Disaggregate Behavioral Models of Travel Decisions Other Than Mode Choice: A Review and Contribution to Spatial Choice Theory

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In recent years, considerable effort has been spent on the disaggregate, behavioral modeling of travel decisions: The rationales of Marble (59), Nystuen (68), and Stopher and Lisco (82, 83, 84) have been used. For obvious practical and policy reasons, much work has centered on intraurban mode-choice decisions and on home-based person trips for work purposes (82). Disaggregation has been accomplished by a focus on the travel behavior of individuals or of subgroups of the urban population; subgroups are defined by either socioeconomic characteristics (29, 49) or class of residential location (for example, city, suburban) or both (70). Preliminary attempts to incorporate more realistic assumptions about human behavior in traditional models (83) have led to probabilistic approaches (82, 87) and to the a priori specification of perceived time, comfort, safety, convenience, and other variables as factors influencing mode choice (11, 84). Attention is now being paid to the measurement of these variables (28, 29, 37, 66, 69, 85). This paper attempts to extend this work by

1. Collating and reviewing literature to assist with the disaggregate, behavioral modeling of intraurban travel decisions other than mode-choice applications in the trip generation, trip distribution, and route assignment phases of current transportation planning;
2. Focusing attention on the importance and salient features of spatial choice models in these contexts, particularly destination choice models for shopping, recreational, and social trips; and
3. Outlining research problems and strategies.

The need for a review paper of this kind is manifest by the variety of unrelated work in several disciplines that bears on travel decisions other than mode choice (the list of references includes journals in behavioral geography, marketing, transportation science, and environmental psychology). There is also a dearth of work on the identification and criticism of common assumptions and methodologies, with the possible exception of very recent and still unpublished papers by Allen and Boyce (2), Brand (13), and Ben-Akiva (9). In addition, the problems discussed below were encountered as the more difficult and important ones in the subject area as the author attempted to develop mathematical behavioral models of destination choice (17, 18, 19).

For the purposes of this paper, it is necessary to assume that travel decisions are "separable" and not "simultaneous." That is, non-mode-choice decisions can be assumed to be made, modeled, and hence discussed separately from mode-choice decisions. Obviously, the separability assumption is a debatable one (9, 15, 57). However, it has not yet been demonstrated to be unrealistic. For example, Ben-Akiva (9) and Liou and Talvitie (57) present conflicting evidence on the timing of different kinds of travel choice. The separability assumption also proved necessary as a simplifying premise for model development in the early disaggregate behavioral work, which is reviewed below. Finally, the assumption is required for pragmatic reasons: It permits a focus of attention on a critique of past work and directions for further research in travel decisions unrelated to mode choice.

SPATIAL CHOICE THEORY AND MODELS OF TRAVEL DECISIONS

Formal Characterization of Destination and Route Choice Models

Decisions are, by definition, choices by individuals, where a choice is a selection from a number of known alternatives (the choice set) and is manifested by an observable action (overt behavior). Obviously, urban travel decisions are a subset of individual choices; the observable action is person trips by time, purpose, origin, and destination. Hence, in urban transportation planning, trip generation models are models of the choice of the timing, purpose, and frequency of trips by individuals in different locations; trip distribution models are models of destination choice; and route assignment models are models of route choice. [Route choice is a decision concerning the path of travel for an activity, such as the journey to work. Destination choice involves the choice of a location at which to conduct a short-duration, recurrent activity (work, shopping, recreation, social visits); it also involves choice of locations to investigate for future long-duration activities, as in search for business, industrial, and residential sites (78).] Now selections of origins, destinations, and routes by individuals at different times and places are locational choices; theories of individual choice behavior within urban spatial structures are therefore particularly relevant for modeling travel.

So far, disaggregate behavioral models of spatial choice broach either the selection of destinations (1, 16, 34, 50, 51, 59, 64, 95) or the selection of routes (73, 79, 93). Formally, models of these decisions deal with the following problem. Given (a) a set of m individuals who are in given locations ($I_1, \ldots, I_i, \ldots, I_n$) and who have identical decision-making processes (often all are utility maximizers) and identical space preference functions (74), and (b) a choice set ($A_1, \ldots, A_j, \ldots, A_n$) of known alternative points or lines for the conduct of a particular activity, a, what is the spatial choice probability, $P_t(A_j/A_1, \ldots, A_j, \ldots, A_n)$, of the m decision-makers choosing alternative A_j for the conduct of the activity a in time period t? (There are very strong homogeneity assumptions in the above. Some of the problems of relaxing them are discussed later.)

