CHAPTER 2

A Survey of Urban Travel Demand Models

2.1. Introduction

The historical development of urban transportation systems, with heavy reliance on the automobile traveling on a network of public roads, has induced a parallel development of theories and models of urban travel demand. These tools have been oriented toward problems of automobile traffic flow, and have emphasized the demographic and network determinants of travel demand rather than behavioral responses.

We shall not attempt in this survey to give a comprehensive picture of the technology and economics of urban transportation, or an exhaustive description of existing urban transportation planning models. Instead, we concentrate on ideas and techniques which are useful in formulating a disaggregated behavioral model of travel demand. The reader interested in a general introduction to the problems of urban transportation is referred to Meyer, Kain, and Wohl (1966) or Oi and Shuldiner (1962). We first give a capsule summary and critique of conventional urban transportation planning models, and then take up a series of issues whose analysis contributes to the development of behavioral models.

2.2. Conventional urban transportation planning models

There have been about 200 urban transportation planning studies, each differing somewhat in design and in detail. Because of this proliferation it is impossible to be completely accurate when generalizing about the conventional demand modeling approach. It is useful, however, to try to set out the main features of these models, even though there may be exceptions to almost any general statement made about them.

A number of authors have developed convenient summary descriptions of these models and there are several excellent discussions of their shortcomings. Our discussion borrows heavily from these works. Fertal et al. (1966) and Weiner (undated) provide excellent taxonomic descriptions of the conventional approaches to modeling urban travel demand and modal split. The shortcomings of these models are discussed in a number of sources; particularly useful are Stopher and Lisco (1970), Hartgen and Tanner (1970), Charles River Associates (1967), and Brand (1972).

The conventional models of urban travel demand separate the demand function into trip generation and attraction, trip distribution, modal split, and route assignment. The observations are zoned aggregates. The basic structure of these models is set out below in a manner similar to that used by Manheim (1970) to highlight the fundamental properties of such systems.

2.2.1. Trip generation: $N_i = f_1(SE_i)$

The number of trips leaving a zone i is typically modeled as a function of the socioeconomic characteristics of zone i. Transportation variables are typically not incorporated into this model, so by *assumption* the model asserts that trip frequency is totally independent of changes in the transportation system. The model is non-behavioral and non-causal since it does not represent the decisions faced by persons trying to decide how frequently to travel. As stated in the above equation, the model is also non-policy oriented since policy variables are not included in the model. It implies that no change to the system that policy officials make will have an effect on trip frequency. In an attempt to rectify this deficiency, some studies have included a general accessibility variable in the trip generation equations. However, because this variable measures the general accessibility of the given zone to every other zone in the area, rather than measuring the access to the destinations that are relevant for the particular zone, it tends to be a very clumsy means of introducing policy considerations into the equation.

2.2.2. Trip attraction: $N_j = f_2(E_j, LU_j)$

In this model, the number of trips terminating in any zone j is typically made a function of the characteristics of the zone, such as employment or a description of the land use in the zone. By leaving the transportation variables out of the equation, this model asserts that the accessibility of the zone has no effect on the total number of trips to the zone. Like the first, this model is not policy oriented, and it is mechanical rather than behavioral. It provides no means of measuring the effects of, for example, downtown parking charges or an improvement in transit service on the total number of downtown shopping trips. It asserts, by assumption, that such variables have no effect on the total number of downtown shopping trips.

2.2.3. *Distribution:* $N_{ij} = f_3(SE_i, E_j, T_{ij})$

This model, typically called the gravity model, distributes the predicted number of trips generated by each origin zone i to each destination zone j. The distribution is based on the relative attractiveness of zone j as measured by the trip attraction equations and the travel impedance T_{ij} between i and j. In principle, this model allows the matching of origins and destinations to be sensitive to travel times through the impedance variable. Because of the structure of the two preceding models, the distribution process is not allowed to change the total number of trips leaving a zone or going to a zone as a result of changes in the performance of the transportation system, but is only able to alter the allocation between zones.

