variables previously described, we estimated a number of joint car-ownership and travel-mode-to-work models. The first models developed were for each of the market segments defined in the section on issues in model development. However, some of these segments were too small for reliable results to be obtained. For this reason, segments 2A and 2B, blue-collar and white-collar young married couples without children, and segments 4A and 4B, blue-collar and white-collar older married couples without children, were collapsed into 2 segments corresponding to life cycles 2 and 4. Furthermore, segment 3B, households with children, was so large that, to reduce computational requirements, only half of the available data were used.

Some of the market-segment models are slightly different from the general form described in the section on specification of the joint utility functions. For example, life cycle 1 consists of single-person households; therefore, the 2-car alternative is not relevant. In the model for this segment, the single-family housing variable was redefined to apply to 1-car alternatives rather than the multiple-car options. For the same reason, the generalized price ratio for the 2-car alternatives and the constant terms in the 2-car utilities were omitted in the models for this life cycle. Because the number of licensed drivers in these segments is always 1 (if the number of licensed drivers is 0, only the 0-car and transit-to-work alternative is available and the observation is omitted from the data set), the cars per licensed driver and the inverse licensed drivers variable also were omitted.

The model for the market segment consisting of life cycle 5, those households with no primary worker, is also quite different from the typical joint model. Because no work trip is made by members in this life cycle, only car ownership is considered. All the variables describing the attributes of the alternative models for the work trips (cars per licensed driver, in-vehicle time, excess time/distance ratio, and CBD-

work-place dummy) are omitted entirely. The set of alternatives is reduced from the 5 car-ownership and travel-mode-to-work alternatives to 3 options: 0, 1, and more than 1 car. Therefore, the 4 constants measuring the pure alternative effects are reduced to 2 constants; as before, the 0-car alternative is taken as a base. The omission of all level-of-service-to-work variables does not mean that transit level of service is excluded entirely from the market-segment-5 model. The generalized price ratio variables representing shopping accessibility still enter into the utility functions.

The remaining models are almost identical with 1 exception: The cars-per-licensed-driver variable was significant only for households with children. In the remaining life cycles, it is probable that the variation in the number of licensed drivers was insufficient to measure its effect on choice of travel mode to work. (The licensed-driver variable still entered into the model through its effect on the inverse licensed-driver variable, which only distinguishes among car-ownership levels but not travel modes to work.) Furthermore, experimentation with alternative measures leads to the formulation of a similar variable defined as the number of cars per licensed worker in the household.

Table 4 gives a summary of the final 7 models ultimately selected for the market segments. Each model is listed, the segment to which it applies is described, and the important characteristics of how the model specification differs from the general form described in the section on specification of the joint utility functions is given.

In addition to these models, a 1-in-5 sample of households in life cycles 1 through 4 was taken, and the model described in the section on specification of the joint utility functions was estimated. Because the behavioral process being modeled for this group is so different, members of life cycle 5 were not included in this pooled sample.

Coefficient estimates and "t-statistics" for the variables or constants of each of the models are given in Table 5. (The statistic in this computation is not distributed the same as the t-statistic is in ordinary least squares regression. However, for large data sets, both the t-statistic and this statistic approach a normal distribution.) Where a variable was not used, the entry is left blank. Table 6 gives the log likelihood function if all values were 0, $L^*(0)$, the log likelihood function for the actual estimates, $L^*(\beta)$, the number of observations, NOBS, and the total number of alternatives in excess of the number of observations for the entire data set, NCASES. (NCASES typically is given in reporting the results or choice model estimation because it reflects the number of degrees of freedom in the data set, that is, the number of alternatives in excess of 1 per observation.)

All coefficients in all of the models have the anticipated sign, and virtually all are significantly different statistically from 0 at the 90 percent confidence interval. Only 1 of the t-statistics is less than 1, and only 3 are less than 1.5. In each of these cases, the strong theoretical justification for including the variable overrode statistical considerations.

In no case is the question of whether the estimates, taken collectively, are significantly different from 0 in doubt. However, this is an extremely weak test because of the unreasonableness of the null hypothesis that all parameters are 0. Zero values imply that all the alternatives are equally likely. Nevertheless, failure to pass this test would indicate a serious problem with the models.