The spatial choice probability P_t can be expressed in terms of a conditional spatial choice decision and a trip purpose decision at time t.

$$P_t(A_j/A_1, \ldots, A_j, \ldots, A_n) = P_t(A_j/a\epsilon t) \cdot P(a\epsilon t)$$

This states that the unconditional spatial choice probability of any alternative, A_j, being selected is the product of (a) the conditional probability of A_j being selected, given that activity a is to be conducted in time t, and (b) the probability of choice of activity a in time t. This, of course, follows normal probability laws and also the work of Massy, Montgomery, and Morrison (62).

Spatial choice models, as applied to travel decisions other than mode choice, should thus predict route or destination choices over time as the outcome of 2 processes: the conditional spatial choice process and the activity sequencing process (25). Most work, however, still concentrates on deriving operational, analytical expressions for either one process or the other. Studies of route choice, and models that allocate trips to points or areas within cities, focus on the conditional spatial choice process. Studies of trip linkages over time constitute models of activity sequencing.

For example, the disaggregate, probabilistic, utility or entropy models of Wilson

(98, pp. 65-66) and Beckmann and Golob (8) analyze the decision process of a group in selecting one of a set of destinations in time period t, given that an activity or activity combination is to be undertaken. The authors thus ignore time variations in trips by individuals or groups to an alternative, consequent on trip purpose sequencing and trip purpose changes over time. On the other hand, Markov models of land use linkages during trips, like those of Westlius (94), Sasaki (76), and Horton and Wagner (49), ignore the problem of predicting which of the particular locations of a land use activity will be chosen, given that an activity is selected.

Space-time budget studies (3, 24) attempt to combine the 2 decision processes, but have yet to find a well-articulated conceptual framework or a satisfactory methodology. Pipkin (71), following Nystuen (68), has produced a utility theory model predicting both activity sequencing and spatial choice for an individual on a multipurpose trip from home. However, he takes the trip purpose combination as a datum, so the approach actually generates a sophisticated model of conditional destination choice.

Models of spatial choice for intraurban travel are thus distinguished by their variety and lack of integration. The most important tasks, therefore, appear to be the rigorous testing of the models, the specification of the links between them, and the development of a unified stochastic theory of choice of activity and location over time. Leads in this direction and specific problems to be solved have been given, but not yet followed up, by Garrison and Worrall (31) and Worrall (100).

Importance of Modeling Shopping, Social, and Recreational Trips

Disaggregate, behavioral models of spatial choice are also predominately concerned with shopping, recreational, and social travel. There are seemingly fewer interesting problems in the disaggregate, behavioral modeling of destination choice, route choice, and activity sequencing for the journey to work. Most persons have only 1 workplace and travel directly along the same route to and from home. Moreover, there is a regular, daily sequencing of work activities for the majority of the population.

For other kinds of travel, it is not immediately obvious that activity sequencing and route and destination choice are orderly [though well-known descriptions of order are given by Berry and Pred (10), Hanson (40), Marble and Bowlby (60), Spence (80), and Thorpe and Nader (89)]. The description and prediction of "travel patterns" and the determination of their underlying causal mechanisms are by no means easy, as pathbreaking work by Garrison and Worrall (31), Marble (58, 59), and Nystuen (68) showed. In shopping, recreational, and social travel, the number of route and destination alternatives in the individual's choice set fluctuates over time, as he or she starts from different origins or tries out new alternatives. In addition, activity sequencing is irregular and trips may be multipurpose.