In practice, the travel impedance factors are typically based only on auto travel so that changes in transit service frequently have no influence on predicted trip distribution. The full range of travel time and cost factors for all relevant modes of transportation is very seldom included in the impedance factor. Therefore, in practice, trip distribution is basically a mechanical allocative procedure in which the complex set of policy variables (modal cost and service variables) are typically represented by a simplified measure of auto impedance.

In fact, a more disturbing consideration is that the travel impedance mechanism is usually based on a fixed distribution of trip lengths (in minutes). As Brand (1972a) points out: "Trip distribution is modelled as a function of a simple distribution of the trip lengths which prevailed at the equilibrium between supply and demand in the base data file."

Thus, the distributive mechanism is descriptive rather than causal, and accordingly it will not accurately predict the trip distribution resulting from the new equilibrium conditions that would prevail if the transport system were changed.

2.2.4. *Modal split*

The modal split function probably varies more widely in practice than the previous elements of the urban transportation planning package. Descriptions of the conventional approaches to modeling urban modal split are given by Fertal et al. (1966) and Weiner (undated). In the more sophisticated urban transportation planning studies, modal split is modeled after trip distribution with a model of the following form:

$$\frac{N_{ij\,\mathrm{auto}}}{N_{ij\,\mathrm{transit}}} = f_4(T_{ij\,\mathrm{auto}},\ T_{ij\,\mathrm{transit}},\ SE_i,\ LU_j).$$

That is, the number of trips distributed between zonal pairs is allocated between auto and transit on the basis of relative travel times and costs between modes, and also, in some cases, on the basis of selected socio-economic characteristics of the origin zone and land use characteristics of the destination zone. The diversity of modes is usually ignored or handled by combining all modes into two dichotomous modes, transit and auto. This is the only model which is fundamentally behavioral and policy oriented. However, because it is tacked on to the end of a largely mechanical process, the policy variables are only able to change the split between modes. The total number of trips and the distribution between zones is already predetermined, largely without regard to the transportation system.

There are numerous other shortcomings to these models which limit practical usefulness. The estimation techniques are often very primitive, and very little thought is given to the functional form of the model. Furthermore, the models frequently include as explanatory variables descriptive information about zones (such as residential density) that is only indirectly related to relative travel times and costs, and they often either fail to include all the door-to-door components of travel time and cost, or aggregate them in ways that limit the applications of the model.

2.2.5. *Route assignment:* $N_{ija} = f_5$ *(minimum time path, capacity)*

This model assigns auto trips to highway routes based on minimum time paths and capacity constraints. Transit assignment is typically not modeled in smaller urban areas. This step is the closest these models come to an equilibration process, and it is not very close. The route assignment model in effect generates an auto impedence measure T_{ija} which could be fed back into the trip distribution and/or modal split models to provide some aspects of an equilibration process. In practice, however, this is usually not done. The feedback effect on trip generation and attraction cannot be estimated, even in principle, for models in which travel times are not included in the trip generation and attraction models. The only possibility for feedback is then on the land-use projections.

These models assign auto trips to routes on the basis of a minimum time path assumption. The fact that considerations other than in-vehicle time enter into the route choice are ignored. Again, the route assignment process is a largely mechanical procedure with little provision for interaction between the choice of route and the other demand decisions.

2.3. A critique of conventional models

From the preceding description of the conventional urban transportation planning travel demand model it can be seen that there are numerous faults and shortcomings in the conventional approach to modeling urban travel demand:

(1) The models are basically non-behavioral. They replicate the results of conditions existing at the time of the survey and provide little or no guidance to the effects on travel decisions of changes in travelers' circumstances or in the terms upon which they are offered competing alternatives in the transportation environment.

