CHAPTER 1

The Scope and Objectives of Urban Travel Demand Analysis

1.1. Introduction

The life of a metropolis depends upon its transportation system, and a healthy urban economy requires that transport be smooth and efficient. The automobile-centered, unplanned travel networks of today are proving increasingly inefficient as urban activity and congestion grow. Further, the costs of continuing to support automobile-based transport systems are forbidding, in terms of space absorbed for highways, energy requirements, and ecological consequences.

Aware of these factors, most metropolitan areas are moving to coordinate and streamline their transport systems, and to provide mass transit alternatives to the automobile. These shifts have required urban transportation planners to forecast accurately the response of transportation demand to changes in the attributes of the transport system. Traditional urban transportation planning models, developed primarily to forecast the effect of long-run changes in population demography on travel demand in a static transportation system, have proved poorly suited and unreliable in providing answers to the policy questions facing planners.

In this book, we develop a theory of urban travel demand which is specifically directed to the analysis of urban transportation policy. Four questions formed our starting point: What is the scope of travel demand? What are the objectives of travel demand analysis? What behavior underlies travel demand, and how does it respond to changes in the attributes of the transport system? How can one obtain, from a knowledge of behavior, the system-wide implications of changes in transportation policy? The following sections of this chapter discuss these questions and the methods of analysis and specific models we propose as an answer.

1.2. Travel demand

The subject of urban transportation is concerned with the movement of goods and people in a metropolitan area, and with the supply and demand for transport facilities. In this book, we shall concentrate on the demand for personal transport facilities by individuals. Each consumer makes a complex set of decisions based on his needs and environment. These include purpose, frequency, timing, destination, and mode of trips. Further, these decisions must be analyzed in the context of the intertemporal behavior of the consumer, and long-run decisions on home and work location and on automobile ownership. Finally, since travel is a concomitant of consumption activities such as work, shopping, and recreation, the theory of travel demand must take into account the demand for these activities.

The bulk of the research in travel demand analysis has concentrated on the determinants of mode choice, assuming that frequency, timing, and destination of trips are demographically determined. However, from the standpoint of the individual decision-maker, all these aspects of the travel decision are interrelated. For example, a reduction in travel time by bus to one destination may induce a shift not only in mode, but also in destination and frequency of travel for this individual.

1.3. The objectives of urban travel demand analysis

Transportation planners are focusing more and more attention on the development and improvement of public transit as an alternative to be explored and evaluated in alleviating various urban transportation problems. Transit and auto can often be regarded as differentiated but competing products in a single transportation market. Selected improvements to the transit system might therefore divert enough persons from auto to transit to reduce highway traffic congestion and parking problems significantly. The need for urban highway construction, with its potential social disruptions, might be reduced accordingly.

Yet the transportation analyst finds himself inadequately equipped to evaluate the proposals for public transit improvements which are suggested. As a result, the planner cannot determine with any reasonable certainty how many riders would use the transit systems if a given transit proposal were implemented, nor can he realistically forecast the diversion of auto riders to transit. Consequently, he cannot evaluate the effects of alternative technologies or service improvements on transit ridership and revenues, auto congestion, parking requirements, and so forth.

The shortcomings in the conventional urban transportation planning models go well beyond the lack of satisfactory models for analyzing transit demand, however. The very nature of urban transportation planning models makes them largely ineffective in appraising the effects of changes in either the highway or the transit system on the volume of travel on the system or its distribution between modes or destinations.

There is a need to develop models of urban travel demand which can satisfy the end objectives of transportation planning: (1) The "fine tuning" of existing public transit and transit-related tax policy by adjusting fares, headways, feeder service, tolls, etc. within given budget constraints to maximize social benefit. (2) The estimation of benefits for alternative designs of new transit systems. (3) Simulation of the urban economy and projection of long-term transport needs. These objectives require demand models that are sensitive to transportation policy and that depend explicitly on policy variables, so that the effects of policy alternatives can be forecast.

The ability of a travel demand model to forecast correctly the effects of policy changes requires that it be *causal*, establishing the behavioral link between the attributes of the transportation system and the decisions of the individual. This leads us to the investigation of *behavioral* models of individual travel demand.

