Passenger travel demand forecasting: applications of disaggregate models and directions for research

by
MOSHE BEN-AKIVA
Massachusetts Institute of Technology
Cambridge, Massachusetts

1. INTRODUCTION

The Williamsburg Conference on Urban Travel Demand Forecasting held in 1972 observed that:

"The confidence in that approach (conventional aggregate travel demand models) has been shaken and significant changes must be made to restore it" (Transportation Research Board Special Report 143, page 11)

The conference concluded that:

"Travel demand forecasting is entering into a new era in which are emerging a stronger behavioral basis for travel demand models, a coherence and unity of directions of current work, and the potential for major improvements in practical capabilities for forecasting future travel in the context of today's urban transportation decisionmaking needs" (Page 207)

The purpose of this paper is to provide an overview of a body of research and practical applications of urban travel demand models since the Williamsburg Conference. Two major observations are made:

— The disaggregate choice models which were viewed then as "emerging techniques" have been developed into a flexible forecasting approach which addresses the shortcomings of the conventional models. The feasibility and validity of the approach has been demonstrated in several empirical studies and practical planning applications.

— The progress in the implementation of disaggregate travel demand models in recent years has opened many directions for further research which will bring further improvements in aspects of traveler response prediction that are important for transportation policy evaluation.

The most significant theoretical and practical characteristics of the applications of disaggregate travel demand models are as follows:

1) **Policy relevant** - The models that have been developed are capable of more accurate travel response predictions to a wider range of operating and construction options.

2) **Explicit theory of individuals' choice behavior** - The models are based upon explicit hypotheses about individuals' travel behavior. Travel demand is viewed as a process arising directly from individual decision maker's choices. Every observed trip is the result of a selection made by an individual traveller from some set of feasible choices.

3) **Explicit structure of all relevant travel related decisions** - The models are based on an explicit theory of choice which includes the entire set of relevant decisions (unlike simple mode-choice models). Thus, the models are derived from a theory which includes employment location, residential location, housing choice, automobile ownership, mode to work, and frequency, destination, mode, time of day, and route choice for various non-work travel purposes. This structure provides a basic working hypothesis within which the various models operate. It includes interdepencies among related decisions and among individuals in the same household.

4) **Valid statistical estimation** - The models, primarily based on the multinomial logit form, are statistically estimated using the methods of maximum likelihood and least squares. Disaggregate survey data is used directly for estimation. This reduces the data requirements needed to develop the models and fully exploits the information available from a given survey data set. In contrast, aggregate modelling approaches lose a great deal of the variability inherent in existing data by grouping observations at the zonal level. Disaggregate estimation also reduces the potential of biases in estimated model coefficients due to the existence of the simultaneous link from travel demand to level-of-service attributes.

5) **Explicit aggregation** - The disaggregate models are employed to produce aggregate forecasts based on available aggregate input data. A variety of procedures for aggregating geographic areas and socioeconomic market segments have been developed and applied.

6) **Equilibration of travel demand and transportation system performance** - The models have been applied together with efficient iterative network equilibration techniques.

7) **Variety of application procedures for different planning contexts** - The models have been applied in a variety of planning situations including long- and short-range predictions, sub-area and are wide analysis, as well as in a conventional urban transportation study framework. The wide range of applications is demonstrated by the following list of transportation policy options that have recently been analyzed in the U.S. using the disaggregate models:

— carpooling incentives
— pollution control strategies
— auto restricted zones

— parking restrictions
— downtown circulation system
— feeder bus service to rail stations
— public transportation system in suburban communities
— demand-responsive transit
— dual mode/transit feasibility
— bridge tolls
— transit fare structure
— ramp metering and preferential lanes
— effect of highway supply on vehicle-miles of travel (VMT)

The remainder of this paper is divided into three parts. Section 2 provides a brief summary of the theoretical aspects of the disaggregate modelling approach. Section 3 reviews systems of models and application procedures. Finally, Section 4 presents a discussion of current and future areas of research.

2. THE DISAGGREGATE TRAVEL DEMAND MODELLING APPROACH

Choice Models[1]

Conventional consumer demand models are not suitable to the qualitative and discrete nature of travel-related decisions such as mode of travel and automobile ownership. Therefore, the approach is based on qualitative choice models. The individual behavioral unit is faced with a feasible set of alternative travel options from which one is selected. Denote the choice set of individual t as

$$C_t = \{1, 2, \ldots, i, \ldots, J_t\}$$

where J_t is the number of available alternatives. The choice process is analytically modelled using the concept of utility maximization. Denote the utility of alternative i to individual t as U_{it}; alternative i will be selected if and only if

$$U_{it} \geq U_{jt}, \qquad j = 1, \ldots, J_t$$

For predictive purposes the relative values of the utilities must be related to observed variables as follows:

$$U_{it} = V(Z_{it}, S_t) + \varepsilon_{it}$$

where
Z_{it} = a vector of attributes of alternative i faced by individual t;
S_t = a vector of socio-economic characteristics of individual t; and
ε_{it} = an unobservable random component of the utility of alternative i to individual t.

