



ABSTRACT

AN EVALUATION OF MODELS OF MODAL CHOICE

By
Philip Hampton Wheeler

Increasing urban traffic congestion in recent years, has led planners of transportation systems to consider new transit policies and technologies, for the provision of transportation services in urban areas. These planners require information on the effects such policies and technologies can be expected to have on future travel behavior, and more specifically, on the choice of modes of transportation by travelers. The models for predicting modal choice and generating the needed information that are currently available, however, may be inadequate to the task of analyzing the effects of radical policy changes, due to their insufficient theoretical basis. Thus, most conventional modal split models derive their predictions on the basis of the "maximum correlation criterion," yielding an ad hoc set of relationships which are assumed to remain valid into the future. Radical changes in policy or technology may invalidate the assumption, and render the predictions meaningless.

In an effort to remedy this situation, several relatively new types of modal choice models are being developed. These new approaches are based on theories taken from micro- and macro-economics, and from the behavioral sciences. By strengthening the basis in causal structure of modal choice forecasting, it is expected that these models can determine the effects of transportation

system changes with a greater degree of validity. In the course of developing these new approaches, several practical and theoretical issues have arisen relating to the types of variables that should be included, the level of aggregation at which the models should operate, the theoretical basis the models should operate from, and the functional form the models should take.

This thesis examines the theoretical nature of these issues, in attempting to provide planners with an evaluation of several types of modal choice models that have been developed. A framework for evaluating the model types on theoretical grounds is proposed, and applied to the analysis of modal choice model types ranging from the early "urban-form" models to the most recent "demand" and "choice" econometric models. In addition, the travel demand forecasting model systems are discussed, in order to put the evaluation problem into the context of transportation planning as a whole.

It is found that there are many problems with the variables used in conventional modal split models. Some of these problems continue in the newly developed models, including problems related to aggregation, inadequate theoretical bases, data biases, and measurement problems. Overall, the outline of the requirements of an ideal modal choice model is suggested.

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By

Philip Hampton Wheeler

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TABLE OF CONTENTS

Acknowledgments	Page ii
List of Figures	v
Introduction	1

PART I. THEORETICAL ISSUES

Chapter

I. Theoretical Justification of the Thesis Approach	8
A. The Empirical Approach	9
B. The Conceptual Approach	13
II. Evaluation Criteria	17
A. The Need of a Research Strategy	17
B. The Need for Policy Orientation	18
C. The Need for Efficient Causes as Variables	20
D. The Need for an Individual Orientation	20
E. The Need for Appropriately Chosen Simplifying Assumptions	21
F. Summary	24
III. Difficulties with Empiricism--Applications of the Criteria	26
A. The Issue of Sex as a Variable in Modal Choice Models	26
B. The Secondary Employment Issue	28
C. The Issue of Race	29
D. The Issue of Automobile Ownership	30
E. Summary	32

PART II. MODEL EVALUATION

IV. The Urban Transportation Planning Process as a Whole	35
A. Trip Generation Models	37
B. Trip Distribution	42
C. Trip Assignment	49
D. Conclusions	52

Chapter	Page
V. Classification of Modal Choice Models	59
VI. Empirical Models	63
A. The Earlier Models of Modal Choice	63
B. Conventional Empirical Models	66
C. Conclusions	74
VII. Conceptual Models	83
A. Attitudinal Models	84
B. Econometric Models of Modal Choice	98
C. Conclusions	114
PART III. CONCLUSIONS	
VIII. Conclusions	120
BIBLIOGRAPHY	124
APPENDIX: GLOSSARY OF TERMS	132

LIST OF FIGURES

Figure	Page
1. Classification of Modal Choice Models.	61

INTRODUCTION

A. The Problem

Recent concern over problems related to the use of automobiles and highways as the primary mode of transportation in this country (problems such as congestion, pollution, the disruption of neighborhoods and other land uses, and the waste of urban land, among others) has prompted a great deal of interest in devising ways to encourage the use of alternative transportation modes. Several strategies for accomplishing this have been proposed. Among these strategies are pricing policy changes, such as the imposition of higher parking fees, changes in transportation technology, such as the various proposed personal rapid transit systems, the development of commuter information systems matching possible car-or bus-poolers, and the initiation of programs to improve the competitive position of established modes of transit, such as the Shirley Highway Bus-On-Freeway project. While experiments with these proposals have been carried out, a parallel effort to improve the capabilities of travel forecasting methodologies has been undertaken. Those who design and implement solutions to the problems of urban transportation, that is, planners, must be able to anticipate the effectiveness of these alternative programs and policies, and to evaluate their potential consequences, in order to make reliable judgments concerning them. This requires a much sounder travel forecasting system than the one currently in use.

Conventional travel forecasting can be seen as having originated in the forties in this country (although clearly the intellectual roots go back at least as far as the spatial distribution model of von Thunen) with the standardization of origin and destination surveys and data requirements. By the late fifties a fairly standardized package of computerized models had been developed, related and applied primarily to the automobile/highway mode of transportation. As increasing urban sprawl made the fallacy of this approach plainly obvious, the search for techniques of forecasting the effects of policy changes on travel demand began. It is the basis in theory of this latter phase of the growth of transportation modeling, as it relates to the question of modal choice, that is the subject of this thesis.

B. Orientation and Goals

The orientation of this thesis in evaluating models of modal choice is to regard them as social and behavioral theories, and to examine their theoretical soundness. Britton Harris has characterized models as "truncated theories whose richness has been sacrificed for operational feasibility";¹ while it is agreed that models should be treated as theories, this thesis takes exception to the notion that operational feasibility requires the sacrifice of theoretical richness. Very much to the contrary, this thesis maintains the position that operational feasibility is impossible without sound theory, and that consequently a good deal of the comparative evaluation of competing models of travel demand and mode choice can be done on the basis of a priori criteria of logic and reasonableness.

One goal of this thesis, then, can be seen as that of providing

the practicing urban planner (rather than merely the mathematically oriented transportation system researcher) with a basis for evaluating the results of modal choice forecasts that he may be presented with. This goal is especially important in view of the increasing complexity of transportation models, the increasing specialization within the field of urban planning and research, the resultant isolation of practicing planners from theoretical developments, and the consequent growth in the remoteness and prestige of the transportation analyst. In a period in which urban groups and state highway departments are increasingly at odds with each other, it is important that planners be kept up to date on the advantages and shortcomings of various forecasting models. In a sense, therefore, this thesis represents both an evaluation of recent transportation modeling developments, and an attempt to provide planners not well versed in mathematical modeling with a means of evaluating the results of these models.

Another broad goal of the thesis is to demonstrate the potential of the sort of individually-oriented, policy-sensitive research strategy that conceptual models of modal choice are seen as representing. In this sense, the discussion and evaluation of modal choice theories presented in this thesis are only illustrative, the purpose being to point out the sorts of considerations that should be taken into account in the development of any planning theory. The discussions of predictiveness and causal structure in planning theory are seen as having implications beyond the area of modal choice theorizing.

More specific goals of the thesis are presented below:

- (1) To formulate a set of valid, logical criteria with which to evaluate modal choice theories;

- (2) To apply these criteria to the study of modal choice theories;
- (3) To demonstrate the advantages and the potential of economic and behavioral research strategies as applied to the problem of forecasting modal choice; and
- (4) To demonstrate the importance of the contributions that conceptually sound models may make to the study of mode choice.

C. Approach

The approach to the achievement of these goals has been divided into three separate sections:

(1) Part one analyzes the theoretical issues involved. The first chapter in this section examines the validity of the sort of inquiry undertaken in this thesis, by comparing two approaches to the evaluation of social theories: the empirical approach and what is termed in this thesis, the "conceptual approach." The second chapter develops the criteria to be used in the "conceptual approach" to the evaluation of transportation models. Several issues relating to the need for causal structure in transportation planning theory are addressed, including the issue of the validity of a research strategy, the need for policy-sensitivity, the need for an emphasis on "efficient causes," the need for an individual-based orientation, and problems related to the specification of explanatory variables. The third chapter provides examples of the application of the criteria established in the second chapter, to some of the assumptions implicitly made in conventional modal split models.

(2) Part two begins the evaluation of the modal choice models with a brief review of the transportation forecasting process

(Chapter IV), first for the purpose of placing modal choice models in their appropriate context, and second to expose some of the weaknesses in the processes upon which some of the models evaluated rely. This is followed by a brief section (Chapter V) describing the classification of the models to be evaluated, with the purpose of providing a perspective on the problem as a whole. The review and evaluation of the modal choice model types then follows. In this process of comparison, several reasons for concentrating attention on the conceptual models, and some of the issues to be resolved in the theories behind these models are discussed.

(3) The final section, part three, summarizes the points made in the body of the thesis, discusses some of the issues that remain, and suggests areas in which improvements should be made.

A glossary is provided in the appendix, devoted to a presentation of some of the usages and definitions necessary to the understanding of the problems of modal choice forecasting.

FOOTNOTES

1. cited in Consad Research Corporation, Transit Usage
Forecasting Techniques: A Review and New Directions
(National Technical Information Service, 1968), 28.

PART I

THEORETICAL ISSUES

CHAPTER I

THEORETICAL JUSTIFICATION OF THE THESIS APPROACH

The approach to evaluating models that is most common in the literature of transportation planning involves the use of statistical tests. Thus a model is developed, figures representing present-day values are input to the model in place of the independent variables, and the success of the model in approximating present-day values for the dependent variables is gauged. In proposing to evaluate modal choice theories according to criteria that are not statistically verifiable, therefore, this thesis is controverting a well-established practice in the field. For this reason it is felt necessary to devote some attention to the problem of justifying the use of non-statistical criteria in evaluating modal choice theories.

An attempt to justify the concentration on a priori criteria will be made on the basis of the dependence of the statistical ("empirical") approach on what is felt to be an incomplete concept of social science. This concept is described below (section A), and then criticized; in the following section the concept at the basis of the approach of this thesis is brought out. Chapter II then uses this concept as a basis for developing the criteria to be used in evaluating modal choice theories; Chapter III then demonstrates their application to some of the problems of conventional "empirical" modal split models.

A. The Empirical Approach

A.A. Walters,¹ in his textbook on econometrics, classifies approaches to the evaluation of economic theory into two types: the "assumptionist" approach and the "predictionist" approach. The assumptionists attempt to evaluate a theory on the basis of its assumptions. For the predictionists, on the other hand, "...correspondence between the assumptions and the facts is not necessary for a theory to be useful....[The validity of a theory is]...determined solely by the efficiency of the model in predicting events."² Walters clearly sides with the predictionists in the argument, citing as vindication an example from the physical sciences, the theory of gravity. The theory as stated by Newton ignores the effect of air resistance, thus assuming the existence of a perfect vacuum. Clearly no one would argue that the theory is invalid merely because such a thing as a perfect vacuum does not exist, Walters states; hence, the assumptionist argument must be invalid.

Thus, in his own words, Walters and the predictionists "...argue by analogy with the physical and biological sciences. Results, and results only, matter in science; the assumptions can be forgotten."³ Since (according to Walters) results alone matter in social science, then statistical tests will be adequate for evaluating a given social science theory (such as a modal choice theory). Out of Theil's four criteria (validity, accuracy (statistical success), sharpness (ability to make fine distinctions), and simplicity⁴), only the last three need be paid attention to. In fact, if the accuracy of a model can be demonstrated this will prove the validity of the model. This notion is in fact the basis of the physical and biological sciences,

where the repetition of an experiment numerous times over is held to "prove" the validity of an hypothesis. An analogy between the physical and the social sciences is therefore at the root of the empirical approach. Thus claiming the exclusive importance of "results," Walters and the "predictionists" therefore deny the validity of a priori criteria. While modifying this stance somewhat by admitting that limited a priori reasoning is helpful in situations of relative ignorance,⁵ and that problems can arise from "...the lack of experimental data" and from "...the interpretation of the results,"⁶ Walters nevertheless fails to see these problems as constituting any real challenge to the primary importance of predictionist evaluative criteria. The difference between physical and biological sciences on the one hand, and social and behavioral sciences on the other hand, is seen as being a difference merely of degree, such that the only difference between social and physical sciences lies in the number of variables.

