APPROACHES TO TRAVEL BEHAVIOR RESEARCH

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Research approaches to improving the understanding of travel behavior are outlined in this paper. The objective of the travel behavior research is to make more informed judgments concerning trade-offs between the basis in behavior, and thus the logic and plausibility of travel forecasts, and the time, money, and skills required to carry out the forecasts. The behavioral assumptions to be evaluated relate to the perceptions, valuation, and structure of choice and possible conditioned or learned behavior resulting from the stimuli that give rise to travel decisions for various household and individual travelers. The paper focuses on 7 major issues around which research on travel behavior may be structured. Some recent findings related to each issue are presented, and current uncertainties and untested hypotheses are exposed for discussion. The significance of the research issues also is discussed. Criteria for evaluating alternative behavioral approaches to travel theory are presented.

• THE PURPOSE of this paper is to describe various travel behavior research approaches for evaluating the behavioral assumptions underlying the different models currently in use and models being proposed for passenger travel demand forecasting. The behavioral assumptions to be evaluated relate to the perception, valuation, structure of choice, and possible conditioned or learned behavior resulting from the stimuli that give rise to travel decisions for various households and individual travelers.

In transportation planning, planners have come to take for granted the detailed simulations and forecasts of travel on multimodal transportation networks that current urban travel estimating procedures make possible. Social scientists are awed by the boldness of planners in applying at different times and places relationships derived by using data from choices exercised over limited sets of travel and household-location opportunities. Psychology, for example, is much more tentative and fundamental. Models of perception and preference are derived from precisely defined axioms. Behavior is observed under controlled and fully described conditions. Burnett (27) said, "What knowledge we possess of the relations between human learning, perception, and choice derives from experimental psychology, and the connections between the simple nonspatially-oriented decision-making tasks of the laboratory and real life spatially oriented decision-making are tenuous." Travel modelers working on transportation studies have not enjoyed such luxury.

Nevertheless, transportation planning has made sizable strides in recent years in applying a variety of travel models that replicate urban travel patterns. The models address a great variety of transportation policy issues arising at both the aggregate policy level (for example, free transit) and the more fine-grained network levels of detail.

Recently, travel modelers have analytically derived several of the rules of travel behavior implied (or required) by the alternative travel modeling approaches that have been taken (21). These rules allow them to evaluate how well alternative travel models match their understanding of travel behavior. What travel modelers lack, of course, is the basic understanding of travel behavior.

TRAVEL MODELING

Except for the arrows from box 1, the current state of understanding of the interactions
Figure 1. Travel modeling diagram.

1. Travel Behavior and Human Opportunities
3. Alternative models to replicate travel choices
4. The rules of behavior implicit in alternative travel models

of travel behavior, travel models, and observed travel data may be represented as shown in Figure 1. In Figure 1, travel behavior and the set of spatially distributed human opportunities (box 1) drive the travel choices observed in urban areas (box 2). These, together with critical criteria such as time, budget, and available work-force skills, drive the travel models (box 3) that should be used in a particular transportation planning situation. Recently acquired knowledge of the choice behavior implicit in alternative travel models (box 4) allows use of this information in selecting and using alternative travel models. Notice, however, that no arrows go from the remaining boxes back to the travel behavior box. Statistics cannot demonstrate causality. In this case, statistics cannot discern the reasons why particular travel choices have been made. New approaches to understanding travel behavior are needed. These approaches will have to come from outside the traditional data collection and statistical methods in which transportation planners and researchers become quite expert. Because data can be used ultimately only to reject hypotheses, powerful theoretical development accompanied by careful and informed data collection procedures clearly is needed. Skills and techniques will be required from disciplines that have developed experience in understanding human motivation and behavior.

As transportation planners and economists move toward psychology in trying to understand travel-choice behavior, they find psychologists and other behavioral scientists moving to meet them in exploring ways to mesh individual-level data with aggregate-level data in real-choice situations. The main focuses to date have been where aggregate-level data were readily available (primarily in the fields of election forecasting and market research), but the trend is also apparent in other substantive areas such as demographic research that uses family-planning attitudes and behaviors in various cultures. These developments have become possible only recently mainly because of the increasing availability of high-speed, large-capacity computers and problem-oriented software that implements many of the new psychometric techniques.

The ultimate objective of the research approaches outlined in this paper is to allow trade-offs to be made in specific planning situations between the basis in behavior (and thus the logic and plausibility of travel forecasts) and the time, money, and skills required to carry out the forecasts. For certain kinds of situations, some models will dominate. That is, they will be better on all counts and thus should be used. In effect, a certain kind of code or set of recommendations of "what models to use when" must be a pragmatic and hopefully not naive goal of travel behavior research. Such recommendations and modeling choices always are being made, implicitly or explicitly, based on one's knowledge of all factors in a particular planning situation. However, because of the great variety of planning circumstances, a complete code of recommendations is obviously an elusive goal.