The random utilities are due to omission of unobservable variables, measurement errors and other possible source of errors in the specification of the utility functions (Manski, 1973). Thus, only choice probabilities can be predicted, as follows:

$$P(i|C_t) = \text{Prob}\ [U_{it} \geq U_{jt}, \ j = 1, \ldots, J_t]$$

$$= \text{Prob}\ [\varepsilon_{jt} - \varepsilon_{it} \leq V(Z_{it}, S_t) - V(Z_{jt}, S_t), \ j = 1, \ldots, J_t]$$

where $P(i|C_t)$ denotes the probability of individual t faced with a choice set C_t selecting alternative i.

A probabilistic choice model is derived by assuming a specific joint distribution of the random utilities $(\varepsilon_{1t}, \ldots, \varepsilon_{J_t t})$ for given values of the observable variables. Assuming that the random components are independently and identically Weibull distributed results in the following multinomial logit model (McFadden, 1974):

$$P(i|C_t) = \frac{e^{V(Z_{it}, S_t)}}{\sum_{j=1}^{J_t} e^{V(Z_{jt}, S_t)}}$$

The utility of the choice to the individual denoted as U_t is the value of the utility of the chosen alternative as follows:

$$U_t = \text{Max}\ (U_{1t}, \ldots, U_{J_t t})$$

Since the utilities are random, the maximum utility is also an unobservable random variable. However, its expected value can be determined. For example, the distribution assumption of the logit model results in[2]:

$$E\ [U_t] = \ln \sum_{j=1}^{J_t} e^{V(Z_{jt}, S_t)}$$

A measure of consumer benefits is obtained as the difference of the expected utilities from before and after the change.

The parameters of the systematic utilities functions, $V(Z_{it}, S_t)$ are estimated using a random sample with the following information:

$$[c_t, C_t, S_t, (Z_{jt}, j=1, \ldots, J_t)], \ t=1, \ldots, T$$

where
T = number of observations in the sample; and
c_t = the chosen alternative by individual t.

Maximum likelihood with linear in the parameters utility functions is the method of estimation used most frequently.

Choice Sets

The summary presentation above of choice models treats the choice sets available to individuals, C_t, as given. Traditional models of consumer behavior usually consider income and time constraints. However, the set of feasible travel alternatives is also determined by a variety of other factors. An example would be a trip to a location which is not served by transit; the use of transit to this location is not a feasible alternative. Socio-economic characteristics, other than income, also influence the available alternatives. For example, a person without a driver's license does not have "auto driver" as an available mode. Empirical tests have shown the importance of information on availability of travel modes for accurate forecasts (Koppelman and Ben-Akiva, 1977). Thus, the determination of the set of feasible alternatives is a key element in any application of disaggregate choice models to travel related decisions.

Aggregate Forecasting

Aggregate demand is by definition a sum of disaggregate demands as follows:

$$T_i = \sum_{t=1}^{T} P(i|C_t)$$

where
T_i = the expected number of individuals selecting alternative i; and

T = the number of individuals in the aggregate group.

In addition, it is often necessary, particularly in application of location choice models; to aggregate over alternatives.[3]

Since detailed data is not available, aggregation must be based on limited information about the distributions of socio-economic characteristics and attributes of the alternatives. Several aggregation procedures that have been developed are evaluated in Koppelman (1975) and their applications in travel demand forecasting will be reviewed in the following section of this paper.

3. APPLICATIONS OF DISAGGREGATE TRAVEL DEMAND MODELS

Estimated Models

The development and applications of disaggregate travel demand models are described in two recent books by Domencich and McFadden (1975) and Richards and Ben-Akiva (1975), a recently completed report by Spear (1977), and a survey paper by Ben-Akiva, Lerman and Manheim (1976).

The initial transportation applications of disaggregate modelling techniques were made for the choice of travel mode (e.g. Warner, 1962; Lisco, 1967; Lave, 1969; McGillivray, 1972; and Peat, Marwick and Mitchell, 1973). A large number of researchers have investigated the performance of mode choice models for work trips. Atherton and