Justifying the approach taken in this thesis thus depends on a refutation of the analogy with the physical sciences as it is applied to social science research. To do this requires demonstrating that the difference between the social sciences and the physical and biological sciences is more than one of degree, or at least is one of very large degree. The demonstration of this notion draws upon some of the problems Walters cites, but emphasizes their importance; since the empirical approach depends on an analogy with the physical sciences, for its epistemological foundation, then if it can be shown that the absence of experimental data, the problem of interpretation, and other problems not mentioned by Walters, are so important as to

throw into doubt the validity of the analogy with the physical sciences, then it can be considered that the a priori approach of this thesis is justifiable.

While Walters admits that the lack of experimental data constitutes a problem for social science, he sees the source of the problem as being the "youth" of social theory.⁷ It is the position of this thesis, however, that the lack of experimental data is a problem that is inherent in social science, deriving instead from the impossibility of establishing scientific controls. This is impossible for several reasons, including the problem of interpretation and more importantly the problem of self-fulfilling (or self-defeating) prophecy. Thus, if the individual participants in the social experiment are aware of its existence, their self-conscious actions are likely to distort the "natural" workings of the social environment, thus rendering the results of the experiment to some extent inapplicable to the society as a whole.

Other problems with establishing controls derive from the problems of first identifying, and second isolating relevant variables in the social system. There is a very large number of potentially relevant variables in the universe of social phenomena; identifying these phenomena and delineating their functions is a very different order of activity from that undertaken in the physical sciences. The reason for this lies in the different nature of social and physical "things." Thus, while there are obvious, intersubjectively valid criteria whereby to identify the "boundaries" of a frog,⁸ no such criteria exist for identifying, say, a social interaction. Furthermore, while the function of a frog's leg is easily agreed upon, and its role

and importance in the life of a frog easily ascertained, the function and importance of, say, religious beliefs, in the life of a society is a subject of very much disagreement. As can be seen, physical and biological phenomena "enjoy an epistemological status which is radically different from that of socio-cultural organisms. It is part of a species-given bio-psychological gestalt...that boundaries of individual organisms are delimited by unequivocal intersubjective criteria. We see whole bio-organisms, regularly, effortlessly, infallibly. We do not see whole socio-cultural organisms."⁹ (It should be pointed out Harris' argument is being used to refute a position which he himself accepts.)

Thus, in carrying out social experiments, it is not only the results that will be subject to problems of interpretation, but also the very data upon which the experiment is based. In the absence of intersubjective criteria for identifying relevant social variables, the proper design of scientific controls becomes impossible.

It might be argued, in response to these criticisms, that an alternative to "artificially" designed and carried out experiments exists in the past and present experience of social groups, and that by examining a large sample of experiences, fundamental causal statements can be tested. As testing by examining future events is termed prediction, testing by this sort of examination has been termed "retrodiction." An analogy is thus drawn with the field of astronomy,¹⁰ in which the comparative method is used to establish probable evolutionary sequences of stellar events. The problem with this analogy is that while the causal statements of astronomy are based on the firm experimental foundation of the other physical sciences,

social theory has no such foundation. As for the derivation of adequately predictive statements from sufficiently large samples of present phenomena, it can be shown that the same problems as face artificial experiments still apply. Maintaining such a position requires making "the assumption that cross-sectional relations can be extended to time series behavior."¹¹ It might be possible to test this assumption by examining a sufficiently large amount of time series data, were it not for the fact that studying social behavior, and especially acting on the basis of studies of social behavior, generates social behavior feedback. This, to a certain extent, destroys any possibility of complete confidence being maintained in the predictive validity of the forecast, by returning the problem to that of the aforementioned issue of self-defeating or self-fulfilling prophecy. Thus, testing the validity of, for example, a stock market prediction, is rendered impossible by the fact that the act of making such a prediction itself generates market behavior that might not otherwise have occurred. This is especially true of those predictions (such as travel forecasts) on the basis of which large expenditures of public money are made. Thus, for example, "roads may so alter a city's development that all predictions will work out irrespective of the original estimates...."¹²

B. The Conceptual Approach

Thus predictive success in the social services, while certainly yielding support to the successful social theory, cannot be considered the only test of that theory's worth; this test can only be found with the addition of the application of a priori criteria of logic and reasonableness. The "validity" of a model thus depends partly on the

relationships of cause and effect it presents, and not solely on its predictive ability ('accuracy') especially as it is approximated by tests on data from the present. This is because it is possible to include in any model of social processes (though the statement cited was applied only to economic models) "...at most a large subset of the complete set of equations that describe the behavior of man and the laws of the physical environment...."¹³ The model that reproduces present behavior well may do so only because the variables it includes vary closely with more causal variables, at the present, possibly short-term, equilibrium position.

Fisher, in discussing the limitations of time series models in economics, states that

...we [economists] cannot hope to overcome the fact that the parameters of our [economic] subset are variables of the larger set (i. e., that our equations are degenerate cases with certain important sociological variables held constant) save by choosing our observations so that the ceteris paribus assumption that the parameters were constant is approximately satisfied. This is why we do not ordinarily combine observations from twelfth century Britain with observations from modern-day America.... Because of our inability to perform controlled experiments ourselves in the socio-economic area, we are forced to select from the experiments performed for us by Nature those which are at least approximately controlled.¹⁴

It follows as a corollary of this statement that in models of social processes whose validity is presumed to apply to the long run (where the constancy of sociological parameters cannot be assumed), the only hope social scientists can have to overcome the relatively limited size of the subset of variables included in the model is to insure that the variables included are causal variables (and to insure that all "relevant" causes are included, where relevance is determined

statistically). Causal relationships are the only relationships that can be assumed to persist through time; hence, a theory that is developed from a causal basis is ultimately more likely to be met with predictive success than a theory based purely on what is called the "maximum correlation criterion,"¹⁵ that is, on a high degree of success in reproducing present data.

In the face of inherent uncertainty, therefore, social theory must develop from a strong causal basis. Establishing the causality of a variable, however, is "impossible," for the reasons cited above (the impossibility of experimentation, the problem of interpretation, the existence of self-conscious actors, and the possibility of self-fulfilling or self-defeating prophecy). Nor can causality be proved by high "predictive" success; the existence of a high degree of correlation is a necessary but not sufficient condition criterion for the existence of causality. A continuing high degree of correlation will tend to indicate that more confidence can be placed in the "causality" of the independent variables, especially when other variables have shifted without altering the relationship of independent to dependent variables. Nevertheless, since such a condition could be true of relationships of a clearly ridiculous nature (e. g., a relationship between asparagus-eating and transit riding), a priori criteria of logic and reasonableness must be considered to be essential to the test of a theory's validity. (This is true except perhaps in those cases where choices are to be made between very finely distinguished mathematical forms of functional relationships, for which no a priori basis of evaluation is readily apparent; such situations, however, are not usually the case in social theory.)

FOOTNOTES

1. Walters, A.A., Introduction to Econometrics (W.W. Norton, 1970), 13 et seq.
2. Ibid., 15.
3. loc. cit.
4. Oi, Walter Y and Paul W. Shuldiner, An Analysis of Urban Travel Demands (Northwestern Univ. Press, Evanston, 1962), 73.
5. Walters, op. cit., 18.
6. Ibid., 16.
7. loc. cit.
8. Harris, Marvin, The Rise of Anthropological Theory (Thomas Y. Crowell, New York, 1968), 256 et passim.
9. Ibid., 257.
10. Ibid., 153.
11. Oi and Shuldiner, op. cit., 63.
12. Ibid., 60.
13. Fisher, Franklin M., A Priori Information and Time Series Analysis (Contributions to Economic Analysis 26, North-Holland Publishing Co., Amsterdam, 1962), 5.
14. loc. cit.
15. Oi and Shuldiner, op. cit., 73.

CHAPTER II

EVALUATION CRITERIA

What is true of social science in general also will be true of social science-based planning theory; hence, if a priori criteria are an acceptable basis for evaluating social theories, such criteria should also apply to such planning theories as the various models of modal choice. Criteria such as those of "logic" and "reasonableness," however, are rather uselessly vague in evaluating specific transportation planning models; hence this section will be devoted to generating a more extended and a more specific basis of evaluation.

A. The Need for a Research Strategy

At the basis of the discussion in the first part of this thesis is the notion that specific social science models must be based on a structure of causal relationships among variables. This constitutes nothing more than a restatement of the notions that scientific hypotheses must fit into the body of established scientific theory, and that specific theories must be based on general theories. In devising models of modal choice, therefore, the body of theory established in the social and behavioral sciences must serve as the basis for the orientation of the research, that is, as the basis for the structure of causal relationships.

Reliance on the body of social and behavioral theory is necessary as a means of providing a logical and consistent orientation to the search for causal factors. In this sense, the "body of theory" referred to is made up not so much of specific laws as of general principles, forming the foundation of a basic research strategy, from the application of which there is an expectation that a causal understanding of social processes may be achieved (paraphrasing Harris¹). An analogy can be made with the doctrine of natural selection,² which, while it is quasi-scientific in the sense that it cannot be disproved, is nevertheless useful for science in that it generates questions orienting biological studies along the (successful) lines of determining explanatory differences in adaptiveness. In a similar way, a modeling effort oriented along the lines of such social theories as macro- and micro-economics, and behavioral theory in general, has the advantages of a systematic and consistent set of questions that can productively be addressed, and of a systematic rationale for choosing relevant variables for inclusion in the model.

As a general criterion for the evaluation of modal choice models, therefore, it can be stated that those models are to be preferred which develop from a strong orientation in one of the social or behavioral sciences. Those approaches are to be disfavored which develop from an ad hoc collection of variables which may be relatively successful in reproducing present data, but to which causality is adduced on a post hoc basis, if at all.

B. The Need for Policy Orientation

It has been seen that causal relationships among variables are

the only relationships that can reasonably be expected to persist through time, and that therefore the variables included in transportation planning models should be causal (or very close proxies of causal variables). This requirement is perhaps more important for transportation planning theories than for most social theories, since planning, after all, is presumed to be an "applied" social science. In terms of the problem at hand, this means that transportation planning models must account not only for the "natural" shifting of social interrelationships, but also for the purposeful manipulation of social system interrelationships for social ends.

This has three ramifications for transportation planning modeling efforts: (1) The first of these is that planning models must account for changes created by policy; thus, models must be "... statistically sound but sufficiently sensitive to changes in the transportation system to reflect the effect of new transit modes."³ Accounting for transportation system changes requires that characteristics of existing systems be included among the model variables.

(2) Another ramification stems from the role models play in policy-making, which to date has been limited to the indication of the kinds and magnitudes of problems policy-making will have to contend with. It would seem useful to expand this role to the point of demonstrating more effectively the areas wherein policy changes would be the most efficient.

(3) Accomplishing this requires satisfying the the third requirement, that there be included in the model causal variables of a manipulable nature. This is summed up by Quarmby who states that "...where one is concerned to explain and predict what will

happen in new circumstances, or to suggest ways of implementing change, it is imperative that all variables which are likely to change, or can be changed, be incorporated into a model which has some a priori causal basis...."⁴

C. The Need for Efficient Causes as Variables

The implications of all this are that planning models must concentrate on efficient causes, that is, on direct instrumental variables, in explaining such a phenomenon as modal choice. The more remote the "cause" is from the effect (travel behavior), the more difficult it will be to be confident in its validity, to manipulate it effectively without disrupting other systems, to model the impact of policy changes, and to manipulate it from the vantage point of the transportation planner. Thus while it is probably true that a higher density in urban areas leads to a higher percentage use of transit, this information is of little use to the transportation planner, since he has little direct control over density. Similarly, while the nature of the private property system and the predominance of individualistic values in this country probably have something to do with the low occupancy ratio on its streets and highways, the ordinary transportation planner cannot change these factors within the usual planning period, and these variables are equally useless.

D. The Need for an Individual Orientation

Within the limitations of the transportation planners' role in society (that is, accepting the fact that he can effect significant change only in those areas directly related to transportation system

characteristics), the concentration on efficient causes implies a concentration on those factors entering into the individual consumer's decisions. The variables that models of modal choice should thus concentrate on are those having to do with the factors entering into individual trip decisions; these factors include characteristics of the trip (such as for shopping, for work, or for recreation), characteristics of the alternative systems (time, cost, comfort, and convenience of travel), and characteristics of the individual (i. e., the individual's utility function, or set of values and preferences).⁵

An important ramification of the need for a policy orientation is the consequent requirement that the model equations be developed from a disaggregated data base. If, for example, trip time is determined to be an important factor in individual trip-making decisions, then equations relating trip time to, say, transit use should be derived on the basis of actual trip times for actual individuals, rather than average trip times for "average " individuals. An extensive discussion of this problem is given in Part II.