From the policy-making point of view, it is obviously a mistake to leave aside the individual's journey to work as an uninteresting spatial choice problem. Moreover, many work-based trips are not simple; they are linked with travel for shopping and other purposes (40, pp. 11-12). Modeling the journey to work as part of an individual's sequence of activities at different locations, therefore, poses questions worth attention and will further the much-needed focusing on both the spatial and temporal structures of trips. However, it seems essential to continue to emphasize shopping, social, and recreational travel. Little work has been done on these kinds of trips (91, pp. 176-177) despite the fact that most person trips in urban areas terminate at commercial land. In addition, although home-based work trips constitute approximately 40 percent of all person trips in metropolitan areas, trips for recreation, shopping, and social purposes also constitute approximately 40 percent of the total. About 15 to 20 percent are for shopping purposes; shopping thus is the most important kind of travel after the journey to work (91, p. 177; 102, p. 33; 103, p. 13). The percentage of trips for nonwork purposes may also be expected to rise as leisure time and incomes increase. There are therefore cogent reasons for continuing to concentrate on shopping, social, and recreational trips in the disaggregate, behavioral modeling of travel decisions other than mode choice (32, pp. 1-3).

PROBLEMS AND STRATEGIES

Three major problems appear to bedevil the development of disaggregate, behavioral models for travel decisions other than mode choice:

1. The aggregation problem;
2. The problem of common choice set definition, that is, the problem of defining for an activity one given set of destinations or routes that are all known by, and therefore constitute relevant alternatives for, every member of a population group; and
3. Problems of including attitudinal and perceptual variables.

The second problem is important because all choice models so far developed, including destination and route choice models, assume that individuals can assign a utility value and thus a preference ordering and choice probability to every alternative in a choice set. Some of the utility values assigned to known alternatives may, of course, be zero (5, 9, 13, 17). However, individuals cannot be held to have formed utilities, even zero utilities, for completely unknown alternatives. It, therefore, does not make sense to develop choice models for individuals who cannot be shown to know and share an identical set of spatial alternatives for a given activity.

The first and third problems are already familiar in disaggregate mode-choice modeling (11, 29, 37, 54, 72, 88). Consequently, a brief evaluation of strategies for their solution in spatial choice studies should assist with some general methodological issues in behavioral transportation research.

The Aggregation Problem

Much of the work on spatial choice carries the main argument for disaggregation to its logical conclusion. Since it is not possible to make inferences about individual or group behavior from observations on a population, methods must be found to isolate the causal decision mechanisms of individuals. Then aggregations can be performed to combine the models for individuals into models for successively larger groups until accurate, controllable population predictions can be made. Models of travel decisions other than mode choice, therefore, initially focus on the behavior of either individuals or small, relatively homogeneous population groups (34, 47, 49, 52, 59, 92).

There is a sporadic but by no means pervasive recognition that problems of ecological fallacy have been replaced by problems of finding ways to add together or combine models for different individuals in different locations at different times. The aggregation problem is particularly acute in Markov models of land use linkages by individuals and groups over time (49, 76). It is also acute in models of group place or space preferences, derived from attitude scaling models of individuals' subjective utility functions (17, 18, 34, 74, 75). In these instances, decision-makers are simply assumed to have identical place utility functions and thus identical destination choice probabilities. Accordingly, a model of travel behavior for a group is assumed to be the same as the model for any individual member of the group. Even if the actual heterogeneity of individuals in terms of place utility functions and spatial choice probabilities is recognized, the consequences of such heterogeneity are not formulated.

Accordingly, a crucial problem for future research is to develop mathematical techniques to enable the prediction of the spatial choices of a heterogeneous group from a model of the individual's decision. Several possibilities may be evaluated here.