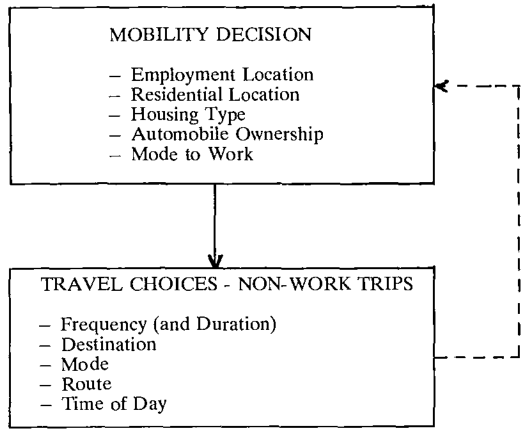

Figure 1 - A simple choice hierarchy

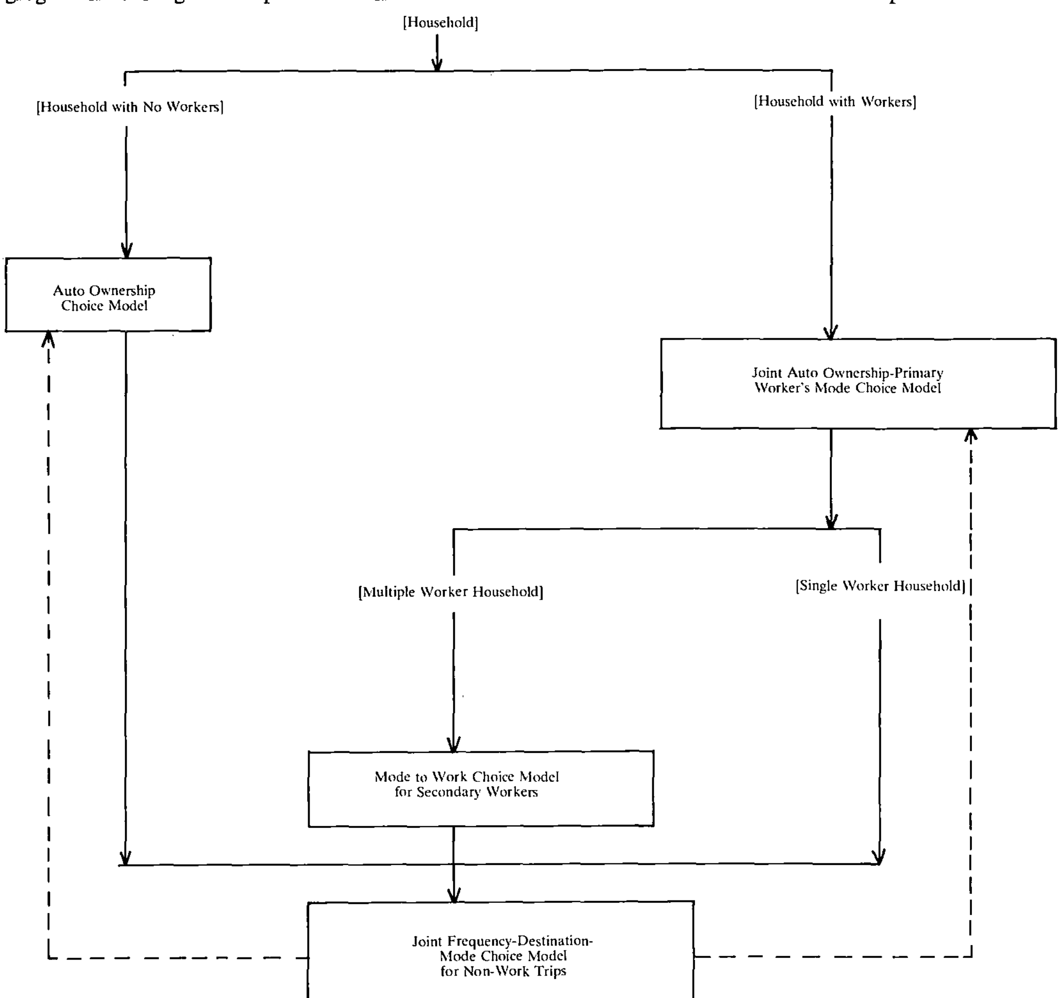

Figure 2 - Short range travel demand forecasting system

Ben-Akiva (1976) used data from widely different urban areas and obtained remarkably similar estimates of model coefficients. Ben-Akiva and Richards (1975) have successfully tested a work mode choice model with six modes using data from the Netherlands. Parody (1976) and Train (1976) showed that the inclusion of socio-economic variables in a work mode choice improves significantly the forecast accuracy. Several disaggregate work mode choice models were estimated and incorporated in existing systems of aggregate models (e.g., Cambridge Systematics, 1975; Richards, 1975; Pratt and DTM, 1976).

The first extension of disaggregate models to a multi-dimensional choice situation was made in a study by Charles River Associates (1972). In this study, the choices of frequency, destination and mode for shopping travel were modelled with reasonable results. However, each choice was modelled separately and in an arbitrarily-assumed