E. The Need for Appropriately Chosen Simplifying Assumptions

The issues involved in establishing the appropriate form of and set of each of these types of characteristics have not yet been settled; as a consequence of this and other factors, "...proxies rather than genuine causal variables are generally in abundance."⁶ The problem is that models must satisfy requirements other than those of statistical accuracy and causality; they must also meet the requirements of "sharpness" and "simplicity"⁷ as must all theories. Since "a forecast formula is said to be sharp if it enables us to distinguish

between alternative hypotheses..."⁸, it seems likely that sharpness will increase as the causal efficiency of the variables included increases. The requirement of simplicity (that is, of ease of calculation and comprehension) may be at odds with those of accuracy and validity, however, both because of the relatively more complex functional form that causal relationships may take, and because of the difficulty of fulfilling the data requirements of causal models. Thus, for example, Reichman and Stopher assert that "where the behavior of individuals is considered in decision-making, it is desirable to consider their individual utility functions. Detailed considerations of these utility functions is not possible, however, so socio-economic characteristics of the users are introduced instead. These characteristics serve as proxies to represent the average behavior of the individual decision maker" [underline added].⁹

The assumption that socio-economic characteristics of trip-makers give an adequate indication of their utility functions thus sacrifices a degree of validity for a (presumably larger) degree of simplicity. This is in the nature of proxy variables: all assumptions establishing proxy variables are simplifying assumptions.

There are problems in choosing proxy variables, however, having to do with the relationship between the causal variable and the chosen proxy variable. Using the example of Reichman and Stopher again, it can be seen that, if anything, income is one of the determinants of the individual's utility function (though feedback relationships may exist, and some people may be free of material wants). Income is, therefore, a more remote cause of travel behavior.

In terms of causal direction, the relationship between individual travel behavior and individual utility preference is the same as between individual travel behavior and individual income level. As a general rule it can be asserted that the proxy variable should stand in the same relationship to the dependent variable as the causal variable; hence, the proxy variable should always constitute a more remote cause of the dependent variable.

Problems in the use of proxy variables are important basically because they can constitute specification errors. Specification errors occur primarily when relevant variables are excluded. If the excluded variable is correlated to an included variable, and is in addition a causal variable in its own right, then the importance of the included variable will be wrongly exaggerated. (Thus Oi and Shuldiner have demonstrated that the importance of auto ownership in trip generation, as indicated by the regression coefficient estimated by least squares, is exaggerated by roughly ten percent when the factor of income is excluded.¹⁰ Such a result will not occur if the excluded variable is not sufficiently "relevant"; thus excluding the variable "hubcaps owned," while including the auto ownership variable in no way exaggerates the importance of auto ownership variable.)

The importance of this for the choice of appropriate proxy variables when relevant variables must be left out of the model, rests in the implication that the proxy variable chosen must be more closely related to the excluded relevant variable, than to the variables already taken account of in the model. Thus the variable "hubcaps owned" would be a poor proxy for income. This is essentially the basis for Lave's criticism of the use of the income variable in modal

choice models.¹¹

The implication of all this is that in evaluating modal choice models, the success of the trade offs between validity and simplicity must be assessed carefully. In general, simplifying assumptions generating proxy variables are acceptable only when the efficient causal agent is not measurable, and when the proxy is chosen according to the considerations discussed above.

F. Summary

The criteria that have been established thus far include the need for a research strategy, the need for a policy orientation, the need to include efficient causes as variables, the need for an individual orientation, and the need for appropriately chosen simplifying assumptions. These criteria are not meant to constitute an all-inclusive list; thus, flaws such as a failure to take account of the equilibrium nature of travel demand can be addressed without translation into the terminology of these five criteria. It is felt that some of these criteria may be specific to the field of transportation modeling, but that the principles involved should have a wide range of application.

FOOTNOTES

1. Harris, Marvin, The Rise of Anthropological Theory (Thomas Y. Crowell, New York, 1968), 4.
2. Ibid., 3.
3. Ferreri, Michael G. and Walter Cherwony, "Choice and captive modal split models," Highway Research Record 369 (1971), 80.
4. Quarmby, D.A., "Choice of travel mode for the journey to work: some findings," Journal of Transport Economics and Policy I, 3 (Sept. 1967), 276.
5. Hartgen, David T. and George H. Tanner, "Investigations of the effect of traveler attitudes in a model of mode choice behavior," (New York Dept. of Transportation, Albany, 1970), 1.
6. Quandt, R.E., "Introduction to the analysis of travel demand," in R.E. Quandt (ed.), The Demand for Travel: Theory and Measurement (D.C. Heath, Lexington, Mass., 1970), 12.
7. Oi, Walter Y. and Paul W. Shuldiner, An Analysis of Urban Travel Demands (Northwestern Univ. Press, Evanston, 1962), 73.
8. loc. cit.
9. Reichman, Shalom and Peter R. Stopher, "Disaggregate stochastic models of travel-mode choice," Highway Research Record 369 (1971), 97.
10. Oi and Shuldiner, op. cit., 55.
11. Lave, Charles C., "A behavioral approach to modal split forecasting," Transportation Research III, 4 (1969), 470-471.

CHAPTER III

DIFFICULTIES WITH EMPIRICISM-- APPLICATION OF THE CRITERIA

Several examples of the difficulties associated with the empirical approach to transportation modeling will be discussed below. This should provide an indication of the sorts of arguments that will be presented in the model evaluation that follows, as well as indicating some of the theoretical failings of existing modal choice theories.

A. The Issue of Sex as a Variable in Modal Choice Models

An excellent example of the problems involved in the specification of non-causal variables in forecasting models is provided by the various treatments sex has been accorded in the literature. The history of the sex variable in travel demand studies probably begins with the standardization of origin and destination survey data, in 1944. The advantage to be obtained in including sex as a variable derives from the fact that currently women are more likely than men to use transit. Hence, in testing a model for predictive purposes, by determining the quality of the model's "fit" with present data, the use of the sex variable improves the correlations derived. While including the sex variable in modeling present-day travel demand may

be justifiable, however, there nevertheless are no grounds for assuming that sex will play any role in determining travel demand in the future.

While this fact seems eminently reasonable (i. e., there do not seem to be any biological attributes of women necessitating their use of transit), its acceptance by modal choice theorists is by no means unanimous. Thus, even so causally-oriented a theorist as Stanley L. Warner has claimed that "...women are...more apt to take transit than men are in the same circumstances...[due perhaps]...to a comparative lack of confidence in driving ability."¹ Projecting this "lack of confidence" into the future implies that this quality is inherent in women, and not men, and that consequently sex must be an enduring efficient causal variable. It is the contention of this thesis that sex is, on the contrary, merely a proxy (or surrogate) variable, and that the advantage of sex as a fitting variable derives from the present social milieu (a social milieu which has been changing rapidly of late).

A question arises, of course, as to what other variable the sex variable represents. Howard S. Lapin asserts that "...classifying information on travel patterns in terms of primary and secondary employment incorporates not only the factor of sex of persons making urban trips but also that of age. Thus, this classification is believed to be more useful in the study of work trip patterns than classification by age and sex."² Lapin does not expand on the reason for this. However, if residential location is seen as being determined by primary employment (the employment of the head of the household), then consequently this work trip will tend to have the highest priority.

The employment of other household members (secondary employment) will not be so important, and consequently will rely more heavily on transit. Secondary employment may even be sought in those places either accessible by transit or within walking distance; to the extent that secondarily employed workers are working wives, this tends to explain the sex variable's fitting qualities. Projecting this sort of correlation into the future then implies a belief that the current culturally derived sex roles are immutable, an implication that has clearly been made untenable.

B. The Secondary Employment Issue

It should be pointed out, however, that there has not yet been presented any "proof" of the secondary employment hypothesis; further, there have not yet been presented any cogent reasons why the secondary employment/transit use relationship should persist. There are some suggestions of empirical evidence in favor of this hypothesis in the work of Charles C. Lave. In attempting to determine the wage rates of tripmakers from family income data, he was forced to exclude from his sample all multiworker families (since family income is only a proxy variable, for his purposes). With this taken into account (that is, with only primary employment work trips under consideration), he finds that the "sex variable is clearly insignificant... [since]...the selective nature of the sample assures that any women present must be heads of households."³ It is thus something in the nature of secondary employment, rather than womanhood, that promotes transit use.

Some reasons for the persistence of this phenomenon have been

alluded to above (e.g., the higher priority for primary employment work trips, the location of the household in relation to the primary employment place of work, and the constraint of transit or pedestrian accessibility on secondary employment job searches). The question arises, however, as to whether secondary employment is an efficient causal variable, or whether it is itself a proxy variable. In other words, in order to project the relationship between secondary employment and transit use into the future with confidence, it might first be necessary to determine what the characteristics of secondary employment leading to transit use are. Thus, it might be asked whether the lower priority accorded secondary employment is a result of (1) shorter hours; (2) lower wages; (3) a more flexible schedule; and thus, (4) a lower penalty for late arrival; or (5) something else entirely. A theory accounting for these possibilities would approach the problem from the level of the individual; this is something that a theory dependent on such a variable as sex or secondary employment cannot do. As has been shown above, approaching the subject of modal choice from the point of view of the individual trip-maker has advantages, in terms of pointing out the areas in which policy changes can be effective. The development of a model suitable for handling these problems will be discussed below, both in the evaluation of existing models, and in the discussion of the time issue.

C. The Issue of Race

Race is another non-causal variable the use of which has tended to confuse more than enlighten. If race has proved to be a rather successful fitting variable, it is due not to a condition inherent

in racial characteristics, but to a cultural condition which it is the stated policy of American government to eradicate. A more individually-oriented model of modal choice would tend to recognize this fact. Thus, although it has been shown that, given the same level of income, blacks tend to use transit more than whites, attributing any causal force to race per se (on the basis of, say, cultural heritage) is misguided. The causal forces should be looked for elsewhere, in the conditions which individual blacks confront in their choices of mode. Several of these can be considered to be potentially more valid causal factors, including residential density, nearness to the central business district, higher prevalence of part-time jobs, lower job security, and so on. The first two of these influence choice of mode by increasing the relative attractiveness of transit (transit routes are more efficient in higher density areas, and more prevalent nearer the central business district), while the latter two point to choice-distorting factors not evident in the raw socio-economic statistics. While it cannot be denied that cultural-historical forces specific to one race may have shaped the mode choice values of its members, making the presumption that such forces therefore explain modal choice may tend to hide the truth, and thus seriously distort policy decisions made on that basis.

D. The Issue of Automobile Ownership

One final example of the problems associated with the specification of non-causal variables, that of the variable of automobile ownership, will be discussed. The problem with the automobile ownership variable is not directly a problem of causality, as in the

case of the other variables discussed, for clearly automobile ownership exerts an influence on mode choice. The problem is, however, that automobile ownership is being considered as a given, in the same sense as, for example, residential location; car buying though is like purchasing a season bus pass. Hence, specifying automobile ownership as an independent variable is at odds with the ultimate goal of modal choice theories, which is to predict mode choice. Automobile ownership can only be considered as a dependent variable, consequently, and those factors entering into the decision to purchase an automobile should be considered as variables affecting mode choice decisions.

Along these same lines, it can be stated that once the relative importance of the various factors entering into mode choice decisions has been ascertained, it should be applicable to situations in which an individual must decide not only among modes, but also among routes, among speeds of travel in routes, between auto ownership and reliance on transit, between making a trip and not making a trip, among trips at different hours of the day, among alternative destinations, and even (taking account of the feedback between transportation system characteristics and residential location) between alternative origins. The model that can account for all of these factors has not yet been developed; this necessitates making certain assumptions, such as the assumption that residential location and land use can be considered given. Extending these assumptions to characteristics of the transportation system itself (e.g., assuming a given level of auto ownership) is clearly self-defeating, however, since it introduces a dependent variable in the position of a pseudo-causal proxy variable. In effect, predicting levels of automobile

ownership independently of changes in the transportation system as a whole makes the assumption that changes in the relative quality of service offered by alternative modes do not effect automobile buying. This assumption is untenable, and contradicts a basic principle of behavioral theory, stating that choice behavior depends on a utility index that is responsive to changes in characteristics of the objects of choice.