TRAVEL BEHAVIOR

Travel behavior may be defined as the observable reactions of people when they are confronted with choices involving travel. Travel choices include staying in one place or acquiring for the long term either the means of transportation (a car or a prepaid
transit pass) or the spatial prerequisites for travel (residence and employment locations). Travel observed in the aggregate is the summation of all individual decisions to locate and travel at a particular frequency and time of day by a particular mode and route to a particular destination.

Clearly, a vast number of variables could be used to describe the array of individual travel options and individual and household opportunity and need structures. The circumstances that give rise to travel and changes in travel behavior are as varied as life itself. An improved understanding of these circumstances (trip purpose, the proposed change in the travel-choice environment, physical and nonphysical characteristics of households, individual traveler characteristics, and length of time at place of residence) requires a systematic and well-structured research program. In this paper, such a research program is structured around a list of research problems.

**RESEARCH PROBLEMS**

There are 7 research problems or issues.

1. The scaling-specification problem asks the question, What attributes of the travel-choice environment give rise to or influence amount of travel?
2. The choice-abstract versus choice-specific problem, which is a subset of the scaling-specification issue, asks the question, Are the attributes influencing travel, such as modes used to produce transportation, perceived together with travel choice or independently of travel choice?
3. The measurement problem asks the questions, Are perceived values of attributes that influence travel related to "objectively measured" values and, if so, how?
4. The separability issue asks, What is the structure, or set, of alternative travel choices from which the traveler actually chooses; are travel decisions decomposed; and are there "natural" partitionings such as by frequency, time of day, destination, mode, and path?
5. The independent-choice issue asks, Do attributes influencing travel choices vary in their relative and absolute effect from one travel choice, or subchoice, to another, such as from modal choice to destination choice in a presumed hierarchy of subchoices to make up a complete travel decision?
6. The stochastic issue asks, Can travel be considered to be the manifestation of a set of conditioned behaviors that involves learning and changes in behavior over time?
7. The household behavioral unit and competing demands issue asks, What are the circumstances of households, or other basic behavioral units to be identified, that affect the findings in items 1 through 6?

These 7 research approaches together constitute an initial attempt to list the issues relevant to the study of travel behavior. The questions go beyond the scaling of the kinds of stimuli that govern travel behavior, their relative and absolute importance, and their interrelationships (problems 1 and 2) and include questions relating to measurement (problem 3), choice structure (problems 4 and 5), learning and conditioning (problem 6), and the influence of the household and other decision units on travel behavior (problem 7).

Each of these 7 research problems is important in its own right. All of the problems, of course, are interrelated. The first 5 are pragmatically stated questions brought about by the requirements of the travel models in use today or proposed for use in travel forecasting. The last 2 describe more fundamental approaches to understanding human behavior. The following sections outline the substance and significance of each of these research problems.

**Problem 1: Scaling**

A general statement of the scaling problem is that it is the problem of defining the di-
dimensions of the travel-choice environment that influence travel behavior. The signif-
ificance of the scaling problem is certainly well recognized. The problem of identi-
fying the important stimuli that influence the selection of travel choices is central to a
better understanding of travel behavior. The next few paragraphs indicate how the prob-
lem of scaling intersects with other research questions and how its "solution" may ulti-
mately be affected by data limitations.

Definition of Behavioral Variables

Long lists of attributes that may influence travel abound in the literature. However,
travel times and costs are behavioral variables just as are comfort, convenience, re-
liability, safety, weather, number of transfers, and journey units. A usable behavioral
model is not one that identifies a new behavioral variable but does not characterize it
well enough for it to be measured (problem 3) and forecast. In fact, many definitions
of comfort and convenience in transportation include time and cost components that are
measured relatively easily (162).

Path analysis (151), a technique for rejecting on the basis of observed behavior cer-
tain causal orderings in an assumed completely recursive travel model structure, would
appear to hold some promise for defining independent behavioral variables. However,
it has seen only limited application in travel demand modeling (88).

The last 10 years have seen a sudden proliferation of psychometric analysis tech-
niques for dealing with data on perception and preferences. At first, psychometric
analysis was used primarily in academic psychology, but, more recently, it has come
into favor in market research. The techniques of psychometric analysis differ in the
ways perceived similarities are represented and in the ways they are mapped into be-
havior in particular choice situations. Of substantial interest in pursuing the scaling
problem are techniques that allow the mapping of aggregate or individual "psychological
domains" of items in multidimensional spaces from data on perceived similarities,
characteristics, preferences for items, and substitutability of items (67,106,185). The
initial applications of psychological scaling techniques in travel research are very re-
cent (44,135,162) and certainly do not exhaust the capabilities of the technique. Multi-
dimensional scaling is an important research technique that will see increased applica-
tion in travel behavior research in the near future.

