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Disaggregate Travel Models: How Strong Are the Foundations?

A. G. R. Bullen and Russell H. Boekenkroeger, University of Pittsburgh

This paper presents a review and analysis of disaggregate travel-demand modeling founded on an examination of the published literature. This analysis is directed to the conceptual foundations of the modeling process, which appear to be somewhat obscurely covered by the literature. The analysis is at two levels: (a) a review of where the modeling structure fits into the overall travel process and (b) an analysis of the foundations of the specific models and how they relate to the target processes. The particular disciplinary backgrounds that lead to the model formulations are reviewed since a qualitative interpretation appears to be lacking in the travel literature. From these analyses it is concluded that the basic random-utility travel model does not have a sufficient behavioral foundation that allows its generalized usage for all components of the currently perceived travel structure. As a consequence it would seem to have somewhat limited application for many transportation policy questions. The paper suggests that a more diversified modeling approach is required, that the traditional modeling structure should be reviewed to exclude unimportant functions and introduce more policy-relevant ones, and that, in the development of models, considerably greater attention needs to be given to the establishment of criteria for their evaluation and verification.

Disaggregate travel-demand models (DDMs) have been at the forefront of transportation systems-analysis research and academic activity for the past 10 years. The reasons for this are several. They respond to the practical need to develop more effective models for travel prediction and transportation evaluation. They provide considerable intellectual challenge in their use of sophisticated techniques, and their attractiveness has been heightened by the theoretical derivation of an apparent behavioral basis for earlier empirical developments.

Despite the quantity and sophistication of the work that has been done on DDMs, several areas of concern appear:

1. They still have not been accepted by a substantial segment of transportation practitioners;
2. They have not, so far, provided any spectacular breakthroughs in modeling or understanding; and
3. The literature reveals lingering uncertainties and continuing problems with models and data.

The main response to these difficulties has been greater technical activity in search of a more complex and sophisticated methodology. Nevertheless, the literature has not become much clearer. To many, the methodology remains unclear and the problems remain to be clarified.

This paper postulates that the immediate need is a reexamination of the foundations of the models to provide at least a clear, concise, and simplified explanation of them, if not a redirection of the modeling process. The literature provides much confusion in definition and terminology at the conceptual level. Many of the foundations of the modeling approach are subjectively derived without testing of the underlying assumptions. Some of the most important concepts are left to the references, which also remain obscure.

A clear response to these questions, including clarification of the concepts, would broaden the understanding and acceptance of DDMs. The conceptual base of the current econometric thrust is so narrow, however, as to preclude the confirmation of the strong empirical results claimed. The usefulness of the methodology is thus restricted to fairly limited applications.

BACKGROUND

DDMs are widely reported in the literature. A series of conference proceedings provide the most exhaustive reviews (1-3). Specific modeling developments are provided by Ben Akiva (4), Charles River Associates (5), Domencich and McFadden (6), and Manski (7).

DDMs were originally developed to gain greater insight into travel behavior, particularly at the individual level. This fundamental understanding was found lacking in the aggregate forecasting models generally used in the Urban Transportation Planning (UTP) process. Critiques of traditional aggregate models are abundant (1, pp. 13-19).

The initial modeling work was of an empirical nature, developing logit models of mode choice. Later theoretical work of Charles River Associates (5), McFadden (8), and Domencich and McFadden (6) provided a behavioral interpretation and foundation for the preceding empirical work. Despite this formulation, however, the nature of the DDM methodology remains overwhelmingly empirical. Conceptual difficulties and behavioral inconsistencies have arisen from time to time, and the underlying theory has often been adjusted in an ad hoc manner to account for discrepancies (7). Empirical and technical work has dominated; less attention has been given to theoretical understanding, and, unfortunately, this had led to what seems to be lack of concern for the modeling foundations.

DDMs have been looked on as accurate, inexpensive replacements for traditional forecasting models; they are capable of dealing with policy questions that the earlier methodology could not handle. Yet, with the few exceptions, DDMs have not become a standard tool for analysis in practical settings. This is despite their virtues over the UTP models (4, 6).