(2) Except for the modal choice function, the models are basically not policy oriented. The effects of the variables which policy-makers are able to control are excluded from the trip generation and attraction functions and applied very mechanically, and to a limited extent at best, in the trip distribution function. There is essentially no interaction between system performance and the choices of trip frequency or trip destination.

(3) The decision of time of day of travel is seldom, if ever, modeled.

(4) Equilibration is essentially ignored, except to the limited extent that auto route assignment models take account of capacity constraints in assigning routes.

(5) These models are based on data representing zonal aggregates of trips and socioeconomic conditions. This obscures much of the information in the data, and together with the lack of a behavioral structure, makes the models very difficult to generalize from city-to-city.

This review indicates that the overall demand model needs to be restructured. An approach is called for which makes the entire demand model behavioral and policy responsive. Moreover, the issues involved in using individual trip data in the empirical analysis should be identified and confronted not only for the choice of mode, but for all aspects of the travel demand decision process.

We now turn to the concepts in travel demand modeling which are useful in developing a behavioral theory. The discussion which follows is loosely grouped into three categories. These are: probabilistic models, chiefly value of time studies and probabilistic models of modal choice; direct demand models, principally those arising from the Northeast Corridor Study together with the work at Charles River Associates; and attitudinal studies, including both the discussion of analysis based on attitudinal data and the data itself.

2.4. Probabilistic models

This category of the literature consists of studies which attempt to model the probability of making a transportation choice. The studies are either directed to measuring the value of time as an input to benefit calculations or as a tool in analyzing the consumer's decision about choice of transportation mode, or they attempt to model the choice of mode behavior directly. We discuss both types of study.

This body of literature is of interest for two reasons. The first has to do with the methodology employed. Since disaggregated trip observations are binary (0,1) data rather than quantities of trips, as is the case with zonal aggregates, the natural method of analysis is a probabilistic or discriminant model of choice behavior. Thus, the methodologies employed in these studies are of interest. Second, the substantive findings are of value as a basis of comparison with the empirical results of our analysis.

In an important sense, however, all of these studies are of limited value for our purposes. The reason is that these studies examine only the probability of making a specific choice given that the traveler is making a trip. None of these studies addresses the basic question of whether or not to make a trip. Thus, they provide little guidance in predicting the *number* of people who will take a given mode (or make a specific choice). They predict, instead, the *percentage* of a predetermined market that will take a given mode.

The most important findings in this area have been based on empirical data taken from an analysis of the choice between a toll road and a free road for urban commuter travel. By observing the toll paid to achieve a corresponding reduction in travel time, the value of time is estimated. These research efforts have measured travel time by interviewing travelers to determine subjective time savings or by observing instrumented vehicles. These studies have also included the analysis of other impedance-causing factors, such as the number of stops, but have not established systematic effects for such factors.

The mathematical formulation underlying the model has typically been a binary logistic function, which can be expressed as:

$$P = \frac{1}{1 + \exp(\beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_K x_K)},$$

where P is the probability of taking the free road, x_1 is the net time saved by taking the toll road, x_2 is the cost saved on the toll road, and $x_3, \ldots, x_K$ are other motorist and route attributes. The parameters $\beta_1, \ldots, \beta_K$ are determined by the calibration process, with the value of time given by β_2/β_1. Partitioning the samples by income and considering a variety of cost measures allows some tests of cost perception and the dependence of the value of time on income.

Models based on instrumented vehicle data have generated values of time around $1.80 per hour, in 1969 dollars, whereas those based on reported data resulted in an average value near $3.80 per hour.

Lisco (1967) has estimated the value of commuters' travel time by analyzing data on the choice between taking the Skokie Swift and driving. He employed binary probit analysis which fits a cumulative normal distribution to the data. His model included measures of age, sex, income and family structure as well as the differences between transit and auto cost and travel time. His estimate of the value of time was $2.53 per hour for a commuter whose average wage rate was roughly twice that amount. He also estimated the value of automobile "comfort" from the constant term in the model to be about \$2.00 per day, and he found that the value of downtown walking time was about \$7.20 per hour.