Limits on Human Discrimination Among Attributes

The number of variables that should be included in models of travel behavior must be
limited to the number among which humans can discriminate. Theories of human
discrimination and choice indicate the presence of a minimum variance needed for
discrimination and that the number of variables that can be considered in any single
decision is finite (160). One of the contributing factors to making destination choice
the most difficult of the short-term travel choices to model is the great variety of al-
ternative destinations that are available and the subtleness and temporal nature of the
attributes needed to differentiate among possible destinations (70). Also, it is unclear
whether the traveler, when confronted with a large number of travel choices, breaks
down the choice into smaller subchoices (problem 4) each of which is characterized
by a larger number of attributes, or whether all choices are considered simultaneously
but in terms of a smaller number of attributes.

Deducing Values From Behavior

The major emphasis to date in travel-choice modeling has been in deducing the relative
importance of modal attributes through people's revealed preferences. Revealed pref-
erences are what one may deduce about people's preferences or values from their be-
behavior. The values are deduced by relating people's observed travel, either as indi-
viduals or in the aggregate, to measured changes in transportation system characteristics. For example, the well-known value-of-time studies (108, 167) generally relate travel behavior in a simple model to measurement values of travel time and cost by alternate modes and routes.

However, deducing values from travel behavior is not entirely satisfying because travel choices depend not only on people's values but also on the travel and other opportunities open to them. Boulding (23) said that choices are "necessitated when the elements in the set of choices are scarce, in the sense that there is a limitation in the quantities that can be obtained which prevents the chooser [from] reaching the point of satiety" and revealing his or her true values or preferences.

Value-of-time studies deduce activity-specific, time-cost trade-offs for the limited set of choices (often only 2) that have been defined for the particular study. In reality, travel choices, although limited, are not nearly so restricted. In this sense, value-of-time models are in danger of being seriously misspecified. Lansing, Mueller, and Barth (102) stated that "the fact [is] that there is a tradeoff and what that tradeoff is, depends on where you are. Thus, what is a good thing at one point becomes a bad thing at another, and vice versa."

Also, in deducing values from behavior, there is the problem of the limited available measurements of transportation system characteristics. A severe limitation on the use of the most widespread available data on observed travel, namely existing home-interview survey data, is the lack of data on, for example, alternative travel choices. There are and likely always will be severely limited resources with which to measure everything about available travel choices.

In summary, in deducing values from travel behavior, there is the dual problem of limited choices and limited measurements of the characteristics of the available choices. Both severely hamper the ability to deduce preferences and obtain the underlying values and trade-offs that govern travel behavior.

Deducing Values From Attitudes

Attitudes may be defined as people's "tendencies to respond in a particular manner to social or physical objects" (74), or their "disposition to react towards alternatives either positively or negatively" (70). In the sense of defining and filling in the gaps in the existing and potential output space within which travel decisions are made, information from the so-called transportation attitude survey literature can be helpful. Measurement problems with existing and contemplated surveys can be bypassed for immediate travel-research purposes, and the limitations of current modes can, to a limited extent, be ignored. However, the use of attitude survey results assumes that expressed attitudinal values can be related to behavioral and to corresponding measurement values.

On the relationship of attitudinal values to behavior, the most ambitious study to date, the Maryland study, found "a modest positive linkage between expressed attitudes and reported behavior, particularly for the work trip" (130). Wachs (176), in another study, reported,

Drivers seem to be able to satisfy their preferences for many route characteristics. Drivers who express preferences for many route characteristics actually tend to travel on routes which possess them, whereas drivers who express little preference for such characteristics tend to drive on routes which do not possess them.

Watson (180) reported observing a positive relationship between estimated coefficients on modal-choice variables and the stated relative importance of those variables from a single attitudinal question asked together with those on behavior. Such positive general statements of the relationship are supported by the variations in reported attitudes
of different mode- and route-user groups toward the modes and routes in question and toward their attributes (83).

On the relationship between attitudinal values and corresponding measurement values, the picture is not so clear. The results of attitude surveys must be used with caution. The Maryland study reported that "the importance of a particular attribute is a function of both the underlying strength of the human need or needs it is related to, and its present satisfaction level" (83). This function shows up in the results of many of the attitude studies in the literature. It requires that the use of attitude study results on the relative importance of attributes be weighted by current satisfaction levels. Otherwise, the importance of current, poorly satisfied modal attributes will be overestimated. This means that relative attribute importance ratings from one survey cannot be used as attribute weighting factors in a travel demand model separate from or independent of the values of the attributes in a proposed transportation system. Unfortunately the same can hold true for revealed preference (economic) models. We may safely agree with Wallace (177) that "one area which still needs considerable research because of the need for demand elasticity estimates is that of determining the relationship between attribute satisfaction ratings and the levels of attributes."