E. Summary

These, then, are the kinds of arguments that will be used in evaluating the modal choice models. Except where the functional form of the models discussed is closely related to the type and number of variables involved, the discussion will center around the nature of the variables included, and around the research strategy; policy orientation, and individual emphasis will be discussed as they apply to each of the model types reviewed.

FOOTNOTES

1. Warner, Stanley L., Stochastic Choice of Mode in Urban Travel: A Study in Binary Choice (Northwestern Univ. Press, Evanston, 1962), 33.
2. Lapin, Howard S., Structuring the Journey to Work (Univ. of Pennsylvania Press, Philadelphia, 1964), 79.
3. Lave, Charles C., "A behavioral approach to modal split forecasting," Transportation Research III, 4 (1969), 478.

PART II

MODEL EVALUATION

CHAPTER IV

THE URBAN TRANSPORTATION PLANNING PROCESS AS A WHOLE

Since most of the modal choice models evaluated in this thesis are intended for use in a sequence of travel demand forecasting models, and since as a consequence thereof many of the problems with these models stem from the requirements of other models in the sequence, it has been deemed useful to review this sequence of models as a whole prior to the actual evaluation of types of modal choice models. This should serve not only to point out the context of modal choice models in the travel demand problem, but also to point out the sorts of considerations that go into forming the inputs and outputs of those modal choice models that fit into the sequential scheme. In addition, for the non-sequential (demand) category of models, it should prove useful in outlining the scope of the whole travel demand problem. Since the only complete travel demand forecasting system yet put into operation is the system of models known as the Urban Transportation Planning Package, this system will be concentrated on. While the urban transportation planning process as a whole has been adequately dealt with elsewhere (e.g., Martin, Memmott, and Bone,¹ J.R. Stone,² and the United States Department of Transportation/Federal Highway Administration,³ among others), a more critical

review of the process will be provided herein.

As it is currently envisioned, the planning process is made up of four general phases, including:

(1) The data gathering stage, amassing inventories of the demographic, socio-economic and land use characteristics of the area, of the travel characteristics of the population, and of the various attributes of the transportation systems, coupled with the establishment of goals, objectives, and policies;

(2) The analysis and forecasting stage, involving the prediction of future demographic, socio-economic and land use characteristics, and of future revenues; the analysis and modeling of existing transportation and land use conditions; and the design and testing (with the calibrated models) of various alternative transportation systems;

(3) The programming stage, involving the establishment of priorities on the basis of needs, and the staging of the project; and finally

(4) The actual implementation stage. Throughout this last phase, a continuing effort is made to update and revise data, forecasts, and specific projects, by the use of such modeling techniques as micro-assignment.

Modal choice models fit into this scheme in the second phase, as one of the analysis and forecasting models. In the conventional Urban Transportation Planning Package, modal split models constitute one of the four basic models in the travel forecasting process; the other three models are the trip generation model, the trip distribution model, and the traffic assignment model. Each of these models has

several alternative types; however, their purposes can be defined in inclusive general terms. Since the validity of some of the modal choice models depends on the validity of these models, to a certain extent, it will be useful to review each of these models briefly.

A. Trip Generation Models

Based on data gathered in the inventory phase of the planning process, including auto availability, characteristics of the resident labor force, and travel characteristics for the base year, and using mathematical techniques such as regression analysis, cross-classification, or the analysis of rates, trip generation models attempt to predict either the total "...number of trips per average weekday per small geographic areas (zone),"⁴ or (in the case of aggregate rate generation models) the rate of trips (number of trips per household) per average weekday per zone.⁵ Recent studies suggest that substantial improvement in trip generation modeling can be achieved with the use of disaggregate generation models⁶; arguments to the contrary have been developed however,⁷ and it may be that as long as the geographic units are drawn so as to be sufficiently homogeneous, aggregate equations will be more "efficient" (that is, will be so accurate that the difference in accuracy between disaggregate and aggregate equations will not justify the effort to develop a disaggregated data base). On the basis of theoretical rigor, however, there can be no question as to the superiority of disaggregate equations; statistical proofs can be devised demonstrating that aggregate equations suffer from the problem of group correlation, arising from hidden variances.⁸

The key issue seems to be summed up in the phrase "sufficiently

homogeneous." Since there are limitations on the number of zones that can be handled in the analysis process, for most large areas some of the analysis zones would have to be large also, in both a demographic and a geographic sense. The larger the analysis zone, however, the greater the possibility that the assumption of homogeneity will be grossly violated in the present, and more especially in the future. Any assumption of homogeneity will be violated to some extent, however; hence, aggregating by zones inevitably biases the equations.

Two recent articles discuss possible solutions to this problem, by developing ways to combine the efficiency and economy of aggregate analysis with the theoretical rigor and explanatory validity of disaggregate analysis. Fleet and Robertson⁹ suggest the use of sample surveys taken of individual household units, with the regression equations thus developed applied to the zones as before. In much the same way, Kassoff and Deutschman recommend that trip generation studies "...develop their tools on a disaggregated basis..."¹⁰, before applying the equations in the analysis of zones. Smaller disaggregate sample surveys also give the possibility of adding time-series checks to relationships derived on the basis of cross-sectional data.¹¹

The aggregation problem is a mechanical problem with conceptually significant repercussions. On the one hand, a disaggregated data base permits a theoretically more sound concentration on the actual decision-making unit (the dwelling unit or the individual). On the other hand, however, disaggregate data bases complicate the problem of ferreting out the degree to which each of a number of causal variables contributes to travel behavior, due to the problem

of highly interrelated, collinear variables.

There are other significant problems with conventional trip generation modeling, however. One of the most fundamental of these is included in the ultimate goal of trip generation as it is presently conceived: the goal of predicting the total number of trips generated by a zone per average weekday. In basing this prediction entirely on the land use and socio-economic characteristics of the zones, the trip generation models leave out any possibility of a feedback loop from the third important element in transportation decision-making, the transportation system itself. Thus, "the assumption is made that total travel, as measured by trip ends, varies only as development varies, not as conditions on the tested network change."¹²

This assumption is both unreasonable and inconsistent with the rest of the models in the Urban Transportation Planning Package. It is unreasonable because the demand for travel represents an equilibrium situation (or at least a situation oscillating around an equilibrium situation). Thus, the data of travel demand (e. g., traffic counts and origin and destination surveys) "...represent reduced forms; that is, observed values represent equilibrium positions which reflect balances among the numerous forces affecting the variable being studied."¹³ Neglect of this fact leads to the assumption that regardless of any increased cost in terms of time, money and discomfort due to transportation system congestion, for example, the propensity to travel will remain unchanged. This assumption is inconsistent with the distribution and assignment processes, which predict zonal interchanges and route choice (respectively) on the basis of minimum time paths. If it is true that trip-makers will tend to use

the shortest amount of time possible in travel, then travel must be taken as constituting a costly task. Increasing the burden of this task therefore necessarily induces those who are only marginally committed to making a given trip (such as a pleasure drive) to forego trip-making of that nature entirely. In this sense, trip generation is a special case of trip distribution¹⁴ where the factor of impedance is allowed to effect the decision as to whether or not to make the trip.

Reinstating the fact of equilibrium in the modeling process in part amounts to establishing the fact of a (time, money and/or comfort) budget constraint, limiting the amount of travel. Two approaches to the problem of including this constraint in the travel forecasting modeling process have been developed, including the abolition of the four phase modeling process, and its replacement with a single simultaneous model¹⁵ and the development of an iteration procedure feeding the results of the assignment process back into the generation phase.¹⁶ These approaches are intimately connected to the evaluation of the modal choice models that follows; the discussion of their strengths and shortcomings will be taken up below in the conclusion to this chapter.

Another feedback loop that few of the models examined have adequately taken account of (though mention has been made of the problem¹⁷) is that of the effect of the transportation system on land use. For example, improved transportation systems (that is lowered transportation costs) can lead to the consolidation, in effect, of marginally successful retail outlets, leading to an increase in auto trips as people travel farther for (possibly cheaper) retail goods. In addition, there may be relocation effects not accounted for in the

land use models used as the basis of future trip generation models, such as the relocation of industry to the suburbs in order to lower transport costs. While some land use models do attempt to take account of the future transportation system in predicting the location of various uses, the degree of pressure on land use created by the transportation system cannot accurately be known prior to the operation of the travel forecasting models. Responses to this problem will be reviewed in the conclusion.

A final set of problems with trip generation warranting discussion relates to the types of data used as the basis of the equations. One major data problem is one of omission, from which may stem the basic error of assuming that trip generation is not affected by changes in the cost of trip-making. The crucial omitted variable is income. The lack of data on income in conventional trip generation analyses has been rationalized partly on the basis of the incorrect notion that "...the effect of income is entirely subsumed by the car ownership variable or some other combination of explanatory variables."¹⁸ Some of these "explanatory" variables have been dealt with above (Chapter III); others such as the variable "structure type," are equally remote from efficient causality. If trip generation models are to incorporate any transportation cost feedback loops, then they must be developed so as to take account of some form of budget constraint; if this is to be done, data on income are essential.

Another problem with trip generation model data bases is the presence of a number of statistical biases inherent in the data collection process. A number of these have been reviewed by Oi and Shuldiner¹⁹ and include such problems as the over-representation

of non-trip-making families and individuals resulting from the fact that home interviews can only take place if the interviewee is home ; the exaggeration of the number of trips made by large families (such that the situation of a housewife taking her four school-aged children along with her on a shopping trip is counted as five person-trips); and the under-representation of trips by persons living in or near intensely developed areas (due to the substantial neglect of, for example, walking trips).

While these problems tend to detract somewhat from the accuracy of the trip generation procedure, by far the most serious problems with the models are the lack of an adequate feedback loop from the transportation system to the trip-making decision, and the problem of developing a disaggregated data base. The first problem necessitates making an involved set of assumptions relating to the future relative position of transportation in the cost of living index, such as that transportation system changes will neither so increase nor so decrease the cost of transportation as to change significantly the number of trips. The lack of a disaggregated data base necessitates making the assumption that the analysis zones are homogeneous. Both of these assumptions detract significantly from the validity of the trip generation models.

B. Trip Distribution

In the conventional forecasting process, the phase following trip generation (excluding the modal split model phase) is trip distribution. The purpose of trip distribution is to derive a matrix of trip interchanges between all pairs of zones in the study area for

the future year. This is accomplished in one or more of three ways, including a growth factor method (such as the Fratar method), the gravity model of spatial distribution, and the intervening opportunities model. The most common trip distribution technique uses a combination of the growth factor method (for trips having either their origins or their destinations outside the study areas) and the gravity model. Since it has been shown that the gravity model is a more statistically sound mathematical model than the intervening opportunities model,²⁰ the discussion of trip distribution will concentrate on this combination of techniques.

The Fratar method forecasts future trips between a pair of zones (in this case where one of the zones represents an area beyond the study area "boundary") by (1) developing factors representing the growth rates of the zones; (2) finding the product of the growth factors of the origin zone and the destination zone; and (3) multiplying this product by the number of trips between the zones in the base year. The total number of origins will not necessarily be equal to the total number of destinations when the procedure is completed; hence, successive iterations of the procedure must be carried out until a satisfactory near-equivalence is achieved. While this technique is useful in slowly growing areas, where wrong estimates of growth factors will not generate large errors, and where the iteration adjustments are not overly extensive, the technique is not suitable for rapidly growing areas. Thus, "when an urban area is expected to experience significant growth, the adjustments to the present trip pattern become difficult and, to a considerable extent, speculative."²¹ This is especially true if the base year zonal interchange is very small

or zero, while the future year interchange is expected to be significantly larger; there will be many interchanges of this nature in the rapidly growing study area.

It seems likely that the Fratar method is also ill-suited for distribution purposes in study areas where significant improvements in the transportation system are to be made. Thus, there is no way to account for the effect of transportation system changes on zonal interchanges within the structure of the model, except by manipulating growth factors for affected zones. There seems to be no way to accomplish this systematically.