In all models in which the 2-car alternatives were available, the coefficients for the generalized price ratio variables were both negative, and the magnitude of the coefficient for the 2-car alternative was always greater than the corresponding value for 1 car. For a given household, both of these variables have the same value but each applies to a different utility. This indicates that any increase in car-shopping generalized price will produce a shift toward 0- and 1-car ownership. That is, the utility of 2-car ownership will decrease more than that of 1-car ownership. The 0-car alternative is unaffected because it was selected arbitrarily as the base against which the effect of the generalized price ratio is measured. Conversely, an increase in transit-shopping generalized cost will produce a shift toward multiple-car ownership.

In general, the coefficient of the natural logarithm of remaining income decreases sharply as one considers life cycles in the order in which a household might progress. Figure 3 shows this progression and a hand-fitted curve for the 8 models. This shift

Table 3. Coefficients appearing in utility functions.

Alternative	Constant	Cars/ Licensed Driver	Remaining Income	Single-Family-Dwelling Dummy	In-Vehicle Time	Excess Time/ Distance Ratio	Inverse Licensed Drivers	Generalized Price Ratio	CBD-Work-Place Dummy
0 car and transit taken to work	0	0	β_6	0	β_8	β_9	0	0	0
1 car and car taken to work	β_1	β_5	β_6	0	β_8	β_9	β_{10}	β_{11}	β_{13}
1 car and transit taken to work	β_2	0	β_6	0	β_8	β_9	β_{10}	β_{11}	0
2 cars and car taken to work	β_3	β_5	β_6	β_7	β_8	β_9	β_{10}	β_{12}	β_{13}
2 cars and transit taken to work	β_4	0	β_6	β_7	β_8	β_9	β_{10}	β_{12}	0

Table 4. Summary of market-segment models.

Model	Segment	Description
1	1A	No 2-car alternatives considered; variables relating to these alternatives omitted
2	1B	Same as model 1
3	2A and 2B	Cars per licensed driver omitted
4	3A	Same as described in section on specification of joint utility functions; only half of data used
5	3B	Same as model 4
6	4A and 4B	Cars per licensed driver omitted
7	5	No mode to work considered; 4 alternative dummy variables reduced to 2; variables relating to mode attributes omitted

Table 5. Model coefficients and t-statistics.

	Model 1, Segment 1A		Model 2 Segment 1B		Model 3, Segments 2A and 2B		Model 4, Segment 3A		Model 5 Segment 3B		Model 6, Segments 4A and 4B		Model 7, Segment 5		Model 8, Segments Pooled	
Variable	Coeff. Est.	t-Stat.	Coeff. Est.	t-Stat.	Coeff. Est.	t-Stat.	Coeff. Est.	t-Stat.	Coeff. Est.	t-Stat.	Coeff. Est.	t-Stat.	Coeff. Est.	t-Stat.	Coeff. Est.	t-Stat.
β_1	5.98	7.39	7.39	6.64	7.11	6.67	8.63	9.49	11.3	6.65	12.3	7.54			7.95	9.79
β_2	3.85	5.25	5.55	5.33	5.14	5.16	6.44	7.66	9.89	5.90	10.5	6.60			7.20	9.28
1 car													6.54	11.3		
β_3					9.13	7.07	10.1	8.22	13.9	7.22	15.9	8.32			9.58	9.89
β_4									11.0	5.62	15.4	6.59			7.35	7.59
2 cars													7.08	8.75		
β_5									1.92	3.80					1.92	5.29
No. cars/ licensed worker							0.249	1.19								
β_6	6.74	5.47	8.33	4.55	3.14	6.31	1.07	5.37	1.55	5.51	0.829	2.07	1.88	4.62	2.22	7.43
β_7[a]	0.578	1.71	0.232	0.440												
β_7[b]					0.778	5.11	1.50	9.55	1.32	9.86	0.970	6.27	0.734	2.27	1.26	9.49
β_8	-0.0117	-1.92	-0.131	-1.83	-0.00789	-1.54	-0.00658	-1.35	-0.017	-3.19	-0.0146	-2.72			-0.0120	-2.78
β_9	-0.0831	-2.05	-0.169	4.54	-0.0951	-2.12	-0.0879	-2.03	-0.100	-1.81	-0.107	-2.51			-0.0742	-2.19
β_{10}					-2.33	-3.39	-3.47	-5.58	-6.29	-6.33	5.17	-5.92	-2.04	-5.15	-3.59	-6.45
β_{11}	-5.65	-5.25	-6.59	-4.54	-3.38	-2.39	-5.14	-4.68	-5.11	-2.07	-7.07	-3.15	-5.31	-6.50	-6.46	-6.04
β_{12}					-4.72	-3.27	-6.49	-5.70	-6.45	-2.60	-9.35	-4.13	-6.11	-6.24	-8.17	-7.42
β_{13}	-0.821	-3.01	-0.982	-3.18	-1.33	-4.84	-1.40	-5.63	-2.15	-6.25	-1.58	-5.92			-1.40	-6.46