Problem 2: Choice Abstract Versus Choice Specific

The problem of choice abstract versus choice specific is a subset of the scaling problem. It is the question of the relationship of the stimuli to the travel choices: Are travel attributes perceived by themselves, or are they mapped on particular supply side choices such as mode and route or choice of technology? The question similarly can be extended to attributes of alternative destinations. These alternate perceptions of the travel environment imply that attributes of the transportation system can be included in travel-demand models in 1 of 2 ways: as choice-abstract or choice-specific attributes (21). For example, the gravity model as conventionally applied in transportation studies is a choice-abstract destination-choice model both with respect to its trip-attraction variables and its travel-time variables.

The significance of the question as a separate research focus in this project is that, if attributes are choice abstract, then the numbers of interaction terms in a travel model will be greatly reduced and the model will be much simpler to estimate and apply. Thus the possible payoff is great, and the question becomes well worth researching.

Lancaster (97) provided the classic statement of the choice-abstract concept in economics.

Utility or preference orderings are assumed to rank collections of characteristics and only to rank collections of goods indirectly through the characteristics that they possess....Furthermore, the same characteristic may be included among the joint outputs of many consumption activities so that goods which are apparently unrelated in certain of their characteristics may be related in others. (The traveler is assumed to derive utility, U, from the attributes, Z, consumed and obtained as a result of the transportation activity.)

A variation on the choice-abstract concept overlaps research problems 4 and 5, which relate to choice structure. This is the possibility that at least some attributes may be considered independently not only of 1 choice (such as mode) but also of all subchoices. The attributes may themselves provide the choice structure. For a simultaneous-choice model, the resulting choice-abstract model would be the same as a simultaneous model of choice-abstract attributes. However, if the choice-abstract attributes are themselves considered sequentially, a new choice structure results that corresponds to a recent model in mathematical psychology, the elimination-by-aspects model (173). The model is relatively easy to apply to travel choices (21), and, for this reason alone, problem 2 becomes significant and worth investigating. In addition, the
elimination-by-aspects method may have its greatest usefulness in defining separable (strict-utility) models (problem 4) (21).

Problem 3: Measurement

Whether and how perceived values of attributes relate to physically measured values of attributes is the third scaling issue and has specific measurement implications. The question is not new. Transportation studies over the last 20 years confronted it, not very directly, when plotting perceived travel times from home-interview surveys against objective engineering estimates from skinned trees. The correlation was observed to be considerably less than 1. Some data have been collected specifically for the purpose of relating perceived and engineering estimates of the times and costs of travel (100). However, the problem generally has been ignored until recently when data at the individual traveler level used to estimate (disaggregate) models have shown poor results. Ignoring the issue can result in biased parameter estimates with aggregate models and nonsignificant parameters with disaggregate models. The issue can be ignored no longer.

The problem of measurement is a classic problem in psychophysics, the branch of experimental psychology that relates stimulus to sensation or, in more conventional transportation terminology, the physical measurement of the stimulus to the perceived magnitude. The Stevens power law (159), which relates the magnitude of the sensation to the magnitude of the stimulus, may have important ramifications for the mathematical form in which physically measured variables should be included in travel models. It already has been applied to travel forecasting (with as yet uncertain results) by Ewing (52).

In environmental psychology and the newer subfield of psychogeography, a substantial body of literature relevant to travel has been accumulated (48). For example, it has been found that spatial judgements are influenced by traverse time and the quality of that time. Orme (138) found that "if two parts of a journey are of equal distance, that part will generally seem greater which is traversed at a slower speed for a longer time." Filled time and active participation in complex activity (driving, for example) make time seem to pass faster and possibly at considerably lower behavioral cost or disutility. The converse may be expected to be true for passengers in cars or transit vehicles, particularly if they are not permitted (or not inclined) to read or engage in some form of activity or stimulation. Recent work with children (73) shows that we learn about the environment by active manipulation of it (for example, by driving rather than by being driven), which indicates some profoundly different consequences on residential-location and car-purchase decisions of travel time by different available modes. (Thus there is an overlapping with research problem 2.)

The measurement problem can be attributed, at least in part, to a lack of information on travel costs and opportunities as distance increases. Thus travel may decline with distance in the absence of any additional travel costs of distance. If information levels decrease with distance, then travel models may be falsely attributing declining travel interaction rates entirely to increased travel costs. Hanson (70) reports that "the set of known opportunities (the cognitive opportunity set) constitutes a rather limited proportion of the total opportunity set."

The measurement problem relates also to the question of how changes in the transportation system affect perceptions of the cost of movement. A better understanding of the measurement problem as an aspect of travel behavior could lead to an ability to organize transportation improvements in such a way as to transform the spatial pattern of travel demand in potentially more desirable ways for society.

Problems 4 and 5: Choice Structure

Problems 4 and 5 are the major choice-structure research problems. Are travel decisions decomposed into smaller decisions and, if so, how? Problem 4 relates to the
issue of separable choice, and problem 5 relates to the issue of possible independence among travel choices (and the mobility choices of problem 7). Quite different travel demand models can be derived analytically from or shown to be consistent with alternate behavioral assumptions on whether and how travel decisions are decomposed or partitioned into choice subsets between or within levels in the choice hierarchy shown in Figure 2 (21).