In addition to these studies, there have been several British and one French study of the value of time in the commute to work. These studies all evaluated the choice between auto travel and transit.

Beesley (1965) has used a discriminant analysis to find the value of time which best explained observed modal choices of a sample of employees working in the British Ministry of Transport in London. His explanatory variables are door-to-door times and costs. The choices are all between private car on the one hand, and public transport—subway, suburban railway or bus—on the other. The values found were about a third of the (about 1964) British wage rate.

The Planning Department of the Greater London Council [Barnett and Sallmans (1967)] has carried out two discriminant analyses similar to Beesley's. The mode choices available, and the time and cost definitions used in the study were the same as Beesley's. Value of time appeared to be a designated proportion of employees' income: about 30 percent for those under \$1,000 per year, down to 15 percent for those earning \$2,000 per year and above (for 1964 British wage scales).

Quarmby (1967) uses Beesley's findings, along with his own, to formulate a model for determining the choice of travel mode for trips to work. Quarmby points out that it may be entirely reasonable to value walking time, waiting time and in-vehicle time differently. He points out that travel times, like costs, can be expressed in different ways. The ones considered are: overall and excess travel time differences, ratios, and logarithmic ratios. His models include in the modal split function only the choice between private auto and public transport for the journey to work.

The basic form of Quarmby's model was linear, with the values representing the overall utilities of various factors such as time and cost. Like the previously described studies, Quarmby also used discriminant analysis to calibrate the model. His best results were obtained using the model in which the time and cost variables were expressed as differences. He concluded that overall travel time difference, excess travel time difference, cost difference, and the possibility for using the car at work are all important in influencing modal choice. Quarmby found that walking and waiting times were worth between two and three times line-haul travel time. The value of line-haul time was estimated to be between 21 and 25 percent of the wage rate for a wide range of incomes. Quarmby's discussion of the mathematics of the discriminant function approach is well done and would be a useful reference for a researcher seeking to increase his knowledge of the technique.

Finally, a French study [Institute d'amenagement et d'urbanisme de la Region Parisienne (1963)] also carried out a full discriminant analysis to find good combinations of times, costs, and numbers of transfers which resulted in the same proportion of travelers to a particular destination using transit. The value of time was found to be about 53 percent of the average earnings rate. It was also found that waiting and walking times were worth about twice the line-haul travel time.

In summary, all of these studies are limited to binary choice behavior, and all deal with the journey to work. The estimates of the value of line-haul time range from 20 to 50 percent of the wage, while the estimated values of the non-line-haul components of trip time are about two to three times the value of line-haul time.

2.5. Probabilistic choice of mode studies

In our view, the most interesting and original of the probabilistic models of choice of transport modes are the binary choice model developed by Warner (1962), and the recent multinominal model of Rassam et al. (1971).

Warner's study was one of the first to employ stochastic or probabilistic models to analyze the choice of mode from individual trip observations. His study is limited to pairwise comparisons of alternatives; i.e., binary choice of mode. Both work and non-work trips are analyzed. Interestingly, his study used survey data from the 1956 Chicago Area Transit Survey (CATS) study for which the individual trip records were accessible and which explicitly questioned respondents on the mode actually taken and the best alternative means of transportation. Perceived door-to-door travel times and costs were also collected for both modes. These reported travel times and costs were used in Warner's empirical analysis. His results suggest that if transportation planners had read and understood his analysis when it was first available, and if the 1956 CATS data collection and preparation efforts had been emulated elsewhere, the analysis of choice of mode would be considerably advanced over its present state of development. Warner used a linear discriminant model to obtain initial estimates for a binary choice logit model, which he then estimated with nonlinear regression techniques. The logit model estimated expressed the log of the odds of choosing auto over a specific transit mode as a function of the log of the ratio of door-to-door reported travel times, the log of the ratio of door-to-door travel costs, the logs of several measures of household income and car ownership, and variables for age, sex and distance of the trip.