A familiar approach, paralleling mode-choice modeling, is to construct separate spatial choice models for population subgroups (one model per group), where each subgroup is demonstrated mathematically to be reasonably homogeneous in terms of socioeconomic characteristics. The mathematical constraint on within-group heterogeneity is supposed to ensure that the group choice model somehow reflects the model for any group member. Aggregating the travel predictions for different subgroups results in better total population predictions. This is the strategy endorsed in modeling spatial choice, for example, by Wilson (98, pp. 31-33, 66), Horton and Wagner (49), Horton and Reynolds (47, 48), and Cole (23). One of the obvious deficiencies of this approach is that it remains just as difficult as in aggregate modeling to claim that the causal mechanisms behind individual travel behavior have been identified: The relations between the model for the group and the model for the individual are usually not spelled out. Further, this approach assumes that socioeconomic variables describing groups will be strongly and causally related to group travel choice behavior. The validity of this assumption has yet to be demonstrated; 10 years of work on analogous brand selection problems in marketing has failed to discover any socioeconomic characteristics that are good explanatory variables of group choice behavior (63). Moreover, even where standard statistical procedures may indicate significant associations between socioeconomic descriptors and travel decisions other than mode choice, the problem of spurious correlation remains. As Huff (50, 51) has argued, any of a large number of social, demographic, and economic variables can reasonably be hypothesized to "cause" travel decisions like destination choice. Moreover, it is likely that these variables are highly intercorrelated. The causal connections between group travel behavior and any subset of variables used to segment a population are therefore still obscure. Accordingly, the relative importance of different socioeconomic characteristics as predictors of spatial choice, and hence as desirable population segmentors, remains unknown.

One consequence is that, although models for population subgroups may fit any number of data sets well, the possibility remains that there will be a poor fit in another case because of changes in the effects of some underlying causal variables not taken into account. A more important consequence is that building separate models for population subgroups will only be a reasonable solution to the aggregation problem if much more attention is paid to the rigorous definition of groups with both homogeneous population characteristics and travel behavior. Newer multidimensional scaling techniques, such as Prefmap and Indscal, are designed to assist with the definition of groups of individuals with similar cognition, evaluation, and preferences for alternatives (77, Vol. 1, pp. 21-47). So far, there has been no experimental exploration of the use of these techniques to assist with defining groups for solution of the aggregation problem in the behavioral modeling of travel decisions other than mode choice (though Dobson and Kehoe give an application to mode choice, 29).

The difficulty remains, of course, that it does not matter whether new or old multivariate techniques show that some socioeconomic variables are associated with route or destination choice, they may still not be the best to use for population segmentation. For example, if a socioeconomic or other variable, which is causally related to a dependent travel choice variable, is unknowingly omitted from a regression equation, the regression coefficients may be very substantially altered, although the explained variation remains high. In sum then, although widely advocated, developing models of spatial choice for mathematically homogeneous population subgroups does not appear to be the best solution to the aggregation problem.

Another, more elegant approach to aggregation is exemplified in the recent work of Beckmann and Golob (8). First, a specific utility equation U is derived. This is an expression for the net benefits of travel by a household at origin i to destination k at time t. It is a function of travel costs, benefits, and number of trips from i to k. Next, the number of trips that will maximize the household's utility is derived, constrained by household income m. Different households at origin i are then assigned different special utility functions U_h and incomes M_h. An expression for the aggregate travel from i to k at time t is finally deduced by linear addition of the expressions for each household that yield the utility-maximizing number of trips. The authors admit that this approach to the aggregation problem in modeling spatial choice is "hardly operational" (8, p. 115). Indeed, as Cullen remarks (24, p. 464): "It is not immediately obvious how one would go about testing the basis of this new utility theory.... The problems of establishing utility ratings on all the individual activities ... performed by an individual would be immense." In addition, there are unresolved questions about trip-to-trip fluctuations and long-run changes in household utility functions. Accordingly, this approach, although theoretically elegant, at the moment appears excessively difficult to apply.

Another method of handling the aggregation problem looks promising for future research. This is the use of standard methods of manipulating probability distributions to enable the prediction of the spatial choice decisions of a heterogeneous group from individual choices. Massy, Montgomery, and Morrison (62) first applied such methods to the problem of predicting the sequence of brand choices of a good by a heterogeneous population group. The same techniques have recently been suggested for travel choices by Koppelman (54) and Aaker and Jones (1). A recent application by Burnett (19), specifically for a simplified destination choice problem, may be used to illustrate the aggregation mechanism, and the kind of model toward which progress can be made.