There are basically 3 levels of assumptions relating to the choice-structure issue. These are described in the context of the hierarchy of the short-run travel choices shown in Figure 2.

1. Simultaneous choice means that all attributes of the choice situation confronting the traveler are considered simultaneously. The complete trip is 1 decision. The relative valuation or relationships among the attributes are constant in any travel choice in the hierarchy shown in Figure 2. The hierarchy and the assumption could, of course, be extended to include longer term automobile-ownership and residential-location decisions.

2. In separability there is a set of travel decisions in which certain travel decisions are considered and may be modeled separately from other decisions. However, the relative valuation of choice attributes is constant in any complete travel decision (that is, any single path through the travel-decision tree shown in Figure 2).

3. In independence there is a set of travel decisions (choices) in which certain travel decisions are made independently of other decisions. Thus the relative valuation of choice attributes common to 2 or more travel choices is not likely to be the same in successive travel choices.

The first structure assumption is the simultaneous-choice assumption. The number of explanatory variables and the allowable interactions among variables that may be needed to explain (model) simultaneous travel behavior can multiply rapidly for realistic travel-choice situations in urban areas. The second and third assumptions restrict the attributes the traveler is assumed to evaluate in making his or her travel decision. Restricting the choices that are presumed available to the traveler is an appealing and popular way in which the complexity of travel demand models can be reduced. However, this involves making some important assumptions on the separability and possible independence of travel choices. The second assumption (separability) requires that the relative valuation of choice attributes be constant throughout the set of travel choices. Models of some subset of travel decisions can be calibrated based only on the subset of attributes describing those choices (33). The estimated utilities are then included in the models of the larger set of choices. Use is made of the separability property of strict-utility models derived from the independence of irrelevant alternatives axiom (110) under this recursive modeling method. Separability is a property (and therefore
a behavioral assumption) of all share models in use today including the gravity model and the logit model (21).

There is some uncertainty and disagreement in the field on whether and when the assumption of sequential behavior is a requirement for the previously mentioned method of estimating or applying recursively estimated models. One school of thought holds that, when utilities are preserved in later estimated models of a larger set of travel choices, the sequence is assumed that is implied by the order of the conditional statement used to determine the choice attributes input to the utility function. That is, if, in Figure 2, utilities are estimated for the modal-choice decision by using modal travel costs that are defined by, or conditioned on, destination choice [that is, $P[M|D]$], and these utilities are preserved later in models of the larger set of choices, then sequential behavior is a required assumption. However, the opposite view is that the sequential estimation of utilities implies no such sequential behavior assumption. According to this second school of thought, the method of inclusive prices is simply a first approximation to the utility function estimated simultaneously over all the travel choices, and no sequential behavior is assumed (47).

There is, however, no disagreement on the requirement that separability must be assumed when one estimates share models on a subset of the entire set of travel choices or when one forecasts to a set of choices (such as destinations) that is larger or is a different partitioning from the choice set used in model estimation. Separability (the property that the relative probability of choice between 2 alternatives is independent of the presence of third or additional alternatives) constitutes a strong behavioral assumption by itself. Travel choices must be defined that may be considered substitutable for each other and not special cases of each other, or the separability assumption will be too strong. For example, the results of a gravity model forecast (which presently assumes destination choice as being separate and independent from the remaining choices) are vitally dependent on which destinations are considered to be substitutable for each other and which are considered to be special cases of each other. In current practice, all destinations are considered simple substitutes for each other. This is clearly contrary to the previously stated finding that "the set of known opportunities... constitutes a rather limited proportion of the total opportunity set" (70). Modal-split and path-choice models make the same complete substitutability and perfect information assumptions. Rules for logically restricting choice sets could considerably simplify the mechanics of travel forecasting as well as greatly improve the accuracy of travel forecasts.

The third assumption is the current assumption of urban transportation planning models that sequentially and independently estimate the different travel choices with different valuations of the independent variables in each model. The assumption does not by itself place restrictions on choice ordering. For example, the place of modal split in the order of trip-choice decisions has been called "the most actively debated issue in modal split" (181). However, application of the models in different sequences results in different sets of travel predictions. Also the assumption does not necessarily restrict independently modeled choices to levels (such as mode) in the choice hierarchy shown in Figure 2. They could be sets of alternative complete travel decisions. The third assumption may not be rejected on any sequence assumption so much as on the requirement that, for utilities derived from separately modeled travel decisions to be considered additive, their component attributes must be neither substitutes nor complements (have no interaction terms) (112). That is, if the utilities are assumed to be, strictly speaking, additive and independent sets of attributes governing each separate travel choice, the choices may indeed be modeled separately and independently. For example, some would say that automobile manufacturers appear to have successfully separated consumption of the automobile from consumption of travel. That is, at least until the current concern with energy-supply limitations came about, the attributes governing car-purchase decisions may have overlapped only insignificantly with attributes governing travel decisions.