From time to time questions of a conceptual and theoretical nature have been raised about DDMs. These questions include the difference between aggregate and disaggregate models (2, pp. 116-126), the lack of an appropriate treatment of nonchoosers (2, pp. 173-179), the applicability of these models to policy issues (9), and the wholesale restructuring of the modeling process (10). Recently, a number of interrelated research problems have been proposed (11-13). The questions and problems, however, remain. Questions arising from the basic assumptions of DDM are being addressed at the technical level. If the underlying concepts are being considered, then the literature does not make this clear. Rather, it provides a sometimes confusing terminology and unclear references.

An examination of the assumptions of the theory may be unwarranted if the principal concern is with testing a model's predictions rather than its assumptions (14). The purpose of this paper, however, is to review the modeling processes through an examination of the concepts and assumptions.

FOUNDATIONS AND CONCEPTS

As the literature recognizes, personal travel is an extremely complex process. The actual mechanism by which this complexity is reduced to a manageable methodology is the central theme of this paper. Although some of the assumptions used in a DDM are criticized here, this is not in conflict with the process of idealization and simplification that is essential to develop a workable model of a complex phenomenon. Of principal concern are those instances where basic structures affected by the circumstances being modeled are not reflected in the modeling methodology. Alternatively, there is also concern for those instances where the foundations of the methodology are so imprecise or unclear as to make the user insensitive or unaware of the actual processes being dealt with.

Two distinct levels of concept are dealt with in the analysis of these foundations. The first and more general level that is examined is concerned with the general character of personal travel and how it relates to the overall travel methodology. This provides the background for the second and more extensive level of concept, namely those assumptions and techniques that lead to the specific DDM.

Travel is a realization of human activity structured over a spatial framework. The analysis of these spatial connections is the travel modeling problem and, as such, it has been frequently and clearly described throughout the literature (6). This initial characterization, however, is frequently followed by a precipitous leap to the description of rational economic man as a utility maximizer. At most, strictly qualitative attention has been given to the concepts and subsequent assumptions that transform the former into the latter.

This human activity is an assembly of individual activities integrated into the larger structure of some behavioral unit, generally agreed to be the household. It is here that DDMs are initially tenuous. Although they have been related to household decision questions (such as residential location and automobile ownership), their basic travel structure is concerned with the individual. The models, therefore, will have limited value for policy analyses, where changes in the structure of household interactions are likely. Changes in energy availability, vehicle size, life-style, and the role of women have significance for the internal activity structure of the household—its subtle interactions and substitutions. In these kinds of instances the assumptions of the separability of the individual utility functions, so essential to DDMs, are unrealistic.

The closest approach to the household-identification problem is the market-segmentation process currently in vogue. This, however, cannot analyze changes in household-activity structures unless these changes coincide with transitions between market segments. Market segmentation appears to be an ad hoc response to deficiencies in the abilities of the models to handle demographic or socioeconomic characteristics.

At the level of the individual, DDMs make further idealizations of the basic activity structure. Two key assumptions are made:

1. Activities spatially removed from the home have a suitable surrogate in trip purpose and
2. The separability of utility applies to all components of the activity-travel structure.

These simplifications are sometimes necessary to reduce a complex process to a reasonable model but, once again because of the separability criterion, important interactions are not explicitly considered. For assumptions of this kind, more effort should be given to identification of their range of application.

Some of the conceptual problems raised here are related to the relationship between the traditional aggregate modeling process of UTP and the disaggregate approaches. Although disaggregate theories are intended to overcome basic difficulties of the traditional methods, they are highly derivative of these methods. The traditional aggregate simulation models still dominate travel analysis thought, and some of the conceptual problems of aggregate models transfer directly to DDMs. The difficulties start (2, pp. 116-125) with the mere description aggregate versus disaggregate, which gives the impression that the individual is being analyzed. This, however, is an economic interpretation, and the study of the individual consumer is actually the study of a homogeneous aggregate of consumers and, similarly, DDMs are the study of homogeneous aggregates of travelers. Both models are aggregate. The traditional models aggregate space whereas the newer ones aggregate class of individual (or occasionally household).