The parameter estimates were typically significant for all variables except age and distance and had the expected sign and plausible magnitudes. Warner describes the elasticity of choice formulas and computes the aggregate elasticities for his samples. He finds that for work trips both the aggregate price and time elasticities of auto choice are on the order of 0.2. The income elasticity is very low, about 0.03.

A more recent binary choice of mode model was estimated using San Francisco data by McGillivray (1967). His study is of interest primarily because he formally derives his modal choice model from consumer utility theory and shows the explicit relationships involved.

As mentioned earlier, the Warner model is limited to binary choice of mode. The study by Rassam et al. extends the logit models to analyses of the choice between multiple transportation alternatives. The specific application deals with the choice of access mode to airports in the Washington-Baltimore area, where four modes were available. The model was estimated both by maximum likelihood techniques and by constrained least squares regression. While the actual results are only of peripheral interest here, the authors report that the estimated parameters had the expected signs and relative magnitudes as well as low standard errors of estimates.

This study, like Warner's, concentrates on modal split, based on a predetermined number of trips. It goes beyond the Warner models in considering multinomial modal choice. Within the alternative choice framework there are two important methodological problems that the Rassam study does not consider. One is the treatment of different numbers of alternatives for different observations; the second is the treatment of "unranked" alternatives. An unranked alternative is one for which there may be no natural pairings from individual to individual. For example, one person's shopping destinations may have no natural pairing with another person's.

A more general approach to multinominal logit analysis, of which the Rassam model is essentialy a special case, has been developed in another context by one of the authors [McFadden (1968, 1973a)]. These papers extend the logit model to encompass these possibilities. In chapter 5, in the discussion of stochastic specification and estimation techniques, McFadden's results are drawn on to develop methods of handling multiple alternatives, unranked alternatives, and different numbers of alternatives from observation to observation.

In chapter 7, we show how these methods can be used to extend the models of choice behavior to the choice of trip destination and frequency and we illustrate the linking of separate choice decisions into an overall model of travel demand.

The recent literature on probabilistic demand models has both expanded the range of available methods and clarified the relationship of these models to disaggregated behavioral analysis. A survey by Reichman and Stopher (1971) gives a concise statement of the objectives of disaggregate behavioral demand modeling, and provides a quite complete bibliography of contributions made in this area through 1969. Talvitie (1972) has tested the functional forms of probabilistic modal choice models, examining both the shape of the response curve (e.g., logit vs. probit) and the specification of the independent variables (e.g., differences vs. ratios). Other applications have been made by Lave (1968), Moses et al. (1967), Wigner (1973), Watson (1972), Brand (1972b), and Ben-Akiva (1972).

2.6. *Direct demand models*

Unlike the urban transportation planning (UTP) models, in which the various aspects of the travel demand process are separated into individual submodels, there is another category of travel demand models—sometimes referred to as direct demand models—in which all the elements of generation, attraction, distribution between zones and modal choice are combined in a single demand model. Like the UTP models, these models are differentiated by purpose and typically employ as observations data on geographic aggregates.

Most of the direct travel demand models were developed in connection with the Northeast Corridor Project, and accordingly relate to intercity travel rather than urban travel. The most interesting of these models, in our view, are the Kraft–SARC model (1963), the Quandt–Baumol abstract mode model (1966), and the Blackburn model (1969). The only direct demand model of urban transportation in the extant literature is the Charles River Associates Bay Toll model (1967).