In fact, if travel choices may be modeled separately only if their attributes are neither substitutes nor complements to attributes in the utility functions of other separately modeled choices, then the whole discussion of separately modeling the usually defined choices (Figure 2) perhaps should give way to structuring travel choices for
modeling purposes by independent sets of choice-abstract attributes themselves (problem 2). If it can be demonstrated that travel choices are considered sequentially by travelers, the powerful evidence can be applied to support nonsimultaneous models of travel decisions. Three researchable hypotheses supporting sequential travel behavior have already been described (21):

1. Sequential choice ordering based on timing,
2. Sequential choice ordering based on adjustment time, and
3. Sequential choice ordering based on experience.

Other rationales for choice sequences no doubt also exist. There is considerable overlap here with the stochastic issue (problem 6) as well. That is, the results of research on problem 6 may provide considerable support for assuming certain kinds of choice structures under various circumstances.

The significance of the choice-structure issue is that considerable economies in time, money, and the use of existing skills and computer programs can be achieved if certain behavioral assumptions relating to travel-choice partitions can be shown to be acceptable under certain conditions. Also, to minimize some possibly grievous errors in application, the appropriate set of choices over which travel models should be applied in prediction is vitally dependent on an early resolution of this issue.

Problem 6: Learning

Problem 6 relates to the almost totally ignored possibility in transportation that travel patterns may be the manifestation of a series of conditioned behaviors and not simple behaviors stationary over time. Behaviorists, such as Skinner (152), would seriously question the integrity of anyone who thought otherwise. The basic truth of the "learning" hypothesis can hardly be questioned. Boulding (23) asserted that "a most serious defect" in transportation is to "assume simple preference or welfare functions on the one hand and opportunity functions on the other, without further inquiry and particularly without inquiring as to how these functions came into existence." Boulding accused most practitioners of believing in the "doctrine of the immaculate conception of the indifferent curve." He cited the well-established theory that,

as people communicate with each other, individual preferences and value systems tend to converge into something which might almost be called a common value system....Most people... are socialized into the society in which they grow up, accepting its preference structures and learning its technology.

Hartgen (74) reported that, "of all groups, the family is perhaps the most important in influencing individual behavior." Outside the household there are important differences in people's values, conditioned by the opportunities to which they have been exposed. On a very small scale, Wachs (176) found that "people's preferences for various route characteristics do vary, and the variations can be related to the characteristics of the people, their trips and the routes to which they have been exposed." On the urban scale, McMillan and Assael (123, 124) found that

people in the five rail mass transit cities (in the U.S.) placed a higher value on public transportation compared to people in the rest of the country. They held (relatively) less favorable attitudes toward the automobile both as a mode of transportation and in relation to the satisfaction of specific transportation and personal needs in terms of its social role.

Similar examples of differences in values and relative attitudes toward public and pri-
vate transportation between cities have been reported \((71, 101)\). Because of learning and conditioning, therefore, potential limitations exist on the complete transferability of even a behavioral travel demand model from one population to another. The major issue of problem 6, therefore, is not so much whether travel can be considered to be a set of conditioned behaviors but what conditioning theory can tell us about changes in the transportation system and other circumstances surrounding travel that are likely to produce changes in travel behavior. Research on this issue, although it may be difficult \((27)\), can be of great value in identifying attributes that influence travel choice \((the\ scaling\ problem)\ and in yielding evidence on the structure of choice \((as\ noted\ for\ problems\ 4\ and\ 5)\). However, more specifically, research on this question can identify specific nonlinearities in the effects of certain attributes \((threshold\ effects)\, variability\ or\ reliability\ from\ trip\ to\ trip\ in\ attributes\ \((effect\ of\ reward\ schedule)\, and\ changes\ in\ direction\ or\ change\ in\ the\ circumstances\ surrounding\ the\ travel.\ With\ regard\ to\ the\ last,\ Shaffer\ \((147)\ reported\ that,\ in\ the\ field\ of\ job\ and\ personnel\ research,\ it\ has\ been\ "demonstrated\ that\ job\ satisfaction\ is\ a\ function\ of\ the\ presence\ of\ variables\ different\ from\ those\ that\ are\ present\ in\ job\ dissatisfaction.\ ...\ Correction\ of\ the\ dissatisfying\ elements\ is\ not\ enough\ to\ produce\ satisfaction."\)

Support for the hypothesis that improvement in the travel-cost dimension \((dissatisfiers)\ achieves limited results in increasing mode usage was suggested by Rosinger et al. \((144)\):  

> It should be recognized that lists of negative attributes of transit do not necessarily imply appropriate positive actions. There may be better ways to generate demand than simply to concentrate on making transit 'unbad'... There is no a priori reason why transit might not develop its own set of positive attributes in comparison with the auto. Certainly such an approach is more likely to generate patronage than is an absence of negative orientation.