The major transfer of traditional techniques revolves around the definition of the trip and the maintenance of purpose as a substitute for activity. There appears to have been little, if any, questioning of the basic trip structure of frequency, time, mode, destination, route, and purpose. Perhaps alternative structures are feasible. To approximate activity with purpose requires separability notions that are difficult to justify. The analysis of household-activity patterns is being looked at (15) and the travel implications have been conceptualized (16), but their potential impact on DDMs is limited. More understanding of activities, time consumption, spatial structure, and household interactions are needed. DDM developers have realized this, but they have tended to pass over these subjects through qualitative reasoning and strings of assumptions.

FUNDAMENTAL CHOICE CONCEPTS

The travel process just mentioned is treated in DDM in a traditional economic framework that has some formal mathematical propositions from psychology integrated into it. Theories and models of travel that originate from this framework are well documented (6, 7), but little attention has been devoted to relating the framework to the travel process. The failure to explain precisely how the underlying concepts of the models are related to these economic and psychological foundations is a source of many conceptual difficulties. To develop a cohesive basis for further discussion, these foundations are now highlighted. The material is taken from the standard references cited in the DDM literature.

Theory of Choice in Economics

Current approaches to the theory of choice establish those axioms that must be fulfilled for the existence of any choice problem. The axioms that constitute the general theory of choice ensure that (a) a universal set of choices may be partitioned into the mutually exclusive, attainable choice set; (b) all elements of the universal choice set may be compared and an induced strong ordering of the elements established; and (c) an element will be chosen and it will be the one most preferred (17, 18).

These principles must be made more specific in the consideration of a particular choice problem by asserting clear restrictions on the choices made by a choosing agent, identifying an attainable choice set, and positing the criterion that will rank the choices. In consumer theory, the criterion used is utility, and the mechanism that provides this is the utility function.

Consumer Theory in Economics

In consumer theory the choosing agent is identified as an individual consumer and the commodities that comprise his or her choice set are those that he or she has at hand. Most consumer theory considers that the commodities themselves give rise to utility. DDMs incorporate the approach of Lancaster (19), wherein the intrinsic characteristics of the commodities give rise to utility. Lancaster postulated that the characteristics possessed by a good are the same for all consumers. In DDM a somewhat modified approach is taken wherein different homogeneous segments of a population have different consumption characteristics.

To delineate the attainable choice set for individual consumers, additional assumptions are required of these assumptions, and they ensure that the preference of utility function possesses certain properties that are to be exploited. Once a consumer's utility function is known and if he or she continues to behave rationally, the demand function may be derived.

Theory of Revealed Preferences

For DDMs, McFadden (8) has identified modeling travel choices as the population analogue of the theory of revealed preferences for individual consumers, which originated with Samuelson (20, pp. 90-123), who proposed that, by observing a consumer's actions, preferences would be established. The advantage of this theory is that, being based solely on observed behavior, it is presumed to be testable. In its most general statement, the theory entails two axioms:

1. Given a choice set, the consumer must make a choice and
2. If the consumer reveals a preference, it can never be violated at the same set of prices.

In this theory an outside observer constructs the preference or utility function to conform to the rankings that a consumer makes. If the function successfully ranks the choices of consumers, then it is interpreted as explaining the behavior. However, the theory only allows us to glean information about a consumer after choices have been made. Unless some independent information exists on the way in which a consumer's preference calculus changes over time, the observer is unable to conclude anything before the fact about the process that gives rise to the observed behavior. By assuming that tastes and preferences are fixed in the short run this problem is avoided and the theory is complete.

Utility

The criterion that a consumer employs in making choices is utility, and the mechanism is the utility function. When this concept is employed in consumer theory, some meaning is invariably associated with the term. Utility is assumed to summarize a consumer's sense of well being and it is generally interpreted as a reduced form of a number of complex psychological and sociological processes. Without dealing directly with these processes, utility may be interpreted to take account of them, albeit in an unspecified manner.