Both of these problems with growth factor methods help to explain why the Fratar method is currently applied only to the forecasting of external trips. They also imply that the external cordon line (the study area "boundary") must be drawn so as to include all areas of significant growth and transportation system changes within the study area.

The gravity model of spatial distribution has developed from a loose analogy with Isaac Newton's physical law of gravity; the importance of this analogy is overrated, however. The gravity model states that the number of trips produced at a given origin and attracted to a given destination increases with the total number of trips produced by the origin and with the total number of trips attracted by the destination, and decreases with the generalized cost (impedance) of travel between the origin and the destination.

Impedance is usually represented as an inverse exponential function of the total travel time (including the interzonal driving time, the intrazonal driving time in both the origin and the destination

zones, and the time spent looking for a parking space, parking, "unparking," and walking, at both ends of the trip). However, impedance can be represented by measures other than travel time, and the form of the equation need not be that of an inverse exponential function. The travel time factors derived for each trip purpose in the calibration process for the base year are usually assumed to remain constant throughout the study period; there is some question as to the validity of this assumption, especially as it is applied to study areas in which very large numbers of trips are affected by very drastic changes in the transportation system (as when the distance traveled in ten minutes triples).²² It is recommended that "in such situations it may be desirable to develop travel cost factors (i. e., weight in distance on the minimum time path) rather than travel time factors."²³

The gravity model operation essentially consists of filling out a matrix of zonal interchanges, where attractions are estimated based on knowledge of total and zonal productions. Several iterations of the gravity model formula are carried out, until a balance is achieved between total productions and total attractions. The model is then calibrated by manipulating the travel time factors until the model reproduces the frequency distribution of trip lengths in the base year.²⁴ Where the model fails to account for peculiar movements between zones, caused by unique socio-economic geographic, land use, or other characteristics, adjustment factors can be input to the model to rectify the discrepancy. These adjustment factors are applied only if reasonable explanations of the discrepancy can be developed; such adjustments are only rarely used in the prediction of future trip distributions, since usually it can more validly be

assumed that such unique situations are temporary aberrations than that they are permanent exceptions to the gravity model rule. There have been several criticisms of the gravity model method of trip distribution. Many of these arguments center around flaws in the calibration process; it is argued that calibration by means of the reproduction of the base year frequency distribution of trip lengths should be replaced by calibration on the basis of actual zonal interchange volumes.²⁵ This merits consideration, since it is the volumes of the zonal interchanges, rather than the frequencies of the occurrence of trips of different lengths, that are the objects of interest.

A more fundamental criticism states that conventional trip distribution models are isolated from causal structure by the fact that they are "...modeled as a function of a simple description of the trip lengths that prevailed at the equilibrium between supply and demand represented in the base data file."²⁶ In one sense, this amounts to a criticism of the assumption that travel time factors remain constant into the future. Changes in the "supply" of travel (such as a decrease in the supply of convenience, caused by increased congestion) change the price of travel, thereby affecting demand. In the case of congestion, an equilibrium between the supply of and the demand for travel is established in the following way: as congestion increases, the generalized cost of travel increases (or, in effect, the supply of travel decreases). As the cost of travel rises, the effective demand for travel declines (e.g., as people begin to take fewer pleasure trips). Then as the demand declines, congestion is diminished, having the effect of lowering the cost of travel, and in turn causing an increase in demand. The continuation of this process

ultimately establishes an equilibrium situation which remains in effect until the next disturbance (such as highway construction or population movement) upsets the balance, creating a new set of oscillations. The argument is that the travel time factors developed in the gravity model represent what may be a short-lived equilibrium condition in the transportation system. As was pointed out above, this contention is especially germane where drastic changes in the transportation system are anticipated.

The question may have implications of an even more serious nature, however, if the concept of equilibrium in supply and demand is extended beyond conditions in the transportation system. Row and Jurkat, for example, develop an abbreviated notion of an equilibrium extending beyond the transportation system, by taking into account the factor of population movement. Thus, "income can be used... for rent or transportation;.. the spender seeks a balance to meet his needs....[As] income decreases, the amount of the family budget that can be allocated to the distance costs in the (residential) amenities direction is less."²⁷ Transportation is thus one of many costs taken account of in family budgets; expenditures on transportation must depend on the relative position of transportation prices in the cost of living index (as pointed out above). This relative position is established by the same sort of equilibrium process as operates in the transportation supply and demand problem, except on a broader scale; it is this equilibrium as established for the base year, that the travel time factors developed in the calibration process reflect. In a sense, since time can be considered as one of the goods the price of which is reflected in the cost of living index, the assumption of

constant travel time factors must involve an extensive set of assumptions, relative to the future set of wage rates, the purchasing power of the future hour of labor and so on.

It will be realized, of course, that impedance factors are only travel time factors by convention, and that in fact, the impedance can be as well represented by factors of generalized cost.²⁸ Then, if it is assumed that "...the total amount spent on trips in the region at [a given] point in time is a fixed amount..."²⁹ it can be shown that "...given total numbers of trip origins and destinations for each zone for a homogeneous person-trip category, given the cost of travelling between each zone [sic], and given that there is a most probable distribution of trips between zones, then this distribution is the same as the one normally described as the gravity model distribution."³⁰ Without doubting the statistical soundness of the gravity model, however, and without questioning the usefulness of the assumption of person-trip category homogeneity, this conclusion can nevertheless be called into question by the fact that the assumption of constant total travel expenditure is not supported by the input to the model. Thus, while the gravity model may be potentially fairly sound, as it is currently used it suffers from the fact of a separate trip generation phase, such that the gravity model constraint is not generalized cost, in fact, but the total number of trips from zone to zone.

As an issue of interest to welfare economics, it might further be pointed out that the use of travel time as the impedance factor will tend to bias whatever evaluations are performed against the poor, to whom factors other than time may have a more determinative role.

Thus, while for most people travel time may be a good proxy variable for impedance (Claffey³¹ and Lansing and Hendricks,³² among others, have found that most drivers are unaware of money costs of travel, for example), for the poor this may not be the case.

There is one strong reason for continuing to use travel time as the measure of impedance, however, and that is the ease with which it is measured. Simplicity is also the rationale for continuing to separate the generation and and distribution modeling processes. This is an issue very much at the center of the controversy between demand and choice econometric models of modal choice, and consequently will receive extensive treatment in the section on econometric models, below. All modal split models that are designed to fit into the Urban Transportation Planning Package must confront these problems, however.

C. Trip Assignment

The assignment phase of the travel forecasting process performs two functions, including the derivation of minimum travel times for trips between pairs of zones for use in the distribution phase, and the assignment of trips to routes in the transportation network. In a sense, if route choice is a sub-category of modal choice, the procedure must overlap somewhat with modal choice models; in effect, due to its concentration on travel time as the sole relevant route-choice variable, it overlaps very little. The usual rationale is that each phase of the Urban Transportation Planning Package answers its own specific decision-question, such that population and economic studies determine the level of activity, land use models and policies determine

the number of trips these activities will induce, trip distribution determines where these trips will come from and go to, modal split models determine by what mode trips will be taken, and trip assignment models determine the routes these trips will take.³³

There are several procedures in use attempting to accomplish this.

The most common procedure (and the procedure used in the Urban Transportation Planning Package model) is the "all-or-nothing" assignment technique which assigns all trips from a zone to another zone on the same minimum time path. Clearly there will be problems with this procedure if the predictive model fails to take account of, for example, congestion. Two techniques within the Urban Transportation Planning Package have been developed to handle such a situation: The first is "calibration," whereby speeds on congested links are reduced or increased until an assignment that seems reasonable to the analyst is produced; two analysts may not reach the same result by this process. The second is capacity restraint, whereby speeds and volumes on links in the system are determined by a set of linear relationships between speed, volume, and capacity. A sufficient number of iterations of this model may result in so many changes in the network as to invalidate the distribution upon which the assignment operates. Adequate operation of the system then requires that trip distribution be included in the iterations, such that ultimately as much of a balance as can be achieved given the trips ends as established by the

trip generation procedure is reached.

Another assignment technique that operates within the Urban Transportation Planning Package system and that is based on the same behavioral assumptions, though with differing "mechanics," is Robert Dial's probabilistic assignment model.³⁴ This model assigns a probability of use to all "realistic" routes from one zone to another, such that the assignment can be "calibrated" by varying the probabilities (according to levels of congestion, or to the percentage of people to whom travel time may not be determinative) rather than by manipulating travel times unrealistically. While this technique is much more systematic than the usual calibration procedure, and may be at least as reasonable as the capacity restraint procedure, it is still no more valid in a behavioral theory sense, since the basis of route choice remains the same.

This is essentially the problem with the trip assignment model as it is used in the Urban Transportation Planning Package; the concentration on travel time as the sole route choice variable has resulted in a one-dimensional behavioral model that in effect amounts to no more than a set of rules.³⁵ As the work of the "behavioral" modelers (including both the attitudinal theorists and the econometric "choice" theorists) indicates, the choice of a route in trip-making is the result of a complex set of factors including money cost, relative or absolute time savings, external and internal comfort,

convenience, and many others. In view of the neglect of these factors, it is probably safe to say that whatever behavioral modeling is done as part of the Urban Transportation Planning process is done in the trip generation, trip distribution, and modal split phases; in a sense, the trip assignment models merely sum the results of the decisions predicted in the other three models.

D. Conclusions

Most of the criticisms that have been advanced here in reference to the Urban Transportation Planning Package have concentrated on the absence of adequate feedback mechanisms reflecting the equilibrium nature of urban travel. Two types of feedback loops have been identified: those operating to reflect the balance between the "supply" of travel and the demand for travel, and those operating to reflect the interrelationships between land use and transportation systems. Progress has been made in both these areas and through a variety of approaches. Two of the major types of approaches have been termed the "explicit demand" modeling approach and the modified "implicit sequential" approach.³⁶ In the first approach, the volume of trips going from one zone to another zone, by a given mode and route, is modeled as a simultaneous demand function of the combined effect of all variables describing the socio-economic activity system and all relevant attributes of the transportation system. Several such

models have been developed, including primarily the models discussed in this thesis under the classification of econometric demand models. These models are complete in that they attempt to include the entire array of causal factors entering into travel decisions in a single system of equations. Thus, the attributes of each mode and route should have some effect on the location of each activity, which in turn should effect travel demand, system congestion, and so on. These models operate at an aggregate level of necessity, due to the complexity of the decision-making system involved,³⁷ and to the facts that "determining the demand function (as well as many other elements) to use as difficult; and ...the equilibrium occurs in a network, where flows from many origins to many different destinations interact and compete for the capacity of the network, and the form of these interactions is affected by the topology of the network."³⁸ At the present state of transportation modeling, "...there is not even one operational model that solves for...equilibrium flows exactly and directly,"³⁹ though considerable progress is being made.

The second, "implicit sequential" approach confronts the problems of accounting for missing feedback loops by modifying the current Urban Transportation Planning Package system, while retaining the basic concept of a series of models representing different parts of the decision-making process. It is argued that by reducing the complexity of the problem to this extent, substantial improvement can be made by identifying and including elements of

individual decision-making processes.

The success of a modified sequential implicit model depends on the following:

- (1) Improved land use models incorporating elements of accessibility in the prediction of locational decisions;
- (2) The incorporation of levels of service characteristics of all transportation systems into every step of the modeling process;
- (3) The inclusion of a sufficiently complete set of decision-affecting system attributes into the modeling process;
- (4) The attainment of a valid equilibrium of supply and demand,⁴⁰ such that the same system attributes are used in each phase of the model; and
- (5) The maintenance of internal consistency and statistical validity.⁴¹

If all of these requirements are met, the results of the sequential implicit models series will be the same as those of a valid explicit demand model.⁴² The behavioral models of modal choice that are reviewed below (including both the attitudinal and econometric-choice models) are designed to fit into such a scheme.