Unfortunately, it is not clear that transit currently has any of its own set of positive attributes \((such\ as\ attributes\ on\ which\ users\ score\ it\ higher\ than\ the\ automobile)\ \((83)\). Attitudes and behavior such as this appear to be explainable by the concepts of conditioning theory.

There are several concepts from learning and conditioning theory that provide fruitful approaches to research on problem 6.

1. In stimulus generalization, the traveler may generalize conditioned travel behavior even in different circumstances. For example, the car that was used to "find" the residential location \((active\ manipulation\ of\ space)\ continues to be used for the journey to work even though the utility of the trip by transit is greater than the utility by automobile.

2. In discrimination learning by contingencies, the traveler may learn to associate a different set of utilities with work trips than shopping trips and a different set with day trips than night trips.

3. In the reward schedule, the resistance to behavioral change by the traveler is a function of both quantity of rewards \((the\ utility\ set\ consists\ of\ time,\ cost,\ comfort,\ and\ the\ like)\ and the frequency and pattern with which rewards are administered. In general, partial rewards are more difficult to extinguish than full rewards; for example, some bad trips will not extinguish certain behavior.

4. Satisfaction generally results in a conservative bias in the system of choice. That is, over time, levels of aspiration tend to adjust to levels of achievement. \((The\ difference\ in\ levels\ is\ said\ to\ motivate\ search\ for\ new\ alternatives.)\ A new alternative may or may not change the traveler's perception of difference between current and possible \((future)\ alternative states if he or she changes travel behavior. The reward schedule will have an important effect.

The 2 primary objectives of research on problem 6 are whether and how to incorporate learning into travel models and to discover what conditioning can tell us about
travel behavior as it relates to all the other research questions (such as the formation of values governing travel-choice decisions in households, which is problem 7).

Problem 7: Decision Making by Large Behavioral Units

Problem 7 concerns how the circumstances of the household or other units affect travel behavior. Certain kinds of research questions relating to long-term household behavior and short-term travel behavior are similar. For example, just as short-term travel models may or may not assume that the marginal value of time and money is the same over the various travel choices (separability issue of problem 4), long-term models of household- and employment-location and car-purchase decisions may or may not assume the same marginal value of time and money for all categories of expenditures (including travel). And long-term choices may or may not be interdependent on each other or on short-term (travel) choices (problem 5) depending on the stimuli affecting those choices, their interactions, and their correlations.

It may be hypothesized that individual travel behavior results from the individual's perception of the quality of the transportation choices available to him or her that he or she evaluates in light of the requirements of a set of tasks or activities assigned by the household. It may be further postulated that these tasks are selected by the household through a decision process that considers the various needs of its members and the various alternative activities that may satisfy those needs and the constraints imposed by the cultural and financial circumstances of the household. The process may be said to have 3 components. First, through past experience, the individual selects alternative activities that satisfy his or her needs. Second, the activities and resources allocated to each household member are defined. Third, the elements of individual travel behavior are structured and performed to complete the assigned task.

Hartgen and Tanner (75) summed up the interplay of individuals and the groups to which they belong:

Each individual has associated with him a set of needs defined by the roles he assumes in his interaction with other persons and groups. Through experience, individuals and groups develop both awareness of and attitudes toward alternate courses of action that may satisfy needs. Through awareness, a person or group recognizes the existence of those particular actions offering some potential for satisfying needs.

Various categories of needs (such as physical, social, and psychological needs) exist, and the circumstances of the household will affect the awareness of and attitudes toward alternative courses of action to satisfy those needs. For example, physical and nonphysical characteristics of individuals and groups will have an effect on the formulation and perception of their needs (25, 116) and on the information levels that they have on alternative trip-end opportunities (17).

It can be hypothesized that the family decision-making process evaluates the activities preferred by its members along 2 dimensions: the importance of the need that the activity is intended to fulfill and the resources and opportunities available for the activity. The task of child rearing may be completed within the physical confines of the household. However, other tasks such as income earning normally are accomplished in other locations, which gives rise to travel.

In the context of household needs and allocation of scarce resources (time and money) each individual must make subsequent decisions for completion of his or her assigned tasks. It is hypothesized that he or she reviews these activities and resources in relation to his or her own needs and experiences and determines those tasks that will best satisfy both the household's and his or her personal requirements. He or she then arranges these activities in a sequence for completion.

This social psychology stream of research already has been the subject of reviews as it relates to travel and car-purchase decisions (76). A second stream of research
is the set of more purely economic investigations of household budgets, their changes over time, and their changes with respect to varying household circumstances, location in the metropolitan areas, and proximity to public transportation services. Such consumer budgeting studies at the household level, can be helpful in determining how changes in circumstances at the household level affect travel behavior.