The characteristics of the choice are selected for inclusion in the utility function by the observer based on his or her substantive knowledge of the choice problem. He or she may not know for sure what the characteristics are and, in the empirical analysis of consumer-choice problems, different characteristics and transformations are tried to obtain that combination that is both theoretically plausible and empirically valid. Of the two classes of variables that enter the utility function in DDM (characteristics of the chooser and the choice), utility is encapsulated in characteristics of the choice. The characteristics of the chooser are used primarily to establish homogeneous market segments of consumers.

The concept of utility is a controversial one, even within the economics discipline, and considerable argument exists about its measurement and validity (21, 22). As a basis for travel modeling, Fried and others (10) tend to dismiss it entirely. Nevertheless, it is a flexible concept, wide ranging over many disciplines, and it provides a driving mechanism for the models.

CHOICE THEORY IN PSYCHOLOGY

The study of choice behavior in psychology is a search for the laws between stimulus and response relations, which can be generalized in many cases to the gamut of human decision-making situations. Empirical analysis guides the determinations of which theories are applicable to particular choice situations (23-25). Those developing DDMs have referred to and used formal propositions of mathematical psychologists, particularly Luce (26) and Thurstone (27).

Luce's Theory of Individual Choice Behavior

Luce presupposes that choice behavior is best described as a probabilistic phenomenon. This philosophy is adopted because of observed intransitivities in individual decision making and the plausibility of a probabilistic interpretation for the majority of choice problems addressed by psychologists. Luce's theory has an axiomatic foundation, with the standard probability axioms as its starting point. He assumes only mathematically well-defined sets of choice alternatives.

The core of the model is the choice axiom, which consists of two parts. The first part states that, if all pairs of discriminations among the elements of a universal set are imperfect, then the choice probabilities for any subset are identical to those for the universal choice set, conditional on the subset having been chosen. The second part states that if one particular element is never chosen over another, then the former element may be deleted from the universal set without affecting any of the choice probabilities.

Two consequences of the choice axiom that have been used by DDMs are the constant ratio rule, leading to independence from irrelevant alternatives, and the numerical ratio scale for characterizing alternatives in the choice set. The constant ratio rule states that the probabilities of choosing one alternative versus another do not depend on the total set of alternatives. It is the ratio of probabilities, not the probabilities themselves, that is invariant. The constant ratio rule maintains the assumption of pairs of discrimination among alternatives as well as transitiveness of choices. These are also two of the more important basic axioms of choice theory in economics. The choice axiom also implies that a numerical ratio scale exists over the choice set. In DDM, utility is represented in terms of a numerical ratio scale.

Thurstone's Law of Comparative Judgment

Thurstone's law of comparative judgment (27) is based on the notion that choice alternatives (as a stimulus) are subjectively experienced by an individual as intrinsically variable, and this accounts for the variability in individual judgments. Alternatives are treated as normal random variables and are called discriminal processes that represent the indirectly observable psychological values involved in choice. A case V Thurstone model is formally comparable to Luce's choice axiom, and it is the one of importance for DDM. The discriminal processes are assumed to have identical variances and common covariances, such that the marginal distributions differ only in their locations along the axis. The different stimuli or characteristics of the alternatives, described by real valued scale functions, are identically and independently distributed normally about their mean values. Thurstone's case V model is more familiarly known to economists and transportation analysts as the random-utility model.

Thurstone, Luce, and the Double Exponential Distribution

For pairs of discrimination problems, Luce's choice axiom, which results in the logistic distribution and the normal distribution of Thurstone's case V model, produces similar results except for the tails of the distributions (28, p. 216). Conceptual differences between Luce and Thurstone notwithstanding, McFadden (8) and Yellott (29), independently and under different assumptions, have demonstrated for multiple-choice comparisons that, if the random variables for Thurstone's model are restricted to differ only in their means, then Luce's choice axiom and Thurstone's case V random-utility model are formally equivalent. The double exponential distribution provides the linkage between the two. This distribution is referred to as the Weibull in travel literature and the Gumbel in some other disciplines, where Weibull is reserved for an alternative extreme value form. The principal result of this finding is that the multinomial-logit model has a random-utility interpretation along the lines of Thurstone's case V model. By assuming the double exponential as the underlying probability distribution, an explicit model for determining individual-choice probabilities results.