From the standpoint of the urban transportation planner, there are several additional criteria a demand model should meet in order to be a practical tool for policy analysis. First, it should be *flexible*, allowing application to a variety of planning problems without major data collection and calibration costs. Second, it should be *transferable* from one urban setting to another, allowing reuse without expensive re-estimation in each setting. Third, it should be *efficient*, in terms of providing maximum forecasting accuracy per dollar spent on data collection. This requires that estimation of the model be parsimonious in the use of data, and that statistical methodology be efficient.

1.4. The behavioral approach

The first, and perhaps principal requirement of a model for forecasting the consequences of transportation system changes is that the model be behavioral. The term behavioral is interpreted differently by different investigators. Some persons classify a model as behavioral if a given statistical technique is used in estimating its parameters. Others imply that only a model which is based on attitudinal survey data is behavioral. In our terminology, whether a model is behavioral is not determined by either the statistical estimation techniques or the type of data on which the model is based; we define a behavioral model as one which *represents the decisions that consumers make when confronted with alternative choices.*

The traveler must decide whether to make a trip, where and when to go, which route to take, and which mode to select. He makes these decisions based on his needs, his particular income circumstances, occupation, car ownership, etc., and on the terms upon which the different travel choices are offered to him—that is, the travel times, costs, and service levels of the competing alternatives. These competing alternatives can be different modes of transportation, different times of day of travel, or competing destinations. The competing alternatives also include the option of traveling less frequently. As the time and cost of shopping, for example, increase, the household may find that it plans its shopping trips more carefully and makes fewer such trips as a result.

In other words, the model must attempt to describe the *causal* relationships between socioeconomic and transport system characteristics, on the one hand, and trip-making on the other. It is necessary for the model to explain *why* travel decisions vary as conditions change. Unless this is done it is not possible to anticipate how the traveler will behave if his individual circumstances change or the terms upon which the competing alternatives are offered to him change. In short, only by explaining the causal relationships can the model be used to forecast the effects of future changes in the performance of the transportation system. Otherwise, the model will simply replicate the effects of the transportation system that existed when the model was originally calibrated.

If the model is truly behavioral, its parameters should reflect the motivations of people in general, rather than the characteristics of the individual cities from which the data used to calibrate the model were drawn. This is a very important factor because it suggests the possibility that a few carefully structured and estimated models might be applicable to a wide range of situations in different cities. If such models were developed, the need for extensive home interview surveys and calibration exercises for each individual city undertaking a comprehensive transportation study would be precluded.

1.5. Policy sensitive models

A good model of travel demand should be responsive to policy questions. While this seems obvious, far too often demand models are developed which fail to contain the variables that policy-makers are able to control. Because there are a wide variety of transportation planning situations, a set of models may be appropriate, with each model being applicable to a different planning or operating situation. Such situations can range from the large, highly complex regional transportation investment studies that test alternative transport systems made up of many modes and modal combinations, to the smaller, though still complex, fine-level planning studies that involve changes in one mode operating in a simple network.

Typical regional-level policy questions that the planner would like to be able to address with the model are the following: What effect will increases in population, personal income, and car ownership have on travel demand and, consequently, on future congestion on each travel mode? What effect would changes in travel time or cost have on total travel demand and on the demand for the various modes? To what extent would selective changes in travel times or costs divert travelers from peak to off-peak travel times? What effect would changes in the spatial distribution of homes, jobs, and retail establishments have on future traffic flows? To what extent can the distribution of trips be altered by changes in the transit system? Examples of the more fine-grained policy variables concern costs such as auto out-of-pocket costs, fares, parking charges, and toll fees. Other questions are whether transfer or access times are more onerous to transit users than in-vehicle line-haul times, and whether savings in costs are more important to travelers than savings in time.

The service afforded by transit systems can be altered by varying the vehicle seating capacity, use of exclusive bus lanes, interchange spacing on busways, fringe parking, train lengths, speed, schedule frequency, etc.

On a broader scale, the overall system coverage and the different modal combinations are matters open for consideration, and each possibility affords different service characteristics and systems effects.

Alternatively, the scale and distribution of benefits and costs can be altered significantly by making use of different pricing mechanisms to include direct user charges (highway tolls or transit fares), broader types of user charges (gasoline taxation), and direct subsidy from general tax sources or funds.