[a]1 car. [b]2 cars.

Table 6. Model log functions and other data.

Model	Segment	$L^*(0)$	$L^*(\beta)$	NOBS	NCASES
1	1A	-535.0	-325.5	487	974
2	1B	-608.6	-281.3	554	1,108
3	2A and 2B	-1,454	-893	1,092	3,317
4	3A	-2,053	-1,158	1,583	4,526
5	3B	-2,576	-1,295	1,982	5,846
6	4A and 4B	-1,973	-1,080	1,475	4,500
7	5	-718.2	-441.0	853	1,116
8	Pooled	-2,465	-1,392	1,899	5,514

in coefficient value reflects a change in how households perceive the marginal utility of added income for households with equal value of remaining income. Mathematically,

$$\text{Marginal utility of income} = \frac{\beta_{\text{remaining income}}}{\text{remaining income}}$$

where $\beta_{\text{remaining income}}$ is the coefficient of the variable. At first glance, this result might seem incorrect. One would think that households in their childbearing stage of life would have a higher marginal value of money than households in the other life cycle groups. To properly interpret this, however, one must recall that 2 households with equal values of the remaining income variable do not necessarily have equal income. The variable includes a deduction of $800/household member so that, given 2 households with equal remaining income, the larger household generally will have greater total income. Thus, if all else is equal, the households with children typically will have higher total incomes than those in other life cycles and therefore may not necessarily place a higher value on additional income. This argument still leaves open the question of why the marginal utility of money for a given value of remaining income should decrease so markedly. This effect can be attributed to an unmeasured socioeconomic attribute, wealth. Wealth is highly correlated with income and hence is highly correlated with remaining income. Furthermore, as households pass through life cycles 1 to 4, they typically accumulate wealth, in terms of both savings and property. Thus their car-ownership behavior shifts subtly; for example, they may no longer pay financing charges to purchase automobiles and therefore would perceive lower costs. For this reason, the households trade off the benefits and costs of car ownership in different ways depending on which life cycle they are in, and the relative weight of money decreases as the household accumulates wealth.

Another interesting effect is the value of the coefficient of the single-family-dwelling dummy variable. The way in which the coefficient varies across life cycles is shown in Figure 4. Note that this curve is unimodal; its peak is around life cycle 3. This is entirely consistent with the behavioral justification underlying this variable presented in the section on choice of variables. In that section, the effect of multi-family-dwelling ownership on car ownership was attributed to a number of factors one of which was the need to chauffeur children to a variety of activities. This behavioral factor, however, applies only to life cycle 3 because the households in the remaining life cycles have no children residing at home. Thus one would anticipate that the coefficient of the single-family-dwelling dummy would be higher for households in life cycle 3 than for households in the other life cycles.