CONCEPTUAL ISSUES IN THE BASIC MODELS

The purpose of this section is to identify and discuss conceptual and theoretical issues of DDM, particularly as they relate to the concepts just highlighted. Some of the issues mentioned here have been presented elsewhere in the literature (1-3, 11). The specific organization given to this discussion focuses on the issues of how travel is characterized and modeled. It is this particular aspect in which the literature is obtuse and usually concentrates on the technical aspects of the models.

Basic-Choice Model: The Probability of What?

The heart of DDM is a basic-choice model, which in its elementary form is written

P (i:A) = probability of choosing i from the travel choice set A.

In dealing with this simple-choice concept as a starting point, however, the transportation literature presents a confusing and often inadequate notion of precisely what concept of choice is being developed and, more importantly, precisely what behavioral ideas are involved. There are three possible interpretations of the probability-of-choice model presented above. They involve to varying degrees the analyst, or observer, and the subject, or consumer.

Model A—The probability involved refers to a sampling probability that the subject, who has completed a fixed choice, will be selected by the observer.

Model B—The probability involved refers to the probability of choice by the subject where his or her choices vary randomly over repeated trials.

Model C—The statistical methodology implied in model A is being used on a group of model B subjects to estimate their probability distributions.

Invariably, DDMs are of the type described in model A. This is often clearly stated (6, 30), but on balance this distinction is left unclear by much of the literature. The question at this juncture then is why the psychologists are references for the basic choice. Clearly, for DDM to be behavioral in any more than a strict statistical sense (where independent variables explain the behavior of the dependent variable), something else is being implied. Are disaggregate models trying to get at model B through model C or what? McFadden (25) uses the mathematical methodologies of the psychologists by restating the choice axioms in the context of model A. The generalized framework of Manski (7) combines observer and subject in the context of model A, but this requires a narrowly defined individual-choice mechanism. Formal similarities aside, the underlying choice concepts of DDM are not those of psychology. Model C presents serious theoretical and conceptual problems.

Conceptual and behavioral confusion first arises from the different probability definitions implied. Model A represents the relative frequency view of probability, and model B implies the degree of confirmation concept of probability, as defined by Carnap (31). These are two of the major definitions of the several put forward by various authors. By adopting this view, probability may be taken to have a substantive meaning in particular applications. Thus, model A and de facto disaggregate models are incapable of logically supporting testing of behavioral hypotheses. By its very structure model A must be an aggregate model.

Model B is a true individual model and is thus disaggregate, wherein a probabilistic mechanism is used to reflect the degree of uncertainty of a decision maker regarding his or her alternatives. Model A, on the

Table 1. Comparison between choice theories of Luce-Thurstone and disaggregate travel models.

Dimension	Disaggregate Models	Luce-Thurstone
Type of probability	Sampling probability, relative frequency	Subjective probability degree of confirmation
Nature of choice experiment	Complex, traditional submodels provide choice sets	Simple
Choice subjects	Aggregates of persons (market segments)	A single individual
Number of trials	Single observation for each individual	Many observations for each individual
Individual decisions structure	Fixed	Random
Underlying individual preferences	True individual preferences unknown	Preferences applied repeatedly to similar choices
Attributes of choice alternatives	Function of attributes of dissimilar choices determined by the observer	A single attribute is varied in a predetermined manner
Intervening processes	Many, not all of which are known, understood, or examined	Controlled by the observer

other hand, results in a sampling probability of choices arrived at by decision makers from systems where the alternatives are fixed. The probability mechanism arises from the variation of that set of characteristics of alternatives for the subject unknown to the observer. The varying preferences are accounted for by the joint consideration of fixed statistical distributions of these unknown characteristics. The justification for these distributions, which are the behavioral core of the DDM is, at best, fuzzy. Unlike the Luce model, behavior is not directly modeled but is inferred from the apparent differences that individuals as consumers of travel indicate in their preference structure. The probabilistic core of DDM, therefore, appears to be predicated on the error term in the model structure and the data base it is calibrated from. Some of the comparative differences between the model concepts are summarized in Table 1.