Several separate "contexts" have been described for the several types of modal choice models to be evaluated. For the earlier and the conventional types of modal choice model, the conventional Urban Transportation Planning Package framework provides the data and analysis inputs; such models therefore operate at a considerable disadvantage. For the econometric demand models, there is no external framework; evaluating these models must proceed on the grounds of analyzing the success of the

trade off between the benefits of functional simultaneity in deriving more or less close approximations to equilibrium flows, and the losses in terms of conceptual validity necessitated by the simplifying assumptions of aggregate level analysis. The attitudinal and econometric-choice models conform to a modified sequential implicit framework, and hence should address the necessity of improving the Urban Transportation Planning Package system (an imperfect and inconsistent sequential implicit model) to meet the several requirements cited above, in addition to demonstrating a degree of conceptual validity sufficient to justify the simplifying procedure of separating elements of the decision-making processes involved in trip-making. These are the issues to be confronted in the evaluation of models of modal choice to be presented below in the evaluation of modal choice models.

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CHAPTER V

CLASSIFICATION OF MODAL CHOICE MODELS

In order to orient the evaluation of the various models of modal choice examined, a classification scheme is presented below. This classification should provide the reader with a sort of "schedule" for the discussion which follows. Several other classifications of modal split models have been proposed (e. g., in Quarmby,¹ Reichman and Stopher,² and Fertal, et al).³ Most of these classifications reflect both the bias of the authors and the state of the art at the time of writing, and hence are largely unsatisfactory. Thus for Reichman and Stopher the primary classificatory criterion is the level of aggregation (the authors advocate the use of disaggregated stochastic models), while for Quarmby the criteria are the degree of causal structure and the relevance of the variables used to policy decisions for implementing change. The Consad Research Corporation⁴ and Fertal, et al.⁵ concentrate on the position of the modal split analysis in the Urban Transportation Planning Package; Quandt⁶ concentrates on the nature of the data base. While none of these classification schemes is completely without merit, for the purposes of the present effort the definitive classification has not yet been written. Some of these classifications in fact are organized along criteria that seem to this author to be both irrelevant and

inaccurate; others are incorporated into the classification presented herein.

The approach taken in this classification scheme is to establish a series of continua along which different modal split analysis types can be placed. The degree of separation of the alternative models will depend on the importance of the continuum. For example, although trip interchange and disaggregate stochastic models both are intended to be used after the distribution phase of the Urban Transportation Planning Package system, trip interchange models are classified with pre-distribution trip end models, while disaggregate stochastic models are classified at the other end of a continuum of increasing causal structure. This is because theoretical structure is held to be more important than internal mechanics.

The classification scheme used herein is presented in Figure 1. The distance from the top of the page down indicates roughly the position of the modal type in the chronological sequence of model development; the distance from the left of the chart to the right indicates roughly the degree to which the model has incorporated elements of causal structure, disaggregation, behavioral rationale, and research strategy, and sensitivity to policy-affected variables.

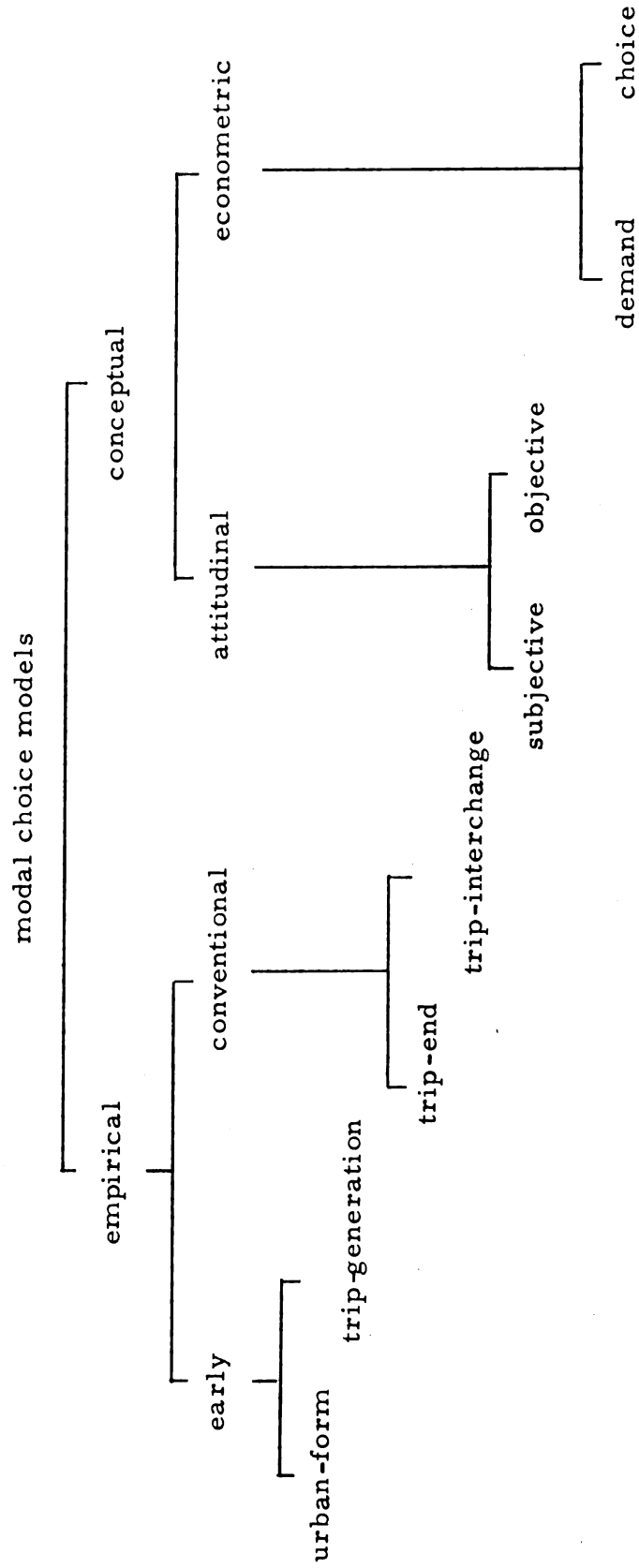


Figure 1. Classification of Modal Choice Models.

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CHAPTER VI

EMPIRICAL MODELS

Empirical models are of two types: the early trip generation and urban-form related theories, and the conventional trip-end and trip-interchange models. These models have been designated as "empirical" based on their isolation from causal structure; this is a point that will be demonstrated below. In terms of conceptual soundness, the models included in this type can be ranked from the urban-form models, which are the least sound, to the trip-interchange models. Each type of model is characterized by the addition of an additional type of variable, or by the concentration on a finer level of analysis. Thus the urban-form models were primarily concerned with the characteristics and trips in the urban system as a whole, trip-generation modal choice models were concerned with characteristics of smaller sub-areas within cities, trip-end modal split models began to deal with characteristics of the tripmakers as well as of the trips, and trip-interchange models now deal with characteristics of the trip, the tripmaker, and the transportation system.

A. The Earlier Models of Modal Choice

1. The Urban-Form Models

The first of the earlier modal choice model types to be

discussed is the urban-form type. The history of the concern with the relationship between travel and land use can be seen as beginning with the spatial distribution model of Von Thunen. Since that model was developed, a long stream of related models have been generated, including those of Christaller, Park and Burgess, Hurd, Hoyt, and numerous more recent works.¹ The urban-form models were developed at least partly from these models, and are the indirect forerunners of many of the macro-level theories now being developed, such as the Urban Systems Model² and other land use models that incorporate aspects of transportation systems, and such as the explicit demand models discussed above, which attempt to incorporate land use impacts into transportation systems models. In the urban-form models, factors such as employment structure (e.g., manufacturing, service, and commercial),³ residential density,⁴ and orientation to the central business district,⁵ based on data collected at a macro-level, are correlated with percentages of transit use. While these theories are useful in terms of providing a basis for further research, they lack the precision necessary for policy relevance. A study by Adams,⁶ for example, relates transit use to the population over five years of age in the urban area, the vehicle-miles of transit service per weekday, areas of commercial and industrial sites not included in the central business district, and their distances from the central business district, income, and square miles of urbanized area, in a series of regression equations "explaining" transit use. A study cited by Quarmby⁷ relates the use of public transit in different cities to "...factors such as size, density, and age of the cities."

In the discussion of the need for policy orientation, and for

the inclusion of variables that constitute efficient causes (see above, Chapter II, C), it was pointed out that the task of designing solutions to urban transportation problems requires that more immediate causes of levels of transit usage be included in forecasting models. Thus, while models of the type Adams has developed may be somewhat useful in explaining the transit usage of the present, they yield no useful information as to how to change the level of transit usage for the future (unless it is argued that changes in the number of people over five years of age, the acreage of urbanized land, the distribution of land uses, and so on, are amenable to policy change for transportation ends). The other major problem with these models is the very gross level of aggregation involved; this problem is closely related to the problem of the remoteness of the variables considered.

2. Trip-Generation Modal Choice Models

Reducing the level of aggregation and concentrating on variables developed in reference to trips (i. e., trip purpose, distance of the zone from employment and commercial centers, orientation to the central business district, and time of day) changed the urban-form models into what have been classified in this thesis as trip-generation modal choice models. The same sorts of criticisms as were applied to the earlier models can be applied here, and expanded upon somewhat. These models leave out any variables describing the transportation system (without which no policy to change levels of transit use can be modeled), and rely on simple extrapolations of transit use trends. Because the broad city-wide socio-economic measures incorporated into these models represent long term trends that have corresponded with a decline in transit use, predictions of future modal splits from

these models "...suggest that transit use will be used by a dwindling proportion of the population, irrespective of any changes in mode characteristics."⁸ This clearly fails to account for the fact that mode characteristics are constant as the result of policy. Changing the policy destroys the validity of the assumption, and therefore of the model. Thus, "simple trend extrapolation will not help us to forecast the effect of changing a bridge toll or transit fare, for example, in a situation where the toll or fare had remained constant over a long period of time."⁹ In an even stronger statement of the same principle, it has been said that "...there is little reason to suppose that raw historical data are a useful indication of what ridership would be upon implementation of a new policy program"; yet "most of the modeling which has been done has concentrated on searching for statistical regularities in the historical data without much regard for the causal implications of the model."¹⁰

While these criticisms apply to other types of models as well, they apply most cogently to the early urban-form and generation models, due to their concentration on gross, descriptive data developed in reference to entire cities, their isolation from causal structure, and their neglect of instrumental variables.

B. Conventional Empirical Models

With the wider availability of origin and destination survey data and the development of computer techniques, higher levels of sophistication could be achieved, leading to the inclusion of more relevant variables and the development of techniques for a finer level of analysis. The first step in this process was made by the conventional

"modal split" models, of which the two types are trip-end and trip-interchange models. The two types of models are distinguished on the basis of their "positions" in the series of travel forecasting models making use of the Urban Transportation Planning Package system. This distinction is important due to the difference in the type of variables that can be included in the analysis. Trip-end modal split models are developed so as to fit into the series after trip generation and prior to distribution; trip-interchange models follow trip distribution and precede assignment. The implications of this distinction will be drawn out in the discussions which follow.

1. Trip-End Models of Modal Split

Trip-end modal split models were developed directly from the transitional trip-generation modal split models; in fact, two of the models that have been classified as trip-end models (the Chicago and Pittsburgh models), had been originally considered as generation models of modal choice in the thesis research. The Chicago model includes basically only two variables in its analysis, including a variable defining two types of trip "purpose" ("central" and "local"¹¹), from which is derived a measure of the orientation of trips to the central business district) and a characteristic of the tripmaker (auto ownership).¹² The Pittsburgh model incorporates three trip purposes (central business district, school, and other) includes a measure of distance from the central business district, and incorporates two tripmaker characteristics; those of automobile ownership and residential density at the zone of origin.¹³ All other trip-end models reviewed attempt to incorporate some measure of the gross effect of the transportation network in

addition to these trip and tripmaker variables.