FORECASTS FOR A TYPICAL HOUSEHOLD

To test how various types of transit service improvements might influence car ownership, we created a "typical suburban household" and applied the models to predict its expected automobile ownership in a variety of policy cases. (To measure aggregate impacts one needs to repeat the application of the model for a representative sample of households not just for a single typical household.) This household is not an average urban household; it is representative of a large group of suburban households residing in single-family dwellings outside the area now served by transit. It is this type of household toward which major transit extensions are most frequently directed. The typical household

1. Has a $13,500 income;
2. Resides in single-family dwelling;
3. Has a white-collar head of household who has a driver's license and works in downtown Washington, D.C.;
4. Has 2 children;

5. Has a spouse who has a driver's license; and
6. Lives in suburban location (Montgomery County) 5 miles (8.0 km) from workplace.

The choice probabilities for this typical household were evaluated for a base case and 3 other cases. Fare policy was held constant for all 4 cases. The level of service used was based on actual network travel times for a Washington, D.C., traffic zone in Montgomery County, Maryland, lying just outside the "10-mile square" (16-km square). The model used to predict the choice probabilities was model 5, which applies to all households with a white-collar breadwinner and with children under the age of 18 years residing at home. Table 7 gives some of the most significant findings resulting from this policy testing. Because the model predicts the probability with which various car-ownership levels will be selected, the expected or average car ownership is reported. Each of the successive levels of transit improvement influences car ownership. However, the greatest shift along the sequence occurs when transit of even relatively low quality is offered. Thus, the mere availability of transit service can have a substantial impact on car ownership. Furthermore, the model results indicate that, even with futuristic transit service offering extremely fast service for both work and shopping travel, approximately 65 percent of typical suburban families still will own 2 or more cars.

CONCLUSIONS

Car-ownership modeling typically has been paid little attention in the transportation planning process; however, the causal linkages between car ownership and the travel patterns in urban areas have long been recognized. The models described in this paper provide a behaviorally sound method of incorporating these linkages and provide a set of reliable, policy-sensitive forecasting tools by which car ownership and choice of travel mode to work can be predicted. In the course of study, 4 things have been demonstrated.

1. To deal with car-ownership and travel-mode-to-work decisions as jointly determined at the household level is feasible. Furthermore, by using disaggregate choice models, one can make effective use of readily available transportation planning data.
2. Car-ownership decisions are made on substantially different criteria by different households depending on their life cycles and occupations. The failure to adequately reflect these behavioral differences in a model will result in inaccurate and possibly misleading forecasts and will fail to adequately represent the distribution of changes in car ownership over various socioeconomic groups.
3. Transportation policy can have a small but measurable impact on the level of car ownership in an urban area. Furthermore, the effects of various aspects of the transportation system such as in-vehicle time, out-of-vehicle time and cost for the work trip of the household's primary worker as well as shopping-trip level of service can be isolated.
4. Introducing transit service to areas where it had been unavailable can have a marked effect on car ownership; the effect of improvements in existing transit is only marginal.

Future research efforts should be directed toward extending the scope of household decisions considered in a joint, disaggregate behavioral model. Research is currently under way to explore how residential-location and housing decisions can be incorporated into a joint model and thereby span the long-term transportation-related decisions a household makes. An improved understanding of these decisions and the role car ownership plays in determining the pattern of urban location should aid in the formulation of more behaviorally structured models for transportation planning.

Figure 3. Remaining income coefficients for various life cycles.

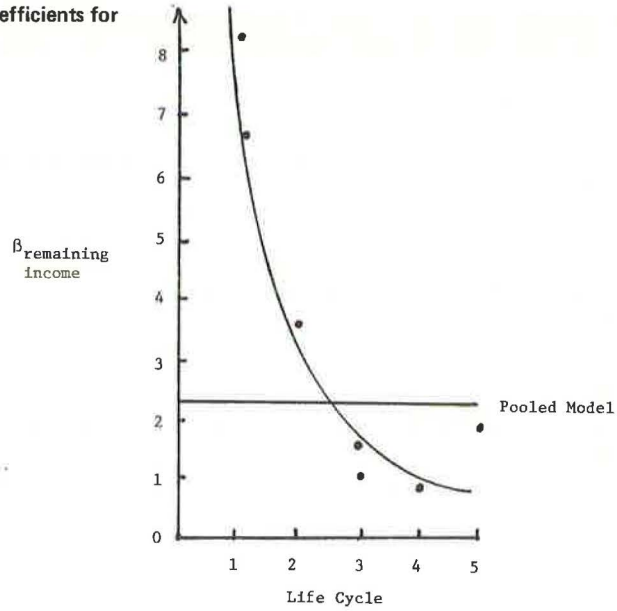

Figure 4. Type-of-dwelling dummy variable coefficients for various life cycles.