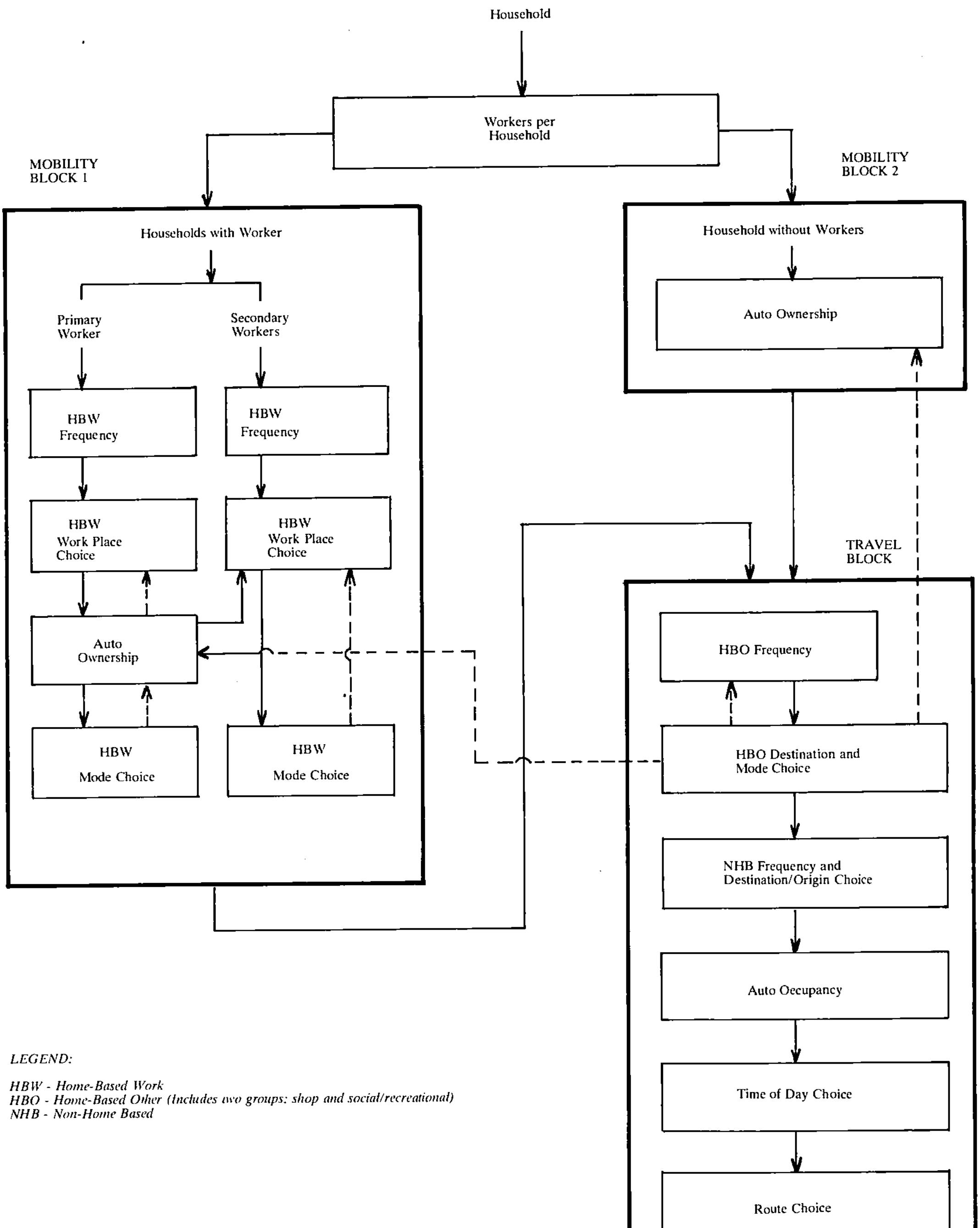

Figure 3 - The MTC travel demand model system

sequence, thereby imposing a strong, and statistically-unsupported structure on the travel decisions.

Ben-Akiva (1973) demonstrated the differences among alternative model structures in terms of behavioral assumptions and statistical estimation properties. For this reason, Ben-Akiva (1973 and 1974), Adler and Ben-Akiva (1975) and Richards and Ben-Akiva (1974) extended this work by applying disaggregate choice models to a set of non-work travel choices in a joint structure. This work also extended by Lerman and Ben-Akiva (1975) and Lerman (1975) to the joint modelling of mobility choices including residential location, automobile ownership and mode of travel to work.

These models follow the hierarchical choice structure suggested by Ben-Akiva (1973) for modelling two classes of choices — mobility choices and travel choices — as shown in Figure 1. The arrows indicate the direction of conditionality and the feedback of expected utilities (defined in the previous section) from lower-level choices, affecting higher-level choices.

Two examples of travel demand model systems that were used in several policy and planning studies are shown in Figures 2 and 3. The short range travel demand forecasting system was used in a study of the effects of alternative carpooling incentive programs (Ben-Akiva and Atherton, 1977; and Cambridge Systematics, 1976) and the MTC model system was designed for conventional urban transportation study applications in the San Francisco region (Ruiter and Ben-Akiva, 1977). These are systems of inter-re-lated disaggregate models which proceed through a set of hierarchically-structured household travelrelated choices as shown. The specific models are described in detail in the references.

Application Procedures

The same set of disaggregate models can be used as the basis for a range of aggregate forecasting procedures:

1) Manual calculations using elasticities or the incremental logit form (Ben-Akiva and Atherton, 1977) for crude predictions of the effects of changes in transportation level of service attributes.

2) Sample enumeration procedure in which a random sample of households is used to represent the aggregate population of interest. Forecasts are made by applying the models to each household individually using revised values of the independent variables. These disaggregate predictions are expanded to obtain the required aggregate predictions. This procedure was used in several studies, focused primarily on pricing policies and low capital options (Cambridge Systematics, 1976 and Small, 1976). An existing sample could be updated, based on available or forecasted aggregate socioeconomic data, using the procedure described in Duguay, *et al.*, (1976) and used by Cosslett, *et al.*, (1977) to generate a sample for the San Franciso Bay Area from Census data.

3) Monte Carlo simulation using available aggregate data to synthesize a sample of households (and a sample of locations if aggregation of spatial alternatives is also required). This approach was employed by Watanatada and Ben-Akiva (1977) for an area-wide sketch planning procedure. It is a simplified procedure that requires limited input data and provides quick turn-around. It is suitable for applications at a high level of geographic aggregation.