The contribution of the Chicago and Pittsburgh models to the development of modal split models however, is perhaps so significant as to warrant their inclusion in the category of trip-end models. The Chicago model was the first transit usage forecasting model to incorporate a characteristic of the user in its analysis. This is significant not because of the strength of the variable included (though an excellent predictor of modal choice, auto ownership constitutes a choice of mode itself, as was seen above in Chapter III, but because of the significance of the decision not to rely entirely on raw historical data in the model. Thus, having found through an extrapolation of past trends that transit usage would decline to half its 1956 level by 1980, the Chicago Area Transportation Study determined that it was necessary to search for causal factors, rather than to assume the trends to be valid. Finding a high correlation between auto ownership and the non-use of transit (that is, between auto ownership and auto use), the study analyzed factors of auto ownership, predicted auto ownership for 1980, and determined the future modal split on that basis, finding no absolute decline in transit usage, but a sharp relative decline.¹⁴ The report even discusses policy measures whereby to increase the percentage of transit usage, but without attempting to include these in the model.¹⁵

The Pittsburgh Area Transportation Study used the variable of automobile availability in a similar way, developing the concept of "captive" and "choice" transit ridership. Captive riders are those who either do not have a driver's license, or do not have an automobile available at the start of a trip; all others are considered

choice riders.¹⁶ The Pittsburgh study also introduced a variable representing net residential density, finding a high correlation between this variable and the percentage of transit trips to the central business district. Then since trends showed marked decreases in both net residential densities and in captive ridership (that is, in the number of families with no autos available), the study reached the conclusion that central business district transit trips would decline absolutely by eight and two tenths percent by 1980,¹⁷ representing a relative decline of even more substantial proportions.

An attempt was then made to introduce a policy measure into the model, by analyzing the effects of several assumed transit service improvements. Thus, "zones served by [new transit routes] had their transit trips by car-owning households subjectively increased by [varying degrees], depending on the type of service and the distance of the zone from the high speed facility. In general, those zones contiguous to the rapid transit facility had their transit trip-making rates increased by 30 percent, those zones 'one layer back' by 20 percent, and those zones served by express bus by 10 percent."¹⁸ With this taken into account, transit ridership was predicted to increase by one tenth of one percent.

The obvious crudeness of this sort of procedure for introducing transportation system characteristics into the models, led later trip-end modal split analysts to attempt to incorporate these characteristics into the structure of the model. The chief means for accomplishing this has been the so-called "accessibility ratio." As used in the Puget Sound trip-end modal split model,¹⁹ and as further clarified by Fertal and Sevin,²⁰ the accessibility ratio consists

of a measure relating total person trip attractions, transit network characteristics, and highway network characteristics. For a given zone there can be only one accessibility ratio, such that regardless of differences in performance by alternative modes on various "routes," if the sum of the accessibility indices for one mode exceeds the sum for another mode, all trips from that zone, regardless of destination or route, will be allocated according to the relationship between accessibility and the percentage of transit use. Thus, if three out of four connections from a zone to zones of equal attractions provide slightly better transit service than highway service, while the fourth connection provides overwhelmingly better highway service than transit service, all trips from the zone on all routes will nevertheless use transit or highway in the same proportion.

In addition, since the measure is so inflexible, any currently existing orientation of transit riders to the central business district, or any tendency for transit trips to be longer than automobile trips, will be extrapolated into the future year without foundation in causality. The factors entering into these biases should be reflected in the model variables; the accessibility ratio, however, merely disguises their influences. The accessibility ratio constitutes the sum of a large number of causal factors in equilibrium with each other; a change in this equilibrium (such as would be caused by a new transportation technology, or a shift in the relative price of transportation in the cost of living index) would invalidate the model.

The concept also is weakened by the fact that it does not take into account the differing economic characteristics of persons living

in the zones. This problem is in part remedied by the Puget Sound model, in the development of its transit usage curves. The analysis zones were stratified by income level, and those zones with identical income levels and accessibility ratios were then grouped together. The composite percentage of transit usage for each income/accessibility ratio group was found, and curves were plotted relating income level and accessibility ratio to the percentage of transit usage. Then by predicting the average level of income in a zone in the future year, and by computing the accessibility ratio for each zone, the percentage of transit usage for trips originating from each zone were found.

In other respects the Puget Sound model does not differ much from the other trip-end modal split models reviewed. The problems resulting from relying merely on income categories and accessibility in estimating transit ridership (i. e., the overestimation of suburban transit trips and the underestimation of central area transit trips led to the inclusion of auto ownership and net population density in the list of variables.²¹ Although neither of these variables explained the discrepancies independently, in combination they were correlated closely with the degree of error.

2. Trip-Interchange Models

Before the final evaluation of trip-end models is presented, the trip-interchange model type will be briefly reviewed, and the two model types will be evaluated, together. Trip-interchange models are distinguished from trip-end models in that they account for transportation system attributes for each zonal interchange. Thus, having established the origins and destinations of all of the trips for each analysis zone, each of the "connections" discussed above can

be evaluated individually. This permits a substantially better analysis of the effect of transportation system characteristics on modal split. The procedures followed in this sort of modal split are primarily of three types, including the transit use diversion curve technique, a multiple regression analysis technique, and what might be termed a "dual distribution" technique. Of these, only the first two will be discussed.

The diversion curve technique developed by Traffic Research Corporation and reported by Hill and Von Cube²² relates transit use primarily to six factors: the ratio of travel times by alternative modes; the ratio of travel costs; the ratio of "excess travel time" (that is, the time spend transferring from one vehicle to another, the waiting time, and the walking-from-stop time for transit, and the parking delay and walking time at the destination for automobiles); the economic status of the tripmaker; and categories of trip purpose. Identifying four ranges of cost ratio, five economic levels, and four ranges of excess travel time (level of service) ratios, and graphing the percentage of travel use against the travel time ratio, Traffic Research Corporation developed eighty transit diversion curves for each trip purpose, yielding a total (in the Washington, D.C. model) of one hundred and sixty diversion curves. This represents a considerable improvement over the earlier trip-interchange technique of using a few more inclusive diversion curves. The Traffic Research Corporation procedure has the advantage of making it easier to apply a diversion curve to a particular zonal interchange. Thus, "...instead of having to make some awkward judgment about the prevailing service ratio in a given zone half a mile square,

one only has to classify the zone in up to five ways."²³ Nevertheless, the sensitivity of modal choice to service ratios is such as to make the procedure difficult to apply to zonal analysis, since there can be as much variation in travel time ratios, levels of service, and so on within a single zone as between the averages for these between different pairs of zones.²⁴ This renders the procedure inapplicable to small area analysis, though for entire areas the procedure has had acceptable results.²⁵

The multiple regression analysis approach developed in the Twin Cities Area Joint Program, and reported by Roger Forbord²⁶ relates the percentage of transit passenger trips to total person trips in a given zonal interchange to the ratio of total travel times by transit and automobile (or some other measure of relative level of service); four production zone variables (income, housing units per net residential acre, cars per housing unit, and accessibility to employment); and to four attraction-end variables (parking cost for nine and three hours, employment per gross acre, and accessibility to population). While the travel time ratio was developed separately for each zonal interchange, the basic data making up the remaining eight variables were summarized at the district level (roughly three times as large as the zones). The advantage of such a model over the diversion curve type of model lies in its greater ability to relate small changes in variables to changes in modal split. Thus, by expressing the relationship between income and transit usage in the form of an equation, instead of as a set of curves, it is possible to avoid such problems as may result from aggregating incomes into

income classes. By increasing the level of geographic aggregation, however, the possible benefits resulting from this procedure in terms of precision are lost, though satisfactory results were achieved for the area overall.²⁷

One problem that both models have in common, in addition to the problem of aggregation, is the problem of "double counting," whereby the use of a measure of accessibility overlaps with the use of a measure of total travel time. This is statistically unsound, but may not have grossly distorted the results of the models, depending on the ratio of excess travel time to total travel time in the case of the Washington, D.C. model, and on the importance of the accessibility variables in the Twin Cities model (due to their relative unimportance, the accessibility measures were ultimately dropped from the model).²⁸

C. Conclusions

Overall, the problems with conventional modal split models can be seen as having two main sources, including the technique of aggregation by zonal analysis unit, and the general lack of a research strategy or causal structure. Reviewing these problems should yield insights into the broader problems of research strategy, policy orientation, causal efficiency of variables, and individual orientation.

Aggregation problems. The extent to which aggregation problems per se detract from the validity of conventional models is significant. However, except for the fact that conventional models fail to develop equations on a less than zonal basis, these problems would be no greater than for any aggregative modal choice models. As such, these problems include:

- (1) problems of group correlation and hidden variance;²⁹ and
- (2) problems stemming from the necessity to use variables that are remote from causal efficiency.

Discussions of these follow.

(1) Both trip-end and trip-interchange modal split models are weakened by their failures to handle adequately the problems of aggregation. As was seen in the discussion of the Traffic Research Corporation trip-interchange model, these techniques are extremely sensitive to geographic aspects of the delineation of analysis zones,³⁰ such that service ratio relationships are largely invalid for purposes of small area analysis.³¹ The use of analysis zones generates problems of inaccurate trip length measurement³² (since all trips produced by or attracted to the zone are assumed to terminate at the zone centroid), and of disguised variance in socio-economic characteristics.³³ There is also the problem that zonal measures of central tendency assume the normality of zonal frequency distributions of socio-economic characteristics, when in fact they are usually quite skewed.³⁴ These are all types of "hidden variance" problems.

(2) The aggregated level of analysis has also had an effect on the choice of variables entering into the models, in the sense of orienting analysts to the inclusion of data that can be gathered at a zonal level, rather than at the level of the actual behavioral unit. Trip-end models especially have concentrated on the incorporation of variables descriptive of zones (e.g., residential density and level of auto ownership), rather than measures of user preferences. The use of the variable of auto ownership has been criticized before; if it is being used in trip-end modal split models as a proxy for income,

then it can further be criticized on the basis of the fact that it is an effect of income, to a certain extent, just as the efficient cause, user preferences, constitutes an effect of income. Hence two causal chains are involved, doubling the uncertainty.

The variable of residential density is somewhat similar to the variables discussed in Chapter III, in that it constitutes a proxy for several less remote causal factors. In addition to the factors Forbord cites as potentially explaining the residential density variable's "predictive" efficacy (i. e., the greater availability of automobile storage space in less dense areas, and the higher level of transit service in denser areas)³⁵ can be cited the factors of reduced transit "pickup" and distribution time, resulting from the greater efficiency of transit service in areas where large numbers of passengers can be serviced with a relatively small non-line-haul mileage. Forbord notes that the variable is highly intercorrelated with income; with this fact in mind, and in view of the fact that high density areas are relatively congested, it may be that time values are low enough, and absolute travel time differences insignificant enough, to render transit relatively more attractive to high density dwellers. Forbord's use of the travel time ratio, instead of a travel time difference, would tend to obscure such a possibility.

Causal structure. By concentrating on such variables, the conventional modal split models are isolated from causal structure, and neglect the need for policy orientation. For example, in the analysis of income it has been found that "... each income level has a different pattern of expenditures..."³⁶; consequently, the use of broad categories of income levels may not be behaviorally valid. By

neglecting the need for an individual level of analysis, they have also been developed on such a basis as to render them geographically unique,³⁷ in the sense of being applicable to only one area. Models based on a structure of causal relationships should be applicable to related choice problems and to unrealed urban areas, as was pointed out above (Chapter II, D).

Another example is provided by the use of trend extrapolations. In defense of the conventional modal split models, it has been argued that although they are biased in favor of the automobile, due to the reliance on the extrapolation of recent trends in auto use, this may not be a flaw, since "...significant change...in the transit system...is unlikely and furthermore,...there may even be a greater potential for a worsening of transits present competitive position."³⁸ As a result of developing predictions on the basis of such present-oriented methodologies as the transit usage curve developed in the Puget Sound model, most conventional modal split models are "...no more than a reflection of today's transportation consumer reacting to today's transportation system for today's transportation system for today's trip purposes....[These models] are not geared for the behavioral inputs which...may spell the difference between success and failure of a new innovation in transportation."³⁹ Thus, policy orientation requirements necessitate the development of more behaviorally oriented data bases analysis techniques.

Another problem (related closely to the universality requirements cited above) is the relationship of these modal split models to related travel decisions that can validly be considered sub-categories of modal choice problems. These travel decisions include such

choices as the decisions to buy a car (as discussed in Chapter III), route choice decisions, and occupancy ratios in automobiles. All of these variables have been treated in either of two ways in modal split models: as givens, constituting variables in the model and assumed to remain constant throughout the study period, or as problems to be dealt with separately, and then input to the models. In neither case are these variables treated as questions involving the same sort of choice as modal choice. A truly causal model would treat these choices as integrally related to mode choice.