First, a model is developed for the individual, to predict his or her sequence of choices over time between one class of destination and another for an activity. Specifically, X is defined as a Bernoulli variable whose values represent the outcome of the individual's selections between a destination class 0 and a destination class 1 on each of n successive choices. It is next assumed that the individual has a constant probability p of a destination class 1 choice on any occasion and that this p value reflects the individual's distinctive preferences for class 1 and class 0 destinations. Finally, to allow for group heterogeneity, we assume the individual's p is a random sample from a distribution of p values (preferences, utilities) over the population. This distribution can be described by the density function f(p). Given these assumptions,

1. b(p/i) is the posterior distribution of p for the individual, after a given sequence of choices i and equals

$$\frac{\ell(i/p) \cdot f(p)}{\int_0^1 \ell(i/p) \cdot f(p) \cdot dp}$$

where $\ell(i/p)$ is the likelihood of the trip history (by Bayes theorem); and

2. The expected probability that any individual with a given past sequence of destination choices i will choose destination 1 next is

$$\int_0^1 p \cdot b(p/i) \cdot dp$$

It can be shown that, with the increase in size of a group of individuals who have the same past history i but different p values, the probability that the group will choose a destination class 1 next equals the posterior expectation of p or

$$\int_0^1 p \cdot b(p/i) \cdot dp$$

This is the same as for the individual in 2 above.

The predictions for groups and individuals can be interpreted in behavioral terms, for example, as the outcome of the effects of so many interacting and influential variables that choices appear to behave like a random variable over time. Other formulations and interpretations are possible; for example, Jones (53) derives individual and group probabilities as the outcome of different Bernoulli, Markov, and linear learning processes in which next destination choice probabilities are affected by last destination choice in different ways.

However, the use of probability theory presents some problems for future research. First, extensions of mathematical theory are required to predict choices of individuals and groups over more than 2 classes of destination. Second, there is little evidence or theory to suggest which, if any, of the standard probability distributions (normal, gamma, beta) should be used to define f(p), the density function that describes the different preference and utility ratings of a population for any destination class. Some specification of f(p) is necessary to produce accurate destination choice predictions for models of this kind. This seems an area for future empirical research.

Finally, there is another aspect of the aggregation problem besides that of aggregation over individuals in different locations. To provide operational models of spatial choice decisions, the custom is to group at least some of the choice set alternatives (e.g., shopping places for a particular good) into classes. In effect, this is aggregating possible choice states of the individual and group. For example, in studies of destination choice, activities, origins, and destinations may be grouped into classes by zone (8), by kind of land use (40, 76), or by locational characteristics (75). Little consideration has been given to the effects of choice state aggregation (27). For example, if travel decision-making is not identical with respect to each member of a destination class (for example, each kind of retail establishment in a commercial zone), then what does a model of decision-making with respect to the class of alternatives mean? Examining the effects of choice state aggregation on predictive accuracy and meaning appears to be an important area for research.

Although models predicting travel for every possible member of a spatial choice set are not analytically inconceivable, they would scarcely be operational for a large area with many activities, origins, destinations, and routes. Two crucial problems arise, therefore. The first is defining what constitutes similarity of alternatives for disaggregate, behavioral models of spatial choice. The second is specifying classes of similar alternatives for choice sets. Rushton (75) has initiated work in these directions. However, he works with a priori assumptions about the criteria (size, distance) that individuals use to define destination classes. The question as to how decision-makers themselves perceive groups of alternatives remains unanswered. Appropriate general specifications of similar alternatives for modeling purposes can only be made after this problem is resolved through empirical research.

Problem of Choice Set Definition

Next, there is the problem of bounding choice sets for disaggregate, behavioral models of spatial choice. At present, aggregative and many disaggregative trip distribution models assume that all individuals in a city share a common set of destination and route alternatives (6, 8, 55, 60, 97, 98). For example, gravity, entropy, and utility models of interzonal trip distribution assume that each individual within a given zone can and does consider every other zone in the city as a potential destination. Some destinations are more likely to be used than others, but only because of variations in attractions and distance impedance. It does not matter whether the trip is undifferentiated by purpose (8, 97, 98) or whether it is specifically for shopping or some other kind of travel (9, 22, 23, 55, 57, 60).