Thus there is a need for a method of projecting travel demand under a variety of different assumptions about price, speed, frequency and convenience of service, etc. of the different modes in the transportation system. Also, in view of the interest and resources being devoted to the development and implementation of new technologies and systems for public transportation, it is important that the demand model be structured, if at all possible, in a manner that allows the incorporation of new methods of travel.

1.6. Transportation system attributes and travel demand decisions

As we mentioned before, the traveler decides where and when to go, which mode to use, and how frequently to travel. It is the consideration of this full range of trip decisions which distinguishes the travel demand study from studies of the division of demand among alternative modes (modal split). Each of these decisions is affected by the times and costs of travel for the available alternatives as well as by the tastes of the traveler and his socioeconomic circumstances, and a given change in the transportation system is likely to affect all of these decisions. For example, an increase in downtown parking charges may shift some downtown shoppers to transit, it may reorient some persons to other shopping areas, and it may reduce the total frequency of shopping trips, as a result of some downtown shopping trips being planned more carefully. Further, if selective changes (such as lower off-peak transit fares) are made to reduce travel times or costs for off-peak shopping hours, it may lead some travelers to shift their trip from one time of day to another.

Since each of these decisions is affected to some extent by changes in the transport system, the travel demand model should be structured so that the effects of the travel time and cost variables can be traced through the entire travel decision process. Each of the travel decisions should be responsive to changes in these policy variables, and the individual parts of the demand model should fit together into a coherent whole.

1.7. Diversity of modes in the modal choice decision

It is important to recognize that modal choice is not a problem of reflecting travelers' choices between two simple dichotomous modes; the choice is not simply "transit vs. auto". Both transit and auto are heterogeneous categories encompassing a variety of travel modes. For transit, there are not only the primary transit modes—bus, rail, taxi, etc.—but also the various line-haul and access mode combinations, including automobile access (drive auto to transit station and park ("park-ride") or be driven to transit station and dropped off ("kiss-ride")). Consequently, the range of transit modal choices and combinations can be very great, particularly in cities with commuter rail and rail rapid transit in addition to bus, express bus, and taxi. There is also a range of mode "choices" for auto. The possibilities range from driving alone, to car pooling with one to five others, and the auto passengers may be from the same or from different households. These options are further expanded by the variety of auto types and the various combinations of parking and walking circumstances. In structuring the demand model it is necessary to give careful attention to the specification of the auto, as well as the transit modal combinations, in order to represent correctly the competition between modes.[1]

1.8. Time of day of travel

It seems evident that treatment of modal choice should be closely tied to people's time-of-day preferences and to the peak and off-peak travel conditions as they influence these preferences. Allowing for these considerations may eventually permit the analyst to provide more reliable information on the effects of changes in transit systems (or private automobile and highway systems) on diversions from one hour of travel to another. (This is the so-called "shifting peak problem".) Associated with

[1] In the empirical work in this study, the choice of modes was explicitly limited to auto drivers driving alone, and bus (and in some cases streetcar) riders who walked to and from the station.

this aspect of model development is the introduction of a "schedule delay" variable, that is, a variable which measures the difference between one's actual and preferred arrival time at his destination.

Because travel times are frequently unavailable for off-peak hours, it may be difficult in this study to calibrate satisfactorily a model which measures the diversion of trips from peak to off-peak in response to changes in peak hour congestion. However, because of its potential usefulness to planners, it is important to give attention to this phenomenon and the interrelationships between time-of-day decisions and modal choice decisions in developing the theoretical structure of the model.

1.9. Trip destination

For non-work trips, competing destinations are likely to be much closer substitutes for one another than competing modes of transportation. Thus, changes in the transportation policy variables designed to change the performance of a given mode may have little impact on the competing mode of transport, but may substantially affect the distribution of trips between competing destinations. For example, a tax on downtown parking may divert far fewer travelers from auto to transit than from downtown to competing shopping locations. These considerations should be reflected in the model structure by enabling the effects of changes in modal attributes to be incorporated in the choice of destination decision.