This class of models uses as the unit of observation the number of (round) trips observed, by purpose and by mode, between zonal (or city) pairs. Thus, it obviates the trip distribution model and separate modal split models. As explanatory variables, these models use measures of the socioeconomic characteristics of the origin zone, measures of the attractiveness of the destination zone, and measures of the performance of the competing transportation alternatives. Since the number of trips by mode is a function of the times and costs of both the mode being modeled and the competing modes, the model measures the effects of changes in the transportation system on both the total number of trips and the diversions between modes. In these models then, both the total number of trips and the allocations to modes are responsive to policy variables.

All of these models are based on aggregated data giving quantities of trips, whereas one of the basic purposes of this study is to develop disaggregated models of travel demand. Thus, these studies provide only limited guidance on a number of the important measurement and specification problems involved in developing disaggregated models of travel behavior. Nevertheless, each of these models contributes interesting and useful ideas to the analysis of travel demand.

The Kraft–SARC Northeast Corridor model was the first of these direct travel demand models to be developed. In addition to socioeconomic and attraction variables, it employs, as explanatory variables in the model for each mode, the travel times and costs of all the modes being considered. In this way it measures the direct and cross-modal effects of each attribute of each mode on travel between each city pair in the sample. Because of problems of collinearity resulting from the inclusion of transportation variables for all the modes in the system, the parameters of the model were estimated by constrained regression analysis.

The so-called abstract mode model designed by Quandt–Baumol (or attribute mode model as the authors now prefer to call it) is an intriguing idea for dealing with the introduction of a new mode. Unlike the Kraft–SARC model, in which mode-specific variables were used, it attempts to characterize modes in terms of generic attributes. This approach is intuitively appealing and, in fact, only insofar as travel alternatives can be expressed in generic terms, rather than in mode-specific terms, can parameter estimates from existing modes be used to predict the effects of a new mode. In spite of its intuitive appeal, however, the formulation of the Quandt–Baumol abstract mode model has some inherent shortcomings. The model is formulated not in terms of the attributes of all the modes in the system (as was the case in the Kraft–SARC model), but rather in terms of the attributes of the mode being considered relative to the attributes of the "best" available mode. As a result, a change in any mode other than the best mode is not allowed to affect the demand for the mode being considered. A more useful formulation is one in which the attributes of all competing modes are allowed to affect the demand for each mode.

The model designed by Blackburn is closely allied in theoretical concept to the approach developed in this study. Blackburn starts by considering a model of individual choice between alternative ways of traveling and alternative numbers of trips. He then aggregates over individual demand functions to get an aggregate model of passenger demand for estimation purposes. He needs an aggregate model for estimation because his data are aggregative. Unfortunately, he is forced to place restrictive assumptions on the model of individual behavior in order to make the aggregation tractable. Most of his analytical efforts are then devoted to aggregation issues, which are of no relevance here. Similarly, the estimation procedures he employs, based on the need to use aggregate data, are of only peripheral interest, since the objective of this study is to develop disaggregated models of travel demand.

Blackburn develops a measure of the inclusive price of a trip in which the marginal rates of substitution between money costs of travel and non-money trip attributes are invariant with respect to the amount the individual travels. We also employ this procedure (see chapters 4 and 7) to simplify the empirical analysis. However, because of aggregation problems, Blackburn assumes that modes, characterized in terms of inclusive prices, are perfect substitutes, so that the individual always selects the cheapest mode (defined in terms of the lowest inclusive price). We allow a more general treatment of substitutes, in which travel options need not be perfect substitutes.

The Charles River Associates urban direct demand model is an outgrowth of the Kraft–SARC intercity model. It essentially applies the same general model structure to urban travel analysis. The model expresses the number of directed round trips between any zonal pair, for a given purpose and mode, as a function of the number of individuals (or households) in the origin zone and their socioeconomic characteristics, the appropriate measure of level of activity and other relevant socioeconomic and land-use characteristics in the destination zone, together with the round trip travel times and costs of the subject mode as well as those of competing modes.