However, the assumption that every individual selects from the same citywide choice set seems most implausible. This contention is supported by recent work on the individual's cognition (33, 35), information field (12, 41), and activity and action spaces (48, 86, 95). At best, individuals in the same neighborhood and socioeconomic class may share some members of their sets of spatial alternatives for different activities (47). However, it is likely that these sets will be different for different activities, that they will be restricted to one part of a city (41), and that they will vary as alterations in the neighborhood occur and as individuals learn more about their area (33, 35, 36, 78). As well as varying with the individual's activity and socioeconomic status and length of residence, the number and locations of spatial alternatives that a person considers seem likely to change with distance and direction from his or her origin (41, 86), with the complexity of alternatives, with the legibility and ease of pathfinding that different kinds of city structure afford (101), and with the base (home, work) from which the person is to travel.

Hence, choice sets are not at all easy to define for disaggregate models of spatial choice behavior. Nor will sets be the same at different levels of aggregation, for example, for residents at neighborhood, city sector, and citywide scales. This contrasts with the position in mode-choice modeling, where a small number of alternatives can usually be clearly defined and remain the same for individuals and groups at most levels of aggregation. Accordingly, much more empirical work needs to be done on methods of delineating route and destination choice sets shared in common by individuals for different activities (41). Until the problem is resolved, disaggregate, behavioral models of spatial choice will lack an operational definition that makes sense, and they cannot be expected to make good predictions of travel decisions other than mode choice.

Problems of Including Attitudinal and Perceptual Variables

Even if choice sets can be defined, questions remain as to how route or destination alternatives are perceived, experienced, or cognized by individuals and how cognition affects evaluation, selection, and overt travel behavior. Similar questions have recently been addressed by Hartgen (44) and others (11, 28, 37, 66) with respect to alternative modes. It is clear that travel decision processes may be influenced somehow by age (4, 61), income (26, 46), occupation (49), race (67), and other socioeconomic characteristics (50, 65, 99). However, such characteristics may not be highly correlated with cognition, preference formation, and overt choice behavior (44; 63, pp. 55-57). Moreover, correlation does not imply direct causation, and hence the use of socioeconomic variables as surrogate predictors may lead to inferior explanations, predictions, and forecasts of destination and route choice. There is considerable evidence from learning theory in psychology that the direct causes of choice decisions may not be the socioeconomic characteristics of persons per se, but the subjective preferences they form for different imperfectly known attributes of alternatives (5, 38, especially chapters on concept identification, judgment, and choice).

Because normal household descriptors may not yield good predictions of travel decisions of individuals and groups, variables must be incorporated in disaggregate, behavioral models to specifically test the effects of individuals' perceptions of, and attitudes toward, route, destination, or mode alternatives. Surrogate indicators of psychological and personality traits, such as apathy and fantasy-proneness, also cannot be used. Although Golledge (34, p. 418), Myers (63, pp. 52-56), Stone (81), and Le-Boulanger (56) indicate that psychological variables may be highly correlated with mental processes in travel decision-making, they are exceedingly difficult to define and measure. Moreover, the same problems of model misspecification arise with the use of these surrogates as with the use of socioeconomic surrogates.

There are, however, conceptual and measurement problems in including perceptual and attitudinal variables in models of spatial travel decisions in future research. First, there is the question of identifying what perceived attributes of alternatives (such as shopping places, recreational areas) are important. It cannot be assumed a priori that travel time, scale of facilities, environmental amenity, travel costs, or any other factor is significant. Maybe, for example, perceived money cost and perceived travel time are linked in a "cost of the trip" dimension in travelers' minds, and alternatives are perceived and evaluated in terms of this rather complex criterion. Indeed, recent studies of the perception of shopping places (17, 30, 96) indicate that individuals may use only a few complex attributes to assess alternatives (e.g., the amenities of the environment in the case of destinations). Moreover, these perceived attributes apparently bear no clear relation to the size and distance variables that traditional spatial choice models have assumed to be important [as, for example, the gravity or central place models of destination choice (7, 10, 16, 51, 55)].

Recent developments in models of the mind, and associated multidimensional scaling (MDS) measurement techniques, have in a few cases been used to identify the attributes of spatial alternatives that are significant to individuals (17, 43, 77, 90). However, MDS procedures are expensive and difficult to administer; they can often be used only with small samples, and the naming of discovered attributes is difficult. Nonetheless, MDS procedures offer the most rigorous way of defining attitudinal and perception variables for disaggregate, behavioral models of spatial choice. They do not require necessarily any prenomination of possibly significant attributes of destinations or routes by the researcher for individuals to score or identify; these may be uncovered indirectly through the use of MDS algorithms. Consequently, considerable application of MDS procedures to identify the perceived characteristics of destinations or routes may be expected in the future.