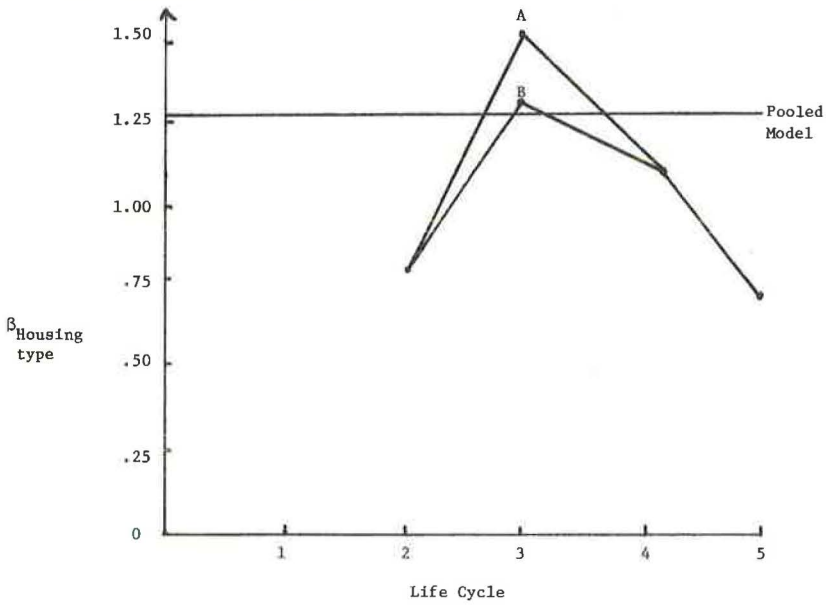

Table 7. Findings from policy testing of cases.

Case	Description	Expected Car Ownership	Change in Car Ownership From Base Case (percent)
Base	No transit available	1.825	—
1	Low-level transit	1.710	6.3
2	Good service (rail rapid transit) for work trips, case 1 transit service for shopping trips	1.660	9.0
3	Extremely high quality transit service (dense area, wide personal rapid transit)	1.622	11.1

ACKNOWLEDGMENTS

This paper is based on work performed at Cambridge Systematics, Inc., under contract to the Office of the Secretary and the Federal Highway Administration, U.S. Department of Transportation. However, the opinions expressed herein are solely ours and not necessarily those of the U.S. Department of Transportation.

We wish to acknowledge Richard L. Albright for his major programming and data-processing effort and William A. Jessiman, the principal-in-charge of this research project. We wish further to acknowledge the advice of Melvyn Cheslow and Edward Weiner, who both served as the U.S. Department of Transportation project monitors at different times during the study. Gregory Ingram, Daniel Brand, Robert Dunphy, Marvin L. Manheim, and Paul O. Roberts provided advisory support to the research. All errors and omissions, however, remain our sole responsibility.