4) Network analysis system with market segmentation using available software such as the Urban Transportation Planning System (UMTA, 1976). An experimental system developed at MIT was used to demonstrate the feasibility of this approach and differences among alternative models (Ben-Akiva, *et al.*, 1977). The MTC system, shown in Figure 3, was also implemented in a forecasting system compatible with UTPS (Cambridge Systematics, 1977). It is being used by the regional transportation planning agency for ongoing studies.

Applications in Policy and Planning Studies

Clearly, one of the most important advantages of the disaggregate models that have been developed is their sensitivity to a wide range of transportation service changes as well as urban area characteristics and socio-economic attributes. In addition, as was shown above, the models can be applied to aggregate forecasting in a variety of ways ranging in level of detail and data requirements from detailled subarea analysis and conventional network-based simulations, to a highly-aggregate sketch planning procedure based on a small number of market segments. Some of the recent applications in policy and planning studies are summarized below to demonstrate the models' wide range of applicability and to emphasize the fact that disaggregate models are "practical" analysis tools. They are no longer the "research frontier", but are "production" methods.

The models have been used for:

— A policy study, for the U.S. Federal Energy Administration, on the effects of alternative programs of incentives to carpool (shared use of autos for work trips). Washington, D.C. and Birmingham, Alabama were used as prototype cities. The Sample Enumeration method was used (Cambridge Systematics, 1976).

— Planning studies of auto-restricted zones, for the U.S. Urban Mass Transportation Administration. The models were used to predict the effects of various auto-restricted zone concepts in selected cities, as part of the process of selecting sites and implementation strategies for a federally-sponsored demonstration program (Alan M. Voorhees, *et al.*, 1976).

— A planning study of anticipated guideway transit strategies for Milwaukee for the U.S. Urban Mass Transportation Administration. The models were used in conjunction with UTPS in both sketchplanning and detailed-network analysis approaches (Cambridge Systematics, 1975).

— For the agency planning a "people-mover" system for internal circulation within the Los Angeles central business district, models have been developed for predicting, for peak-period trips, choice of parking lot and egress mode (travel from parking to destination), if arrival by auto, and egress mode if arrival by transit; and for noon-hour trips, frequency destination and mode of within-CBD trips (modes include walk, minibus, and people-mover systems.) (Barton-Aschman, et al., 1976).

Many other applications, primarily of mode choice models, have been performed (e.g., Difiglio and Reed, 1975; Liou, et al., 1975; Train, 1976; Small, 1976; and Dunbar, 1976). A detailed review of several applications is given by Spear (1977). Thus, disaggregate methods are being used for a variety of practical policy and planning applications.

Discussion

The preceding summary has indicated, in very general terms, the progress made on travel forecasting improvements since the Williamsburg Conference. During the intervening period, as would be expected, the research needs have changed somewhat. The application experience has demonstrated the substantial advantages of well-specified disaggregate travel demand models. Disaggregate models can be estimated using less data than equivalent aggregate models, potentially have better transferability properties, and can be applied at any level of geographic aggregation. In the case study comparisons conducted at MIT by Ben-Akiva, *et al.*, (1977), the importance of a complete specification was demonstrated; omission of level-of-service effects on trip generation and of specific elements of level-of-service (e.g., auto operating costs) resulted in significant underpredictions of the changes in travel due to transportation policies. Since the effect on travel demand of many short-range, low capital options is small to begin with, this underprediction can be very significant in the evaluation of such options.

Thus, travel demand modelling approaches which were viewed by the Williamsburg Conference as "emerging techniques" have now been demonstrated to be both feasible and desirable. While the improved modelling methodology has several shortcomings that require further research as discussed in the next section, it can be immediately applied to produce more accurate and more useful predictions than those available from conventional travel forecasting procedures.

4. DIRECTIONS FOR RESEARCH

The work described in this paper is part of a rapidly evolving body of knowledge. Extensions of existing models, new applications to policy questions, and new methodological developments are underway. While the feasibility and usefulness of the disaggregate modelling approach has been demonstrated in previous work, there are several areas which are being or need to be addressed in further research. These are classified into the following five major areas:

— improved model specification;
— spatial choice modelling;
— sketch planning procedures;
— extensions to other transportation planning contexts; and
— alternative choice models.

Improved Model Specification

Travel demand models are developed to analyze a variety of future scenarios which almost always require prediction outside the range of current data. The likelihood of a successful extrapolation will increase with greater variability of both the dependent and the independent variables in data sets which are used for model estimation. Improvements can be achieved by using data from several geographical areas and several points in time. In addition to transferability tests, the models' predictive validity could be improved by applying the models in situations where data exists before and after a change in transportation services.

However, the basic problem of extrapolating beyond the range of existing data remains and requires the use of behaviorally credible models. The most important step in achieving this objective is a complete description of consumer response which serves at the basis for the specification of the dependent variables of travel behavior models. Examples of significant phenomena of consumer response which have been observed over time but are excluded from some existing models are: consolidation of travel by trip chaining; changes in time allocation to various home and non-home activities; and substitutions among residential and employment location choices, automobile ownership levels and travel choices.

The range of independent variables must also be expanded and should not be restricted to those that can easily be forecast. The importance of a full set of socioeconomic and demographic variables in travel behavior models has been demonstrated in several recent studies. The before-and-after studies conducted by Parody (1976) and Train (1976) showed how a model with a larger set of socioeconomic variables was better able to predict changes in mode choice. Thus, there is a need to expand the scope of the dependent and independent variables in travel behavior models.