Modern scaling procedures not only help define the dimensions of alternatives that are important to individuals but also yield (a) diagrams of the individual's mental positioning of alternatives with respect to each dimension (that is, scores of alternatives for each attitudinal-perceptual variable) and (b) measures of individual and group preferences for each alternative [see Burnett (17) and Downs (30) for the case of destinations]. This paves the way for building models that link, first, functions describing individual and group perceptions of alternatives; second, group and individual subjective preference functions; third, the probability of a group or individual choosing each alternative; and, fourth, the relative frequency of trips by individuals and groups to each member of a choice set. One model of this kind has already been developed and tested for spatial choice and demonstrates a direction for future research using MDS theory and techniques.

$$P(A_j/A_j, \ldots, A_k) = \sum_{i=1}^{m} \frac{V_{ij}}{\sum_{x=1}^{k} V_{ix}} \Bigg/ m$$

$$= 1 \left[\sum_{i=1}^{m} U_{ij} \Big/ m \right]^{h}$$

$$= \hat{1} \left[\sum_{i=1}^{m} D_{ij} \Big/ m \right]^{\hat{h}}$$

$$= \hat{1} \left[\sum_{i=1}^{m} (d^r_{ij1} + d^r_{ij2} + \ldots + d^r_{ijn})^{1/r} \Big/ m \right]^{\hat{h}}$$

$$\log P(A_j/A_j, \ldots, A_k) = L + \hat{h} \log \left[\sum_{i=1}^{m} D_{ij} \Big/ m \right]$$

$$= L + \hat{h} \log \left[\sum_{i=1}^{m} (d^r_{ij1} + d^r_{ij2} + \ldots + d^r_{ijn})^{1/r} \Big/ m \right]$$

where

$P(A_j/A_j, \ldots, A_k)$ = probability of decision-makers' choosing spatial alternative j out of a set of k alternatives;

$\frac{V_{ij}}{\sum V_{ix}}$ = response strength of decision-maker i (or measure of his degree of preference) for alternative j relative to the strength of his response for all other alternatives;

U_{ij} = decision-maker i's judgment of the magnitude of his preference for alternative j (this judgment lies behind the preference rank he will assign the alternative to provide data for a non-metric-MDS procedure);

D_{ij} = estimate of U_{ij} (it is recovered by the nonmetric MDS of decision-maker i's rank order data);

$d_{ij1}, d_{ij2}, d_{ij3}, \ldots, d_{ijn}$ = set of recovered distances of alternative j from decision-maker i's ideal alternative along each of the n dimensions used for assessment;

r = the recovered constant used to combine the distances and otherwise known as the Minkowski metric number (this is the decision-makers' perception of alternatives);

m = total number of decision-makers in a homogeneous sample, that is, in a sample with only random differences between the decision-makers' relative response strengths and judgments;

k, l, L, and h = constants; and

$\hat{l}$ and $\hat{h}$ = recovered estimates of l and h (17).

One problem with this kind of model is that there is little evidence or theory to suggest the appropriate forms of mathematical expression to relate perception and preference functions and choice probabilities. In the model above, as in other subjective utility models of spatial choice so far developed (9, 13, 57), continuous, additive functions form the starting point of model building. As Harman and Betak suggest (43), MDS procedures can also be used to see whether individuals have discontinuous, nonadditive, and nonlinear functions relating cognition, preference, and choice.

Another problem that should be considered is that the number and kinds of attitudinal and perceptual variables that individuals use to make choices may be different for different people and will certainly vary for the same person over time. Burnett (17) has shown that the significant attributes and ratings of shopping places by individuals vary with their stage of learning about their neighborhood. This is consistent with other work on spatial learning and information, for example, by Bowlby (12), Golledge (33, 34, 35), Golledge and Rivizzigno (36), and Hanson (41). Consequently, it seems important to develop process models to describe how spatial learning occurs and how this affects route, destination, and mode choice by individuals and groups over time. The use of stochastic process theory or psychological learning models for this purpose has been shown to be possible (18, 34, 78). These comments also suggest that some modification of behavioral mode-choice models may be required, where it is standard practice to assume that the attributes of modes and their importance to different population groups remain constant over time, that is, reflect stable preference structures and stable subjective utility functions. In a mode or spatial choice environment that is constantly changing, this assumption cannot be made.