The dependent variable is the interzonal round trip. As mentioned earlier, this obviates the need for separate trip generation, attraction, and distribution models. Moreover, all the choices of trip frequency, choice of destination, and selection of mode are sensitive to the performance of each of the modes. The round trip is analyzed on the assumption that the time and cost conditions on both legs of the trip are considered by the traveler in making his trip decisions. Moreover, it is clear that the return trip selection of mode usually depends strongly on the modal choice made for the outbound trip, and the destination of the return trip usually depends on the origin of the outbound trip.

The choice of when to travel (i.e., which hour of the day) was not included in the model. Another shortcoming is that although the model theoretically allows for consideration of a number of transit modes, in its actual estimation all transit modes were aggregated into a single heterogeneous mode. Thus only two modes were considered, auto and transit.

2.7. Attitudinal studies

The attitudinal studies provide an extensive source of data on the relative importance of transportation attributes and on the attributes perceived as discriminating between alternative modes. However, there are several significant problems hindering the usefulness of these data. Chief among these is that the respondents' evaluations of attributes are affected by the service levels of the transport system, which are not normally measured in the studies. As Wallace (1969) states: "One area which still needs considerable research... is that of determining the relationship between attribute satisfaction ratings and the level of attributes."

Without knowing what the respondents are evaluating, it is difficult to make use of their responses, except as a means of suggesting explanatory variables to be included in the demand models. It is not possible from these data to predict the effects of changes in the transportation system in a given area because the original levels of service on which the evaluations are based are not given.

Another difficulty arises from an even more fundamental source. Briefly, should you believe what someone says or what he does? Virtually all modern economic analysis is based on the concept of revealed preferences; that is, a person's preferences are inferred from his actual choices when confronted with a range of alternatives in the market place. The evaluation of attributes is inferred from what individuals do rather than what they say. This impresses us as a much more reliable guide to measuring choice behavior.

The question of the reliability of attitude measures as predictors of behavior is particularly critical when models assume an underlying causal relationship going from attitudes to behavior. Cognitive behavior theories in psychology suggest that there is causality in the reverse direction; i.e., attitudes are adjusted ex post to be consonant with observed choices. There is clearly a reverse effect at least to the extent that individual responses to attitude items are likely to reflect the degree of familiarity with the attribute being examined. Thus, for example, auto commuters may respond differently than rail commuters to items regarding the unpleasantness of traffic jams or the safety of freeway driving. This might occur not because mode choice is a result of selection within the population of individuals with different innate tastes or attitudes with respect to these attributes, but rather because auto commuters are more sensitized to these attributes due to experience. The true picture probably lies between the extremes stated above, with short-run travel demand behavior influenced by attitudes, and attitudes conditioned in the long run by the objective attributes of alternatives and the experiences of the individual. This suggests that attitudes toward transportation alternatives would best be studied in a simultaneous model of attitude formation and behavior, and that simple models predicated on a one-way causality from attitudes to behavior may give spurious and misleading forecasts of demand.

Finally, in most of these studies the attitudinal data are limited to alternative modes of travel. Data for analyzing choice of trip destination or time of day as a function of transportation attributes are lacking. While there are occasionally data which refer to trip frequency, the question usually asked is whether the person would take more or fewer trips if some attribute were changed. Again, it is impossible to derive from this information an estimate of how many more trips would be taken, which is what is needed for planning.

An excellent summary of the data results of attitudinal surveys, as well as a description of the analytical efforts to employ these data in attitudinal models, is presented by Hartgen and Tanner (1970b). The most important finding in the attitudinal data seems to be the relative importance of reliability in evaluating modal attributes. For example, the ranking of the 33 individual attributes investigated in a Maryland study for work trips (the most extensive of these surveys) shows that of the ten most important attributes, four relate to safety and reliability, four relate to shortest time, and two to comfort and convenience. Significantly, three of the four most important attributes scored at or near the top in attribute satisfaction ratings as well. All of these three attributes are measures of reliability. The relative importance of reliability is consistently reported in the different attitudinal surveys.