Deriving the Basic Travel Model

The individual probabilistic choice models of psychology described earlier (model B) are a means of exploring intransitivities of behavior in simple-choice experiments. In the context of simple-choice experiments with repeated trials, the characteristics of the alternatives (their utilities) are treated as random variables that reflect the subjective preferences of an individual choosing agent. The associated response is uniquely determined on each presentation by the choosing agent. The alternatives are all known to the choosing agent and to the person conducting the experiment.

A travel model begins with the random-utility model (model A), which has been interpreted by economists as an econometric interpretation of maximizing behavior. In DDM this interpretation results in the fixed utilities of travel choices being treated as random variables by an observer who samples from the personal travel data set (5, 6, 30). The particular application of the random-utility model used in these models is more in the spirit of deterministic modeling than probabilistic modeling. Consequently, the randomness results not from a lack of rationality or uncertainty on the part of the traveler as to the utility of his or her alternative choices, but from a lack of information on the part of the observer as to which individual is chosen and the true utility of the alternatives.

The characteristics that are specified by the observer comprise the mean utility in the random-utility model, and those characteristics that are not specified are assumed to be part of the intrinsic utility, which each individual considers uniquely, or that utility that the observer does not have knowledge of. The socioeconomic characteristics of the traveler included in the utility function serve the primary purpose of segmenting the sample into homogeneous groups that have similar tastes and preferences. Within each market segment it is assumed that demand has a structure determined by behavioral regularities, which remain stable over time and space. As individuals are sampled from the data set, only the choices made or their revealed preferences are known to the observer, since he or she has no knowledge of the actual alternatives at the time the observed choice was made.

A core conceptual problem is the random distribution of unknown tastes, which is the essential behavioral driving force of the DDM. It has a particular set of properties assigned to it, yet little is actually known about it. It remains unknown, and must remain unknown, for the model as such to survive. The model is data specific. If more behavioral variables emerge they cannot come out of the distribution of unknowns, so a new model is specified. The distribution of tastes then must change its dimension but maintain its distributional properties. There has been no interest in establishing any information about the details of this basic behavioral process. Perhaps this indifference to the behavioral core of the model is responsible for Luce's apparent lack of interest in travel modeling (28).

Less fundamental technical questions arise. The independence of irrelevant alternatives issue has been widely thrashed around, but it presents a conceptual singularity fatal to the imputed behavioral basis of the model. The implication of the distributional independence requirements on the model are rarely addressed. Also, why are extreme value distributions used? In most applications of these, the use of an order statistic is clearly related to the modeling purpose and the parent statistical distribution contributes to that purpose.

The Basic Model Applied to a Perceived Travel Structure

The next stage of the travel-modeling process is to apply the basic random-utility model to the perceived travel structure. As already discussed, this perception is highly derivative of the existing UTP process and the available data bases. Two general approaches have been taken: the recursive approach and the simultaneous approach. The problems discussed below apply to either. The basic choice model is applied to every phase of the travel process, although its derivation has been largely in terms of mode choice. The travel process as conceptualized in conventional UTP submodels is purely descriptive. This breakdown of travel choices (frequency, mode, destination, time of day, route, and purpose) seems to be accepted as a matter of faith. There appears to be little discussion on whether alternative structures may be desirable, whether each of these components is equally important, and whether all components are relevant to the analyses to which the models might be put. This structure will be examined from the point of view of relating a qualitative view of the elements of the travel process to the basic model. The table below summarizes this analysis.

Travel Component	Behavioral Process
Mode	The individual's perception of the modes is constant—model A
Destination	Model A or model B, depending on trip purpose
Route	Generally model A but some model B by regular commuters
Frequency	A renewal point process
Time of day	A renewal process or scheduling process

For mode choice, the choice model is applied to the fixed preferences of a variable population, with complete knowledge of their travel alternatives. Each individual arrives at a consistent choice. Since the random-utility model has been derived in this context, this is a reasonable approach to what can be visualized. Generally, mode choice appears constant and, if the individual does randomly vary choice of mode, it is probably for reasons unrelated to the variables usually calibrated. Mode choice is a model A choice mechanism that has led to the random-utility model formulations.