1.10. Trip frequency

The changes in the performance of any of the modes may substantially change the total number of trips, particularly non-work trips, made per day. Improvements in travel times or reductions in parking charges or transit fares may induce a greater frequency of trips. The opposite may inhibit trip frequency by causing travelers to forego altogether some trips (such as those made for social or recreational purposes), or to plan those they do undertake more carefully so as to reduce the number of trips they make. Again, the effects of changes in modal performance on travel frequencies may exceed the effects on choice of mode for some trip purposes.

1.11. Location and mode availability

In the short run, a few months to a year, the travel decisions of an individual are constrained by fixed residential location, workplace, automobile ownership or availability, and the availability of various modes at the residential location. However, from the viewpoint of the lifetime consumption decisions of the individual, factors such as location and automobile ownership are also decision variables. Furthermore, the attributes of the transportation system may influence these decisions. For example, curtailment of transit service might force an individual to purchase an automobile to commute to work, find a job nearer his home, or move to a location more convenient to his workplace. The introduction of a new rapid transit line may induce individuals to relocate near its suburban stations and seek jobs near its central business district stations.

Urban planning has traditionally treated travel demand and land use as independent phenomena, at least in the sense that there is no feedback from one to the other. Consequently, it has been impossible to provide fully consistent forecasts of the effects of transportation policy on land use and location, and on travel demand, taking into account the effects of changing location.

There is no barrier, in principle, to incorporating individual decisions on residence and work location and on auto ownership in an overall behavioral model on choice among consumer activities; the models developed in this book have in fact been applied successfully in several studies of residential location which take into account transportation system attributes. However, in practice, it is difficult to construct data sets which would be adequate for the estimation of a simultaneous model of the location and travel decisions. This is due to the fact that location choice is a long-run decision which can be studied only by observing a panel of individuals over an extended period or attempting to draw inferences from successive cross-sections of unrelated individuals. The requirements of such data collection efforts often conflict with the data specifications for estimation of a behavioral travel demand model, where one needs only a single observation period, but detailed observations on transportation environment and choice.

We have not attempted to incorporate auto ownership and location decisions as part of the travel demand theory analyzed in this book. For many short-run planning purposes, these factors are effectively fixed, and our models provide satisfactory forecasts. Long-run policy questions may require an obvious extension of the theory developed here to incorporate these decisions.

1.12. Attitudinal versus behavioral models

A dimension on which decisions must be made in modeling travel demand is the emphasis on attitudes versus behavior, and on subjective perceptions and intentions of the individual versus objective measurements and observed choices. Since the end objective of policy-oriented demand forecasting is to predict *behavior* with minimal data requirements, the ideal model would be one which utilizes only readily obtained objective measurements and does not require field measurement of attitudes. On the other hand, it is also important to assess empirically whether attitudes and attitude formation contribute causally to behavior, and whether differences between subjective and objective variables themselves reflect attitudes which influence behavior.

The interest in attitude variables from the standpoint of transportation policy analysis lies primarily in the question of whether planners can influence behavior by campaigns to modify attitudes. A demand model with explanatory attitude variables is not useful in answering this question unless the mechanism for the action of public relations programs on these attitudes can be discovered. In the latter case, one may well be able to bypass the measurement of attitudes entirely, and concentrate directly on the relation between publicity campaigns and behavior.

This approach treats the individual as a "black box", and ignores the internal mechanisms which intermediate the environment and behavior. Alternately, one may wish to develop models of the simultaneous processes of attitude formation and modification of travel behavior. For example, travel behavior may generate experience which leads to modification of attitudes and perceptions, and these changes in turn may lead to changes in behavior. If attitude modification is in fact a slow process in time, the transportation planner may be unable to provide the corresponding series of data necessary to calibrate purely objective models. In this case, attitude measurements may provide a summary of the "state" of the individual at each time, allowing one to forecast his behavior without specifying in detail his travel history. However, it is again true that to make such models fully utilizable in policy analysis, it is necessary to determine the long-run relationship between policy variables and the "state" of the individual's attitudes.

This account of the role of attitudes in demand forecasting has ignored a class of problems in which the attitudes themselves become variables to be explained as an end objective. Such problems are of great interest in investigation of the psychological aspects of decision-making. However, their relevance to transportation planning is limited to non-behavioral questions such as the level of social satisfaction with the transportation system. Except for the case in which a link is established from attitudes to behavior, these models are not useful in forecasting actual travel demand after policy changes.