REFERENCES

1. E. Aldana. Towards Microanalytic Models of Urban Transportation Demand. Department of Civil Engineering, Massachusetts Institute of Technology, PhD dissertation, 1971.
2. M. Ben-Akiva. Structure of Passenger Travel Demand Models. Department of Civil Engineering, Massachusetts Institute of Technology, PhD dissertation, 1973.
3. A Disaggregated Behavioral Model of Urban Travel Demand. Charles River Associates, Inc., 1972.
4. R. T. Dunphy. Transit Accessibility as a Determinant of Automobile Ownership. Highway Research Record 472, 1973, pp. 63-71.
5. M. J. Fertal, E. Weiner, A. J. Balek, and A. F. Sevin. Modal Split. Bureau of Public Roads, U.S. Department of Commerce, 1966.
6. P. Hoxie. Auto Ownership and the Long Run Transportation Decision. Department of Civil Engineering, Massachusetts Institute of Technology, MS thesis, 1970.
7. J. B. Lansing and G. Hendricks. Automobile Ownership and Residential Density. Institute for Social Research, Univ. of Michigan, 1967.
8. D. McFadden. The Revealed Preferences of a Government Bureaucracy. Institute of International Studies, Univ. of California, Berkeley, Technical Rept. 17, 1968.
9. D. McFadden. Conditional Logit Analysis of Qualitative Choice Behavior. In Frontiers in Econometrics (P. Zarembka, ed.), Academic Press, New York, 1973.
10. W. L. Mertz and L. B. Hamner. A Study of Factors Related to Urban Travel. Public Roads, Vol. 29, April 1957.
11. D. Mudarri. Mode Choice for Work Trips: A Key Urban Transportation Problem. Department of Economics, Univ. of Michigan, PhD dissertation, 1972.
12. W. Y. Oi and P. W. Shuldiner. An Analysis of Urban Travel Demands. Northwestern Univ. Press, Evanston, Ill., 1962.
13. Peat, Marwick, Mitchell and Co. Implementation of the n-Dimensional Logit Model. Comprehensive Planning Organization, San Diego County, Calif., 1972.
14. P. L. Watson. Problems Associated With Time and Cost Data Used in Travel Choice Modeling and Valuation of Time. Highway Research Record 369, 1971, pp. 148-158.

DISCUSSION

Fred A. Reid, University of California, Berkeley

The paper presents a clear model structure for joint choice consistent with a behavorial theory of car ownership and travel mode to work. It also gives a convincing empirical

test of the model with a comprehensive set of explanatory variables. The model is sufficiently simple that its joint-choice behavior and the influence of individual variables may be seen clearly, yet it still includes many of the variables influencing the choice set and a simple theory for the functional form of their entry. It seems to be a good base for building a more precise model of transportation ownership and modal choice. The paper also presents a valuable contribution to the evidence that stratification of a sample by life cycle or occupation or both can add to the explanatory power of a traveler model.

The brief theoretical arguments for the construction of the explanatory variables, though plausible and efficient because they include many important factors, are not supported sufficiently. The reader should expect some evidence or at least more comment about the forms considered or tested and rejected. The definition and form of entry of the remaining income variable left questions such as the constancy of car costs per unit and the logarithmic entry of all costs, particularly trip costs.

The stated assumption that ownership and choice of travel mode to work precede the non-work-trip decisions is partially inconsistent with the model structure and tests. Because travel mode to work neither enters the definition of the generalized non-work-trip price ratios nor is distinguished by a separate coefficient estimate for each mode to work, the opposite choice hierarchy is implied by the model. The non-work-trip choice, reflected through the price ratio variable, though conditioned on the car-ownership level, is established before the work-trip modal probability. Several other alternative choice hierarchies and corresponding model structures should be tested in any case because, for example, the originally intended precedence of ownership level over non-work-trip choice is not obviously true, especially for the second car.

The variable for number of licensed drivers is potentially dependent on behavioral choice, especially in good transit areas, and this possibly biases the corresponding coefficient.

The example of the effect of a policy change on a typical case by using the calibrated model is a helpful illustration of the application of and conclusions from this model.

In conclusion, the paper presents valuable initial results and a good base for further revelation of this type of joint traveler choice.

DISCUSSION

Joseph Berechman, Department of Civil Engineering,
State University of New York at Buffalo

The purpose of these remarks is to examine critically the 2 major hypotheses that underlie Lerman and Ben-Akiva's paper. This discussion will argue that these hypotheses are weak and unsubstantiated and will question the analysis that follows the hypotheses.