For the choice of destination, there is the possibility of randomly varying individual choice, as given by model B. The choice set will be extremely complex since trip purpose does not define activity very well. Depending on the activity engaged in at the destination, some forms of the mechanisms supplied by both models A and B will be in evidence. Most work trips entail the fixed preference of model A, but for others, such as shopping or social and recreational trips, some form of model B mechanism may be operational. In any case, a uniform behavioral interpretation is not possible across the various purposes of travel. The choice set will also vary from household to household, confounding the determination of homogeneous market segments.

In the application to route choice the problems inherent with destination reappear. No doubt, many decision makers are displaying a fixed preference and others present more probabilistic individual behavior on a day-to-day basis. The direct application of the random-utility model presents some conceptual difficulties. Route choice deals with one of the most clearly defined choice problems, since the decision is closely related to the usual fixed attributes of cost and time and not relevant to any unknown tastes. The real decision mechanism is probably driven more by incomplete information on the part of the decision maker, a model B process.

Problems arise for the associated choices of frequency and times of day, since they fit neither model B nor model A. Clearly the traveler does not choose frequency in the preference scale of the basic model. What are its attributes? How does the taste variation fit around the do-nothing alternative, which may be a do-it-tomorrow alternative? This particular choice and that of time of day involves some kind of renewal process, a stochastic point process, which hardly fits either conceptual approach.

The simultaneous model structure lumps all of the described choices together into one model, which corresponds with model A. This can result only in models of extreme behavioral obscurity and great complexity.

CONCLUSION

The conceptual foundations of the DDM as they relate to choice theories from economics and psychology have been highlighted and explained. Behavioral interpretations attributed to DDM by the use of these choice concepts appear to be mainly formal in nature and rather obscure when related to the travel processes being modeled. Much of the DDM literature misinterprets what can be achieved from these concepts, and the application of them to the perceived travel process compounds the conceptual difficulties of the DDM. The fundamental discrepancies between the stated and actual interpretations of the DDM indicate a tenuous behavioral base and render its use for most purposes highly suspect.

The random-utility model is perceived as a significant advance, in fact and in potential, on the conventional UTP models—yet the travel structure is unchanged, the calibrated variables are little different, and the aggregation remains, albeit on a different dimension. These models are driven by variation over the population rather than by the imputed variability in the individual decision-making processes. As a consequence, the underlying behavior being modeled remains largely unexplained.

DDMs meet some important modeling objectives in that they are elegant and simple. Yet, as reasoned here, they are not proven behaviorally and, as such, they should not be considered sacrosanct and the only basis for further examination and generalization of travel. The models are helpful to have and they possess properties that may be exploited, but they are not a behavioral truth. DDMs have provided no modeling breakthroughs nor have they led to an increased understanding of travel.

A greater awareness of the complex processes that cause travel is required. Attention at all levels of the modeling process would help to conceptually structure models that are behaviorally and empirically valid. The determination of criteria for evaluation should be a parallel effort to the development of the models themselves, for the lack of clearly stated and operational criteria for evaluation is one of the causes of the confusion and inconsistency in current models.

The use of probability in DDM does not appear to have proved any new insight into the travel process. It is used in a descriptive statistical sense to take account of human variability, whether or not that variability is germane to the problem at hand. Yet, the process at hand may be susceptible to stochastic analysis since the events take place over time. Rather than use probability as a substitute for what is not known, it could perhaps reinforce what is known.

The conclusion is that DDMs lack the strong foundations, the power, or the capability to provide much additional understanding of travel structure. Beyond a predictive capability in the short run within the limits of their empirical calibration, they would appear to be limited in application. The development of more explanatory models for travel analysis will require more diverse research approaches, which will entail a concentration on assumptions rather than on methodologies.

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