1.13. Aggregated data versus individual observations

In developing a behavioral model of urban travel demand, it is most useful to begin with consideration of the individual. Although we are concerned with aggregates of people, their behavior can probably best be understood by considering the behavior of individual travelers. We would like to know (and be able to model) the real decisions the individual faces in his travel behavior, and the factors which influence these decisions. These behavioral factors and their appropriate use in modeling the actual choices confronting the potential transit traveler have been described above.

There are other very important reasons which make dealing with individual travelers attractive. These reasons concern the composition and, ultimately, the size of the data sample used to calibrate the model. In developing a mathematical model of travel demand, the analyst is attempting to explain the differences in observed travel behavior. The more differences he is able to examine and explain, the more confidence he can have in his results; for this reason large samples are desired. However, when household observations are aggregated into origin zones, as is the customary process, the number of observations available to be analyzed and the variability within the sample are seriously reduced.

Recent research by members of the Federal Highway Administration showed that in one instance approximately 80 percent of the variability in socioeconomic characteristics of households occurred within traffic zones, and only 20 percent occurred between zones [Fleet and Robertson (1968)]. Hence by aggregating households into zones, much of the information contained in the sample is lost. At the same time, aggregation to zones may cause the number of observations available for analysis to drop from many thousand to a few hundred, not so much because there are only a few zonal pairs (on the contrary, there are many) but because there are no trips exchanged between the bulk of the possible pairs. This is particularly true for transit trips because the system may provide only limited coverage of the urban area. Thus aggregation obscures much of the large sample. It is important to recognize that the analysis depends on the number of different observations available for analysis, not merely on the number of people interviewed. The sample rate is really meaningless when the observations are aggregated into a small number of zones.

It would therefore be useful to design an urban travel model based on samples of individual observations, because such a model might make it possible to reduce the size of the household survey sample substantially, while increasing both the number of observations for analysis and the accuracy of the information contained in each observation. This could result in a very sizeable reduction in the cost of data collection, a large cost item in transportation studies. This result of disaggregation, together with behavioral models' potentially greater degree of transferability between cities, should have a considerable impact on data collection procedures for transit planning, as well as for urban transportation studies more generally.

Once a behavioral travel demand model has been calibrated on individual observations, the computation of aggregate travel demand can be accomplished by direct aggregation over values of the explanatory variables for a representative sample. For example, if the modal split between auto and transit is found to be a function of the relative travel time, then summing the modal split frequencies over a representative sample of travel time differences provides an aggregate modal split measure. Alternately, statistical procedures may be applicable which allow one to carry out the aggregation process algebraically or by numerical analysis. A more detailed discussion of the issues of aggregation and disaggregation has been given by McFadden and Reid (1974).

1.14. Equilibration

If the travel demand function is structured so that all of the decisions incorporated within it are allowed to be responsive to the performance of the transportation system, then provisions must be made to equilibrate demand and the performance of the transport system to estimate properly the effects of changes in the transportation system on trip interchanges. It is not the purpose of this study to analyze or develop equilibration procedures, but the implications of a policy-sensitive demand model on other modeling requirements should be noted.

Fig. 1.1 provides an illustration of equilibration which will be useful in this discussion. It shows a demand function, *DD*, which relates travel time on a corridor to the number of trips in the corridor. Its negative slope implies that as travel time decreases, the volume of trips increases. The curve S_1S_1 illustrates the relationship between the performance of the transport system in the corridor and the volume of traffic. Its positive slope indicates that as volume increases, speeds drop and travel time