The logit model has been critized for its "independence from irrelevant alternatives property." However, since alternative formulations such as multinomial probit are still significantly more expensive to apply, the logit model will continue to be the most commonly-used choice model. Therefore, it is important to apply tests of the logit specification with multiple data sets as described above as well as the statistical tests of the "independence" assumption described by McFadden, Tye and Train (1977).

Spatial Choice Modelling

Most of the research in behavioral travel demand models has been focused on short-run mode choice decisions, and knowledge of behavioral mechanisms of other relevant impacts is still limited. It should be extended to include other transportation-related choices, especially spatial choices. The key research problems in this area are the joint modelling of the longrun household choices including residential location, automobile ownership and travel to work, and the modelling of trip chaining or tour formation.

These two modelling efforts share a set of common methodological questions. The most critical of these issues are discussed below, with possible approaches to their resolutions.

1) *Definition and Aggregation of Spatial Alternatives*-Spatial choices differ from mode choices in that there is no natural definition of the alternatives. In some spatial choice situations it is possible to define an *elemental alternative* such tha any spatial alternative is a grouped alternative consisting of one or more elemental alternatives and each elemental alternative is included in one and only one grouped alternative. Stores and dwelling units are two examples of such elemental alternatives.

Unfortunately, in most real-world applications the number of possible elemental alternatives is far too large to be of any practical use. Therefore, some form of *aggregation of elemental alternatives* must be performed in spatial choice models.

Two basic approaches can be used to perform such an aggregation: (1) assuming a behavioral choice hierarchy; and (2) explicitly aggregating elemental alternatives. In the first approach, different levels of aggregation of elemental alternatives represent sequential steps in an assumed choice hierarchy. An example would be the aggregation of dwelling units into neighborhoods, communities, sectors of the metropolitan area, etc., where the decisionmaker is assumed to first select the sector in which he wants to reside, then he selects a community, followed by a choice of neighborhood, and finally a choice of an actual dwelling unit. This procedure is commonly employed in mode choice studies when various transit alternatives are treated as one mode and the mode choice model is followed by a transit sub-modal choice procedure. The problem in this approach is that no single hierarchy applies to all individuals and there is no empirical or theoretical evidence to suggest an appropriate hierarchy.

The second approach is to use a theoretically-consistent procedure for the aggregation over elemental alternatives. Such an approach can be based on the concept that the utility of a group of alternatives is the utility of the best member of the group, since only the best will be selected. Lerman (1975) employed this approach in developing a residential location model. An alternative approach is to assume a continuous spatial choice density function that can be integrated over zones using numerical integration methods (Watanatada and Ben-Akiva, 1977; and McFadden, 1976).

2) *Choice Set Generating Process*-The large number of potential spatial alternatives makes the computational requirements of a choice model prohibitively expensive in many applications. But, more fundamentally, the use of very large choice sets to represent individuals' choice processes would appear to be behaviorally unrealistic. In a model of residential location, for example, not all dwelling units in the urban area are feasible alternatives for a given household. Some dwelling units are simply too expensive, others may not be feasible if they are not served by transit and the household members cannot drive, and so on. Yet, even if an alternative is feasible according to these types of constraints it may still not be considered by some consumers due to lack of information. The effect of advertising on consumer behavior can be partially attributed to the fact that an alternative which has been previously unknown has been inroduced into consumers' choice sets. Since for behavioral, practical and efficiency considerations we must define feasible subsets of alternatives, it is necessary to further investigate potential constraints for the feasibility of spatial alternatives.

3) *Activity Time Allocation*-In searching for more powerful constraints for determining the feasibility of spatial alternatives the most obvious measure that comes to mind is that of a *time budget*. If it was known how much time is allocated by a consumer for the performance of a given non-home activity, one could subtract from it a minimal activity duration (which could be zero) and use the result as an upper limit on travel time. This will exclude a significant number of potential destinations.

The concept of time allocation is different from "travel time budget" which has been proposed by some researchers (e.g., Zahavi, 1974; and Goodwin, 1976). Travel is an intermediate good that is only rarely being consumed for its own sake. Travel time and travel costs are inputs required to participate in non-home activities, not anything which people budget without reference to the value of those activities.

This indicates that the allocation of time is a key element in modelling spatial decisions. Explicit time allocation modelling is likely to improve the existing specifications of travel and mobility models. More important, it can be extremely powerful in delineating spatial choice sets. An exploratory study of modelling activity choice and time allocation by Bain (1976) indicates the feasibility of this approach.

4) *Trip Chaining*-The choice set of alternative trip destinations is further complicated by the consideration of trip chaining. A large percentage of urban travel is comprised of multiple-stop tours, where the choices of the destinations visited on a tour are interdependent.

Since much of the short-run response to transportation policy changes now under consideration seems to involve increased trip chaining, it is important that models which explicitly represent such decisions be developed. Exploratory research in this direction by Adler (1976) and Horowitz (1976) provides significant insights into the biases of existing link-based models. This information will be useful in determining the most appropriate simplifying assumptions that are required in order to make trip chaining models feasible.