In brief, the hypotheses contend that the decision to purchase a car is a function of the individual's life cycle and is highly dependent on employment and residential decisions. More generally, Lerman and Ben-Akiva argue that choices of employment and residential location precede car ownership and are viewed as medium-term choices. This hierarchical structure of decision making strongly influences (albeit in a somewhat vague way) the selection and specification of variables for their model. However, when the major findings and conclusions are presented, they do not, in any meaningful way, reflect these assumptions. In particular, a change in the distribution of employment and residential locations is not shown to have significantly reduced (or increased) the expected level of car ownership. In general, I feel that these assumptions are questionable at best and most likely incorrect when applied to real-world data. For example, in 1970, there were approximately 54 million cars in all standard metropolitan statistical areas (SMSAs) (15); the average number of cars per household was 1.22 (and 1.42 cars/household outside the city center). The corresponding figures for 1960 were

34 million cars and 1.01 cars/household, which are changes of 56.7 and 20.5 percent respectively. As a first approximation, it can be argued that an average of more than 1 car/household indicates a tendency to own at least 1 car regardless of changes in the so-called long-term decisions. Furthermore, in the same period (1960-1970), 18 percent of the metropolitan labor force changed its employment location (54 percent outside city center) and about 45 percent of all households changed their residential location. These gross figures, although they conceal some fundamental trends, essentially reflect the suburbanization process in which households from cities and from outside the SMSAs (including other suburbs) migrated to suburbs. Given the state of public transportation systems, a precondition to such a movement is the availability of a private car purchased long before the actual relocation. For these reasons, the assumption regarding the household's sequential decision process is not supported by the facts.

It seems more plausible to argue that the decision to own an automobile (at least the first for households that own 2 or more) is mainly insensitive to locational decisions and rather should be ascribed to cultural, socioeconomic, and perhaps psychological factors. Indeed Lerman and Ben-Akiva's findings tend to support this contention. Table 7 indicates that the introduction of extremely high quality transit service to a hypothetical area where public transit services were previously unavailable will reduce expected car ownership from an average of 1.82 to 1.62. In other words, the desire to own a car is largely unaffected by the state of the transit system.

Another objection to Lerman and Ben-Akiva's hypotheses is based on the unavoidable feedback between short-term choices and long-term choices. For Figure 2, the block representing nonwork travel and employment and residential decisions should have been linked to reflect such interdependencies. In recent years, there has been a growing literature to indicate relationship between (a) residential amenities, environmental qualities, and neighborhood conditions (social and ethnic) and (b) employment and residential locational decisions. On a more general level, such relationships may be interpreted as implying a simultaneous decision process rather than a hierarchical one, and separation of choices into well-distinguished categories is, therefore, unjustifiable. [Interestingly enough, some authors (16) make the distinction between long- and short-term choices (residential location, place of work, and mode of travel to work) to characterize the behavior of low-income, unskilled laborers. Needless to say, the Lerner and Ben-Akiva study implicitly assumes middle-class white-collar households.]

The major assumptions that underlie Lerman and Ben-Akiva's paper are not supported by any available statistics nor by any known theory of urban spatial structure. Consequently, the methodology used in their study to explain car ownership is, in my opinion, rather questionable.

REFERENCES

15. Urban Transportation Factbook. American Institute of Planners, Part 1, 1974.
16. E. Banfield. The Unheavenly City. Little, Brown and Co., Boston, 1970.

AUTHORS' CLOSURE

Both Reid and Berechman raise a number of interesting points in their discussions of our paper. Some of these comments provide useful directions for future research; others raise some significant problems that were considered in the course of model development but were not resolved because of insufficient data or resources.

Reid notes the weakness of assuming a constant cost per automobile. In part, this simplification was required because the models focused only on the number of automobiles a household would own rather than on their age, make, power rating, or other aspects. Thus there is no way in the model to distinguish an old, dilapidated vehicle

from a new, luxury-class car. Ultimately, when appropriate disaggregate data about households' choice of type of car become available, developing more detailed car-ownership models will be feasible.

Reid points out the partial inconsistency in formulating the generalized price measures of shopping trips; travel mode to work does not enter into the choice model used to generate these measures, and trip frequency is ignored. When the work described in our paper was performed, no known shopping-choice model included such interactions, and a reestimation of Ben-Akiva's model to allow for such effects was infeasible because of project resources. However, recent models described by Adler and Ben-Akiva (17) have explicitly included the effect of car-ownership and travel-mode-to-work decisions on non-work-trip frequency, destination, and modal choice. This should be a useful base for later extensions of our methodology.