A research approach that included household-level examination of problems 1 through 6 allows considerable perspective to be gained on the behavior of individual travelers. Households have sets of final demands and ways of accomplishing those final demands that are not available to individual travelers. The trade-offs within the household for time, money, and other resources are not visible and researchable at the individual-traveler level. Research on problem 7 can be expected to yield findings and insights that will be valuable both in terms of developing substantially new approaches to household-level travel modeling and in terms of clarifying issues and approaches to research on the scaling, structure, and learning questions.

CONCLUSIONS

Each of the 7 research problems is important in its own right, and all, of course, are interrelated. An improved understanding of travel behavior as articulated by each question can be a great help in efficient use of travel-forecasting models, and in appropriate selection of what forecasting model to use in the first place. Lack of knowledge of how travelers behave under different circumstances when confronted with high-versus low-capital-intensive transportation alternatives may be requiring the profession to always apply very complicated models. This has been called model overkill.

Four types of criteria are appropriate for evaluating alternative behavioral approaches to travel theory:

1. Travel behavior criteria ("truth");
2. Ability to incorporate behavior in a model;
3. Ability of the behavioral model to improve the accuracy of the conditional forecasts (policy and issue responsiveness); and
4. Planning process considerations (such as time, cost, data needs, and transparency).

The 4 types of criteria are divided into endogenous (item 1) and exogenous (items 2, 3, and 4) classes. Endogenous means evaluation on the basis of internally generated indicators. A travel demand model, like any model, is ultimately a subjective imitation of reality. Ultimately the modeler's understanding of behavior in the system of interest must be the starting point. Evaluating the "truth" endogenously means evaluating how well the theory incorporates the essential phenomena addressed in the first place. The 7 research problems represent 7 useful perspectives from which to evaluate endogenously the alternative behavioral approaches. It may be superfluous to indicate that each of the resulting 7 endogenous criteria incorporates the usual list of internal evaluation criteria such as adherence to theory, internal logic, reasonableness, conformance with prior knowledge, and the like. The remaining 3 types of criteria are essentially exogenous to the research questions. They are the wholly pragmatic considerations of the usefulness of incorporating alternative behaviors in models applied to relevant policy issues.

The second criterion (modeling ability) is important because only a limited number of tractable models that employ behaviorally different underlying assumptions for making operational alternative approaches to travel behavior appear to exist (10, 16, 21).

Three related issues are involved in the third criterion; they fall under the headings of accuracy, option responsiveness, and effects. Accuracy issues relate to the accuracy and the detail in space and time with which models implementing the behavioral assumptions can replicate and forecast travel. Option-responsiveness criteria are, of course, central to the concerns of travel forecasting and transportation planning. That is, for behavioral models to estimate travel and related consequences of trans-
portation options, variables (attributes) describing those options must be included in the set of stimuli influencing travel behavior (the scaling problem). However, option sensitivity is only 1 criterion. If the option truly does not affect travel, the model should not be abandoned or distorted in some way to make it policy responsive. Knowledge of such travel-behavior insensitivity will have important consequences in policy analysis and evaluation. Effect-related criteria are a third type of policy-responsiveness criteria. It is important to clearly draw the distinction between travel forecasting and forecasting other effects. However, insofar as improved forecasts of travel can lead, for example, to improved air quality forecasts, the effect criteria are important for evaluating alternative behavioral approaches to travel theory.

The fourth criterion for evaluating alternative behavioral approaches to travel theory is planning process considerations. The practicing transportation planner is confronted with a bewildering proliferation of travel forecasting models and an increasing array of transportation planning options on whose consequences he or she must provide information. The growing number of options and the growing involvement of citizens in planning are resulting in greatly increased information requirements for decision making, shrinking time available for travel forecasting and forecasting other than strictly travel consequences, and greatly increasing "transparency" requirements placed on technical transportation planning procedures. Travel forecasting is not standing up well to any of these new developments. Although the second and third types of criteria act to a certain extent as constraints on what behaviors can be modeled and what policy issues can be accurately addressed, it is on the basis of this fourth criterion that the decisions in the field are going to be made concerning which travel forecasting techniques will be used in particular planning situations. An initial list of types of process criteria might include:

1. Time requirements,
2. Cost requirements,
3. Forecastability of independent variables,
4. Transparency of the models,
5. Hardware (computing) requirements,
6. Skill requirements,
7. Universality of the modeled behavior (such as transferability over time and space),
8. Reproducibility of the forecasts,
9. Provision of intermediate output, and
10. Ease of aggregating or disaggregating output.

It is clear that considerable research on travel behavior and the application of behavioral travel models will be required before specific planning trade-offs between the basis in behavior (and thus the logic and plausibility of travel forecasts) and the time, money, and skills required to carry out the forecasts can be made. However, such trade-offs are made either knowingly or unknowingly each time a travel-forecasting technique is applied. The research approaches suggested in this paper are directed toward making these trade-offs from a more informed basis.

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REFERENCES

17. S. Bowlby. Spatial Variation in Consumer's Information Levels. Transportation Center, Northwestern Univ., Household Travel Behavior Rept. 4, 1972.