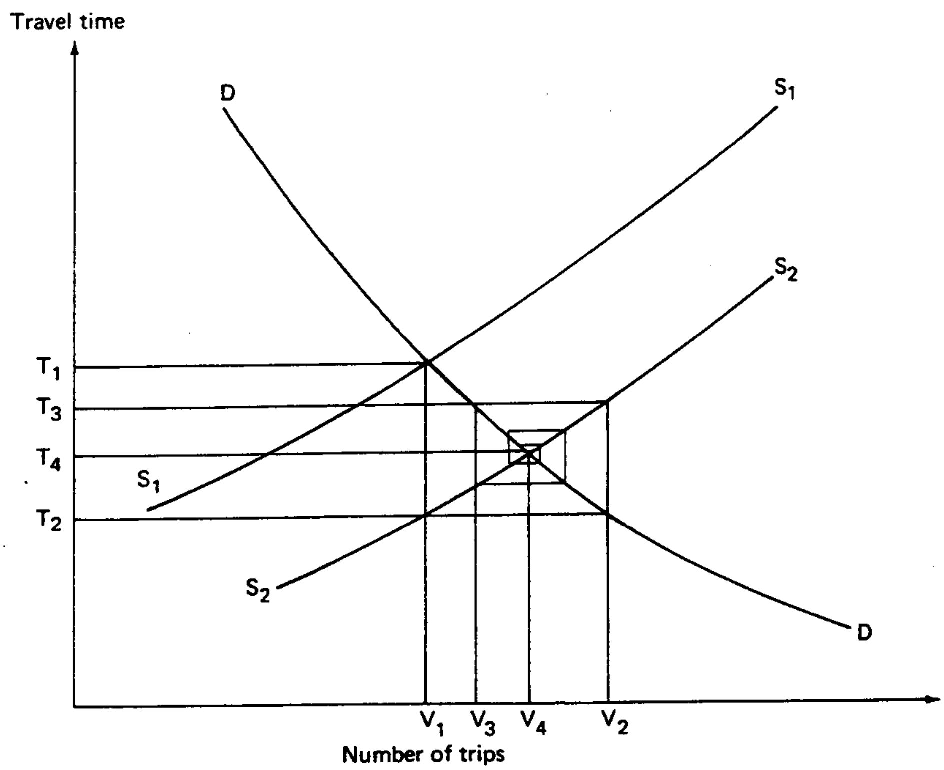

Fig. 1.1. Equilibration of travel demand and system performance.

increases. The curve S_2S_2 shows the same relationship but assumes that the capacity of the system is larger, and therefore that the system is able to handle more volume at a given speed, or alternatively, provide greater speeds for a given volume of traffic than the system represented by S_1S_1.

Now suppose the curve S_1S_1 represents the existing system, and an increase in capacity to S_2S_2 is being considered. With the existing system, the number of trips being generated is V_1 and they are being served at T_1 travel time. To design the system properly and to project its impact for evaluation purposes, estimates are needed of the volume of travel on the expanded facility and the expected performance (speed) on the facility. One means of appraising the effect of the new facility on system performance would be to assume that the number of trips remains constant at V_1 and then determine the new travel times for that volume of traffic. From the figure, this can be seen to be T_2.

However, this appraisal would clearly be unrealistic, because at an average travel time of T_2, the number of trips demanded would be V_2, and from the figure it can be seen that V_2 trips cannot be served at T_2 travel time. If V_2 trips were demanded, travel time would be T_3, but again at T_3 only V_3 trips would be taken. From the figure it can be seen that the actual equilibrium is (T_4, V_4). This is the combination of speed and volume at which the number of trips demanded at the given travel time and the performance (i.e., travel time) supplied by the facility are equal. Establishing this equilibrium may be a difficult task, particularly when the multiple dimensions of both the demand function and system performance function are taken into account. However, failure to equilibrate demand and system performance properly could result in substantial error in estimating the expected impact of a facility change on travel volumes and service levels.

1.15. The plan of the book

The second chapter of this book begins by evaluating conventional urban transportation planning in light of the considerations suggested above. A survey is provided of attempts to develop policy-oriented behavioral models.

Chapter 3 explores the theoretical implications of the economic theory of individual consumer behavior. We find that making plausible assumptions about the additivity of the utility function underlying the traveler's demand behavior enables restrictions to be placed on the demand functions which considerably simplify empirical analysis. Chapter 4 discusses the effect on demand of taste variation in the population, and provides the fundamental theory underlying the construction of the demand models. Chapter 5 discusses statistical methods. Chapter 6 discusses the collection and preparation of data for the empirical study; and chapter 7 presents calibrated models, along with a discussion of policy implications and conclusions.