Sketch Planning Procedures

Sketch planning procedures are designed to perform a quick examination of a large number of alternative policies. Such analysis tools have been or are being developed over the past few years for different planning purposes which range from the study of national urban transportation resource allocation (Weiner, *et al.*, 1973) to the preliminary screening of alternative transportation system configurations at a sub-area level (Dial, 1973). Urban transportation sketch planning packages can generally be characterized by a high degree of geographic aggregation and network abstraction, limited information requirements, ease of input data preparation and fast response times. Reviews of recent research efforts in sketch planning methodologies are given in Landau (1976) and Watanatada (1977).

In achieving these needed capabilities, the incorporation of disaggregate models can significantly increase the validity and policy-sensitivity of impact predictions. The constrasts between disaggregate travel demand models and sketch planning tools are striking. The former require the representation of socioeconomic characteristics, transportation level-of-service and locational attributes at the level of individual behavioral units, while the latter must be capable of operating on highly aggregate, readily available input data.

A promising two-pronged approach to this incompatibility problem is, first, to represent the distributions of the independent variables as parametric functions of readily obtainable aggregate data, and, second, to empoy Monte Carlo simulation methods in forecasting aggregate travel demand. This approach has been used for an urbanized area travel demand prediction model developed by Watanatada and Ben-Akiva (1977). Monte Carlo methods are employed in two stages of sampling. The first stage generates a sample of households distributed over the urban area. The second stage samples a set of potential destinations by trip purpose for each household in the sample; travel forecasts for each household are then computed based on these potential destinations.

The Monte Carlo simulation approach has three important advantages. First, it is not restricted to any type of mathematical presentation. Second, its prediction errors do not suffer from aggregation bias and can be easily controlled. And, third, it has been found from computational experience to be relatively inexpensive to produce the kind of forecasting precision required for most urban transportation planning purposes.

One of the most difficult issues in applying disaggregate travel demand models to sketch planning is the problem of developing concomitant transportation supply and traffic assignment models for different levels of geographic aggregation. One fundamental modelling difficulty is that since a transportation network is not just a direct summation of the individual links, the problem of network aggregation becomes analytically intractable. Because no consistent theory exists for network-abstract supply modelling, past researchers have developed relationships based on experimental results or highly simplified assumptions on transportation supply characteristics. For a given zone pair, the supply models should predict the distribution of level-of-service attributes as a function of travel demand and network capacity.

Because of the extremely wide range of geographic aggregation employed in sketch planning, transportation supply and traffic assignment models should be developed in integrated network and network-abstract forms. Network supply models represent transportation facilities, mostly of major types, as network links. Network-abstract supply models represent transportation facilities, mostly of ubiquitous nature, as aggregate transportation systems defined by mode, facility type and geographic unit. A network-abstract model can be developed to relate parametrically the aggregate performance measures of a system to its transportation supply characteristics and traffic loads. Network-abstract supply models can be developed for both access and linehaul travel. Talvitie, *et al.*, have developed network abstract supply models for the access portion of a trip (Talvitie and Hilson, 1974; Talvitie and Leung, 1976).

Network traffic assignment models for sketch planning can be developed based largely on existing knowledge. Network-abstract traffic assignment models can be developed to allocate traffic, not to routes, but to aggregate transportation systems (Creighton and Hamburg, 1971).

Extensions to Other Transportation Planning Contexts

Some preliminary efforts have been made in applying disaggregate choice models to transportation planning contexts other than urban passenger transportation. In intercity freight transportation, Antle and Haynes (1971) and Hartwig and Linton (1974) estimated disaggregate mode choice models based on data from individual shipments. Antle and Haynes attempted to aggregate their data across commodities and re-estimate the model. The results were significantly poorer. Terziev (1976) formulated a joint mode-shipment size model and estimated the model with available Census data.

In air passenger transportation, Kanafani, *et al.*, (1974) estimated a joint fare type-season choice model based on aggregate data. Fares were the only level-of-service variable employed. This and other attempts to estimate intercity and international models resulted in a limited specification that was attributed to the poor quality of the available aggregate data. Therefore, it appears that a new survey to collect disaggregate data would permit a broader range of policy variables to be incorporated. The cost of data collection is not expected to be excessive. For example, Hartwig and Linton (1974) estimated their freight mode choice model with statistically significant results using a sample of 1,213 waybills.

In terms of forecasting, the Monte Carlo approach, which has been found feasible and relatively economical in urban transportation planning applications, could be extended to other transportation planning contexts. Roberts (1976) has developed a Monte Carlo simulation procedure for forecasting freight traffic flows based on the generation of individual firms of varying sizes as the basic behavioral units. The sum of commodity demand forecasts for the firms generated in the sample are then expanded to obtain freight traffic volumes.

Alternative Choice Models

The choice model which has been used in almost all travel demand applications involving more than two alternatives is multinomial logit. The properties of the model, including its derivation from the theory of individual utility maximization, are given in McFadden (1974). The property of "independence from irrelevant alternatives" (IIA) is the basic deficiency of the logit model. Its key advantage is mathematical simplicity or ease of implementation. However, due to the IIA property, the validity of the model in many travel demand applications has been questioned, particularly in complex choice situations where different degrees of similarities exist among alternatives.