However, even if the changing perceived characteristics of travel alternatives can be identified, measured, and included in models, no assistance will be provided to policy-makers unless they are linked with the manipulatable, objective design characteristics of routes, destinations, and modes. Perceived characteristics of alternatives may be related to objective counterparts in accordance with psychophysical laws of judgment (14). That is

$$0 = kP^h$$

or

$$\log 0 = K + h \log P$$

where P stands for a perceptual characteristic (like psychological distance), 0 stands for the matching objective one (like distance in miles), and k, K, and h are constants and may vary with the individual's position in space and time. Much more work needs to be done to verify that this kind of relation holds in travel decision-making and to look for spatial and temporal invariance or trends in the parameters relating objective and perceived characteristics. If such relations are discovered, then models of response to future systems can be developed based on individual and group perceptions of system characteristics.

By far the most serious difficulties for the development of disaggregate, behavioral models of travel stem from the dubious status of the mind as an object of scientific inquiry. Perceptions, attitudes, preferences, and decisions are mental events and are, hence, nonobservable and unverifiable. For example, Hanson (39) follows behaviorist thinking by arguing that words describing mental processes are alternative words for overt behavior. Consequently, studies of perceptions, attitudes, and preferences may not be analysis of the causes of overt behavior, like movement, as commonly supposed, but rather be alternative ways of describing movement itself. Perceptual and attitudinal studies may therefore be tautologous and scientifically barren. Other philosophies of mind besides the behaviorist example cited, and their consequences for the explanation of spatial behavior, are examined in another paper (21).

Even apart from philosophical debates, to make sense of the "mental" components of disaggregate, behavioral models of travel decisions is difficult. What, for example, are the units of measurement of perceptual time, comfort, or convenience? How will we ever know if the units used by different individuals are comparable? How in these circumstances can we make sense of aggregating the perceptual scales of individuals to help predict group travel? At the moment, perhaps we must treat models with perceptual-attitudinal variables just as plausible, convenient constructs for the prediction of destination, route, or mode choice. One undesirable consequence is the weakening of any claim that this kind of model identifies the causal mechanisms behind travel decisions. It does not, however, follow that disaggregate behavioral models will not make better predictions than aggregate models. This can obviously only be validated (or invalidated) by developing and testing models of both kinds.

SUMMARY AND CONCLUSION

This paper collates and reviews current work on urban travel decisions other than mode choice. Its aim is to assist with the development of disaggregate, behavioral models that have applications in the trip generation, trip distribution, and route assignment phases of urban transportation planning. Particular attention has been concentrated on the theory of individual spatial choice behavior and applications to route choice and destination choice in shopping, recreational, and social travel.

Three problems have been selected as requiring the focus of attention in future research: the aggregation problem, the problem of delineating choice sets, and problems of including attitudinal and perceptual variables in model building. These problems were selected because they are already claiming attention as the cutting edge of present work and also because 2 of them (the first and third) are not unique to modeling travel decisions other than mode choice.

Nonetheless, some important issues have clearly been left aside:

1. How to model interactions between changes in urban land use and transport networks and changes in route and destination choice over time;
2. How to handle the sequencing of different kinds of travel decision (time of day, purpose, route, mode, destination) in a general model of travel behavior (9, 13, 22, 24, 57, 96, 98); and
3. How to model the connections between changes in spatial travel and transportation demands and possible social change over the short and the long term [e.g., the provision of increased access to peripheral city work opportunities and residential and other amenities by the inner-city poor (45) and modeling the social impacts of new transport links (20)].

Despite the fact that these questions have been left aside, it is hoped that this paper has raised and clarified some fundamental issues in the disaggregate, behavioral modeling of urban travel and spatial choice.

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