Reid raises the question of the extent to which the number of licensed drivers is itself determined jointly with car ownership. In an attempt to explore the potential effect of this factor, some models that replaced the number of licensed drivers in the household with the number of household members old enough to drive were estimated. The results indicated that, at least within the groups tested, the coefficient estimates were not sensitive to the assumption that the number of licensed drivers is determined exogenously. This does not, however, exclude the possibility that, among specific household groups (most notably lower income and inner-city households), the effect that Reid hypothesized does not exist. Further work directed at understanding the car ownership of these particular groups should yield useful insights into such phenomena.

Berechman argues that the decision to own a first car is relatively insensitive to household-location decisions and is more closely linked to cultural, socioeconomic, and psychological factors. No attempt was made to measure either cultural or psychological factors, nor do we feel that the inclusion of variables measuring such factors is desirable in a model designed principally for forecasting the impact of alternative transportation policies. However, a wide range of important socioeconomic factors explicitly influence car ownership in our model, and the results given in Table 7 reflect their relative importance (compared with transit level of service) in determining first-car ownership.

Other criticisms raised in the discussions seem somewhat less well founded. Berechman suggests that the coefficients of the models are inconsistent because they represent car ownership and travel mode to work conditionally on location. He cites somewhat unconvincing aggregate statistics about the suburbanization process to argue the possibility that location decisions may be conditional on car ownership rather than the reverse.

As Ben-Akiva (18) points out, conditional-choice models produce consistent estimates of the utility-function parameters as long as the conditional structure is explicitly included in the utility specifications. Indeed, if this were not the case, the entire body of research into choice of travel mode to work would be invalidated. A conditional model, however, should be carefully applied because, in forecasting, some of the choices on which the forecasts are conditional may change. This is the reason that we term our model a medium-term model in the proposed-choice hierarchy. More comprehensive models that include jointly residential location, housing, car ownership, and travel mode to work have been developed recently by Lerman (19) and are more applicable to analyzing longer term policy impacts.

Berechman incorrectly concludes that nonwork travel and employment and residential location decisions are not linked in our model. In reality, exactly the opposite is true. This is precisely why the shopping generalized prices in our model are denoted by residence zone. Different places of residence have different shopping-trip patterns associated with them, and these trip patterns are linked directly to car-ownership choices.

The final significant area of concern raised in the discussions is the role of analytic theory in the development of behavioral models. We do not perceive our modeling approach and the more formal utility theory of Burns, Golob, and Nicolaidis as conflicting efforts. Explicit theories of how household members interact in making car-ownership and other decisions are important additions to understanding choice processes. We

believe that such theories are the first steps in what will prove to be a fruitful research area.

However, strict theoretical approaches currently yield models that are not sufficiently rich in behavioral content to describe observed behavior in a way that is directly useful for analyzing transportation policies. This is the principal motivation for our using the household as the decision-making unit and including factors such as the number of licensed drivers, the number of licensed workers, and household size (as part of the remaining-income variable) in the model. These variables represent in an abstract way the outcome of the extremely complex bargaining process that takes place when a household makes a collective decision on car ownership. Including such variables is consistent with the basic goal of the study, the development of a useful analysis tool with which planners can assess the effect of transportation policy on car-ownership and travel-mode-to-work choice.

REFERENCES

17. T. J. Adler and M. E. Ben-Akiva. Joint-Choice Model for Frequency, Destination, and Travel Mode for Shopping Trips. Paper in this Record.
18. M. E. Ben-Akiva. Structure of Passenger Travel Demand Models. Transportation Research Record 526, 1974, pp. 26-42.
19. S. R. Lerman. Location, Housing, Automobile Ownership and Travel Mode to Work: A Joint Choice Model. Paper presented at the 55th Annual Meeting and to be published in a forthcoming Transportation Research Record.