Two recently developed models do not have this "independence property" and explicitly incorporate different degrees of interdependencies among alternatives. The first is the multinomial probit model which is based on the multivariate normal distribution. Recently, feasible probit estimation procedures have been developed by Hausman and Wise (1976) (for up to four alternatives only) and by Daganzo, *et al.*, (1976) and Manski, *et al.*, (1977). The probit model can be used to directly estimate the correlations among utilities, or similarities among alternatives.

The second development is the derivation by McFadden (1977) of a model which is based on a multivariable extreme value distribution. This Generalized Extreme Value (GEV) model is expressed as follows:

$$p_i = \frac{e^{V_i} G_i(e^{V_1}, \ldots\ldots, e^{V_J})}{G(e^{V_1}, \ldots\ldots, e^{V_J})}$$

where

p_i is the choice probability of alternative i;

V_i is the systematic utility of alternative i;

$G(e^{V_1}, \ldots, e^{V_J})$ is a function which satisfies certain conditions described in McFadden (1977, pp. 6-9); and

$G_i(e^{V_1}, \ldots, e^{V_J})$ is the derivative of the function with respect to its i^{th} argument.

The special case

$$G(e^{V_1}, \ldots, e^{V_J}) = \sum_{i=1}^{J} e^{V_i}$$

yields the multinomial logit model:

$$P_i = \frac{e^{V_i}}{\sum_{j=1}^{J} e^{V_j}}$$

An important class of special cases of the GEV models is based on partitioning a choice set into subsets of similar alternatives. Consider, for example, a choice set where i denotes a subset of similar alternatives and V_{ij} is the representative utility of the j^{th} alternative in subset i. In the following function:

$$G(e^{V_{11}}, \ldots, e^{V_{ij}}, \ldots, e^{V_{IJ}})$$

$$= \sum_i a_i (\sum_j e^{V_{ij}/\delta_i})^{\delta_i}$$

the parameter δ_i is an index of the similarity of the alternatives in subset i. This function results in the following choice model:

$$P_{ij} = \frac{e^{V_{ij}/\delta_i}}{\sum_j e^{V_{ij}/\delta_i}} \cdot \frac{e^{\delta_i \ln \sum_j e^{V_{ij}/\delta_i + \ln a_i}}}{\sum_i e^{\delta_i \ln \sum_j e^{V_{ij}/\delta_i + \ln a_i}}}$$

$$= P_{j|i} \cdot P_i$$

where P_{ij} is the joint possibility of selecting alternative ij, $P_{j|i}$ is the conditional probability of selecting alternative ij given that the choice lies within subset i, and P_i is the marginal probability that the choice lies within subset i. If all the similarity parameters are equal to one we get a joint logit model as follows:

$$P_{ij} = \frac{e^{V_{ij} + \ln a_i}}{\sum_i \sum_j e^{V_{ij} + \ln a_i}}$$

If we assume that

$$\delta_i = \delta \text{ for all } i$$

and

$$V_{ij} = \delta\alpha Z_{ij} + \beta Z_i$$

where

Z_{ij} is a vector of attributes which are specific to both i and j,

Z_i is a vector of attributes specific only to i and

α, β are vectors of coefficients

we get

$$P_{j|i} = \frac{e^{\alpha Z_{ij}}}{\sum_j e^{\alpha Z_{ij}}}$$

and

$$P_i = \frac{e^{\beta Z_i + \ln a_i + \delta LS_i}}{\sum_i e^{\beta Z_i + \ln a_i + \delta LS_i}}$$

where

$$LS_i = \ln \sum_j e^{\alpha Z_{ij}}$$

This special class of the GEV model is a sequence of multinomial logit models that could be estimated sequentially using existing logit estimation packages. This procedure has been applied for special cases in several existing urban travel demand models (e.g., Ben-Akiva, 1973; Daly, 1977; and Ruiter and Ben-Akiva, 1977) and can be used to test alternative partitioning of complex choice sets.

The parameter δ must be between 0 and 1, for the model to be consistent with its basic assumption.[4] However, in estimation the value is not constrained. An estimated value outside the range will indicate an error, either in the specification of the utility functions or in the partitions of the choice set. A value of δ greater than one indicates that the sequence should be changed to $P_j \cdot P_{i|j}$. If the estimated value of δ is not significantly different from one, then a joint logit model is appropriate and more efficient.

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ABREVIATIONS

C.E.	=	Civil Engineering
DOT	=	Department of Transportation
FEA	=	Federal Energy Administration
FHWA	=	Federal Highway Administration
HRB	=	Highway Research Board
MIT	=	Massachusetts Institute of Technology
TRB	=	Transportation Research Board
TRR	=	Transportation Research Record
UMTA	=	Urban Mass Transportation Administration
UTDFP	=	Urban Travel Demand Forecasting Project

FOOTNOTES

1. For more detail see Luce and Suppes (1965), McFadden (1974) Domencich and McFadden (1975) and Richards and Ben-Akiva (1975).

2. For more detail see Williams (1977) and Ben-Akiva and Lerman (1977).

3. A detailed discussion of this definition is given in Watanatada and Ben-Akiva (1977).

4. This is explained in McFadden (1977), Ben-Akiva and Lerman (1977) and Daly (1977).