A final set of problems with modal split stems from the relationship of these models to the remainder of the Urban Transportation Planning Package series. These have to do with general questions of feedback relationships, the representation of system characteristics, and general criteria of consistency. The conventional models are deficient in these respects. Thus, neither model type incorporates an adequate means of relating, say, increased transit usage to lowered congestion, lowered trip cost, and so on. Similarly, both models fail to represent characteristics of the transportation system accurately, partly due to the aggregation bias noted above, but also because the trip-end model uses a fitted function (from the gravity model travel time factor derivations) of accessibility to describe zonal relationships to the transportation system, while trip-interchange models use travel time measurements developed from frequently non-reproducible base year assignment calibration procedures.

Conventional models have thus been found to be deficient

in terms of policy orientation, the inclusion of efficient causal variables and the inclusion of individual decision unit oriented variables, and in terms of the criteria of universality and consistency. The concentration on aggregate measurements of non-causal characteristics of zones and on empirically derived relationships reflecting present trends reflect the absence of a research strategy well-grounded in behavioral or social sciences. It is for this reason that attention is being drawn to the problem of developing conceptually sound models of modal choice.

FOOTNOTES

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CHAPTER VII

CONCEPTUAL MODELS

It has been found that the conventional models are deficient, particularly in that their ability to predict the consequences of policy changes relating to the type and quality of transportation services is limited. Perhaps partly as a result of increasing urban congestion, and the consequent interest in new transit technologies, a concentrated effort has developed in recent years to move away from the extrapolation of trends and to get at the roots of urban travel behavior. This effort has proceeded along several lines; however, out of this movement can be discerned three main thrusts. One is to model modal choice by identifying the individual values and preferences that motivate the use of alternative modes; this aspect characterizes both the attitudinal and the econometric choice models. Another thrust is to confront the problems of equilibration by modeling travel demand as a simultaneous decision; this approach characterizes the econometric demand modelers. The third thrust is to treat travel as a commodity, and use economic theory in its analysis; this approach characterizes both demand and choice econometric models. The limitations and potentials of each of these approaches will be explored in this chapter.

A. Attitudinal Models

As has been seen, widespread dissatisfaction with the conventional modal split models has led to a reevaluation of the procedures involved, and to a renewed search for approaches that account for problems such as those pointed out in the preceding sections.

Among the new generation of models are the attitudinal models.

These are modal choice models that attempt to discover the individual values and preferences that directly motivate mode choice decisions; the techniques used vary from those that attempt to elicit the trip-maker's subjective impressions of various modal attributes, to those that derive objective measures of the unconscious responses of trip-makers to travel situations. In their emphasis on individual responses to various system attributes, the attitudinal models thus attempt to generate measures of the degree of effectiveness which proposed transportation system improvements can be expected to meet with. In this sense, the development of attitudinal models, and of the studies and surveys of the attitudes of transportation system users, constitute a significant addition to the body of modal choice theory. Two separate types of these models have been distinguished for the purposes of this thesis, based on the two types of study techniques used. These are the "subjective" type, characterized by the study of user attitudes primarily through the use of interviews, and the "objective" type, characterized by the use of psychological measurement techniques, such as the use of the galvanic skin response measure. Attitude studies of the former type are frequently used as supplements to econometric models of modal choice, and even, in one case, to a model of the objective

attitudinal type.

Both types of models have been developed to remedy the situation pointed out by Fertal and Sevin¹ and many others, of the "...scarcity of information concerning the factors that affect consumers behavior in transport, the relative importance of these factors, and the effect of varying trip circumstances on them."² Without such information, the task of determining the future ridership on innovative transit modes, it is argued, becomes difficult if not impossible. Thus, "because existing transit usage may be constrained by the lack of some of the attributes deemed desirable by new users, behavioral [that is, empirically observed] data by themselves may lessen the predictive ability of the model if a new mode, consisting of radically different performance levels, is introduced.... One way of overcoming this limitation is to model a user's subjective evaluation of the attributes of any mode to find the relative importance of the attributes introduced in a new mode."³ (As will be seen, other techniques, including the objective measurement techniques and the econometric techniques, including the objective measurement techniques and the econometric techniques discussed in section B below, merit consideration also.) Two examples of analyses of the subjective responses of transportation system users will be reviewed (with references to other subjective attitudinal models briefly introduced), followed by a review of the sole example of the objective measure of user response found in the search of the literature, the galvanic skin response tension studies of drivers carried out by Michaels.⁴

1. The Subjective Type of Attitudinal Model

The first example to be reviewed is the attitudinal model of Hartgen and Tanner.⁵ The authors identify four determinants of travel behavior, oriented around the concept of the household (rather than the individual) as decision-making unit. These include (1) the characteristics of the traveler and his household, defined by socio-economic variables; (2) the types of activities engaged in by individual household members; (3) the distribution of activities about the household by alternative modes of travel; and (4) the attitudes of travelers towards the quality of alternative modes. The study of user attitudes is seen as yielding an understanding of "often subconsciously perceived factors affecting travel behavior such as comfort, convenience, self-esteem, and personal safety."⁶ The authors assert that travel is based on needs established both in the individual's interaction with other members of his family, and in the family's interaction with the remainder of society. Mode choice thus depends on the needs of users, as well as on the characteristics of existing transportation systems. The latter are conceptualized by the users based on personal experience and on an implicit concept of an idea mode. The traveler thus implicitly ranks alternative modes according to "...both the importance and the relative quality of a number of aspects of [the] trip, each represented by a number of specific system attributes."⁷

The methodology used for identifying these system attributes, and their relative quality and importance, was the interview technique. Travelers were asked to rank a set of attributes in the order of importance to them, and then to identify the degree of "satisfaction"

that currently existing modes yielded in terms of these attributes. Transit was found to yield more satisfaction than the automobile in terms of only one characteristic: "Pride in vehicle." Nevertheless, the authors are so encouraged by the results as to proclaim that "...an effective educational campaign directed towards creating a more favorable transit image...could have nearly the same effect as extending bus service so as to make all urban locations as accessible by transit as by auto."⁸

The second example of the application of the subjective attitudinal approach will be reviewed, before both examples are evaluated. This is the approach of Hille and Martin,⁹ whose study consisted of interviewing travelers as to the relative importance of eleven variables describing trip characteristics, ranging from "cost," to the opportunity to be "with friends." These variables were rated on a scale from "not important" to "very important," with the results stratified by four types of trip purposes (work/school, personal business/shop, in-town social, and out of town social). Significant differences among trip purposes were found for the variables referring to characteristics of reliability, travel time, the opportunity to be with friends, and the avoidance of annoyance.

The results were also stratified by characteristics of transportation system users, including socio-economic characteristics such as income, employment, race, age, tenancy, automobile ownership, and education; with geographic variables such as residence distance from the central business district; and with characteristics of transit use or auto use. It should be clear from the discussions of these variables that few of the socio-economic and geographic variables

can be considered causally efficient. In fact, as was pointed out above, making the presumption that race, for example, will have long term effects on user attitudes and preferences is potentially counter-productive, in terms of disguising the more direct causes (e.g., poverty or favorable total cost ratios) of non-white transit use. The variables age, income, education, and employment may be considered directly causal in the sense of determining user attitudes and preferences to a certain extent; however, tenancy and automobile ownership are more likely to be co-effects (with attitudes and preferences) of the four causal variables, than causal variables themselves. There seem to be a good many problems of interdependency in the set of independent variables, therefore.

Some of the conclusions reached by the authors are that

rational sets of differences in the perceived importance of transport attributes were found among respondents based on their particular demographic characteristics and circumstances. One such difference existed for the attribute "independence," which refers to the amount of freedom the individual has or perceives in terms of speed, direction, and personal control of the vehicle. The importance of this factor tends to increase with a person's education, income, residence distance from the central business district and number of vehicles owned.... The importance of cost is greater for people with lower education, non-whites, and those who did not own vehicles. Surprisingly, however, cost was not significantly more important for low-income people than for high-income people.¹⁰

Earlier in the report the authors state that "reliability of destination achievement" was most important to those low-income non-whites who are middle-aged renters of houses, who do not own an automobile, and who are employed.¹¹ They further state that "bus users placed greater emphasis on getting to their destinations in the shortest time and by the shortest distance than did private automobile users,"

and go on to say that "It appears as though a well of dissatisfaction was tapped for bus riders"¹² (emphasis added).

The implications of the last sentence are such as to cast considerable doubt on the validity of the attitude survey method undertaken. If the responses of interviewees are determined by "wells of dissatisfaction," then there are serious grounds for doubting the reliability of attitude surveys in developing long-term projections of user behavior. The statement would seem to indicate that the interviewees rated the importance of modal attributes according to their short-term dissatisfaction with existing modes, or conversely, perhaps, to the degree to which highly-valued modal attributes were taken for granted. This would tend to explain the high preference for "reliability" among transit users, and the disinterest in reliability among automobile users. It would also tend to explain the "surprisingly" insignificant variation in the relative priority of cost among income classes: if the low-income person must concern himself with problems such as reliability, cost will naturally have a lower relative importance.

In general, as long as short-range problems may be overwhelming to people not immediately able to remedy them, attitude surveys of this type will have doubtful validity.

Through their concept of the ideal mode, and by asking interviewees to rank each variable according to their degree of satisfaction with the performance of the system with respect to that variable, as well as according to its importance to them, Hartgen and Tanner may have avoided some of the more obvious problems

related to short term biases. The criticism still applies to a certain extent, however, in that if short-term fads and "irrationalities" can affect the evaluation of mode characteristics, there can be little basis for extending these irrationalities to the future year. Then if status considerations in the present year orient users toward, for example, "big car comfort," there may be little validity in extrapolating these values through what may be the end of the big car era. In a sense, this constitutes an issue of a "new empiricism," in that data of this nature are accepted in the same way that trends are accepted by conventional trip-end modal split analysts (with the difference, of course, that attitudes and preferences are efficient causal variables, and not merely ad hoc correlation-derived variables). This is an issue that will be returned to in the discussion of econometric choice models and the time issue.

Other similar problems arising out of the nature of the interview process can be identified. A list of these is given below.

(1) The shortsightedness bias--interviewees may respond in ways analogous to those in the Hille and Martin study, by emphasizing short-term problems rather than characteristics of an "ideal" mode.

(2) The rationalizing bias--responses may indicate less an accurate appraisal of the factors entering into the individual's decision-making process, than a subconscious attempt to rationalize the decision actually made. (Thomas has dealt with this problem as it relates to time and cost estimates in route decisions.)¹³

(3) The ambivalence bias--an Arthur D. Little study of responses to the roadside environment (Herrman, et al)¹⁴ gives evidence of the occurrence of discrepancies in the behavior of

interviewees. Thus, strong negative verbal responses to visual stimuli (billboards, etc.) are sometimes accompanied by little or no physiological response to the same stimuli. This could indicate either that physiological measurement devices are unreliable, or that informants are unaware of their true feelings on the questions they address, and tell interviewers what they think they ought to believe.

It is also possible to expand somewhat on a similar list that Watson presents,¹⁵ of problems associated with attitude surveys dealing specifically with measuring the relative importance of time. Some of the biases he discusses are listed below.

(1) The perception bias--drivers frequently have only a very vague notion of how long it takes them to drive from their residences to shopping centers, or even to their places of work. While it might be that this uncertainty is the result of a lack of familiarity with the transportation network, might thus be remediable by continuing experience in using the system, it is a matter of question as to whether the future transportation system will be any less rapidly changing (and thus more "knowable") than the present network.

(2) The rounding bias--another problem with surveys of driver perceptions of time is that interviewees almost invariably round their time estimates to five minute intervals. This presents problems, in that the modal choice theorist has no way of knowing how this rounding process has been accomplished (that is, whether estimates are rounded to the nearest multiple of five, to the next higher multiple of five, or to the next lower multiple of five).

(3) The normalizing bias--informants also tend to discount, or to fail to remember, "atypical" trips, such that the tripmaking

behavior reported represents what they consider their "average" behavior. The problem with this, of course, is that in a given "average" day, a sizeable percentage of the total trips made by all people will be "atypical"; this fact will not be reflected in the data. Furthermore, tripmaking behavior may be geared to take into account the atypically long trip, for example, by compensating for potential traffic jams by leaving earlier. Certain aspects of trip-making may appear "irrational" if this factor is not taken into account.

(4) The antimodal bias--respondents may consciously or unconsciously falsify their answers out of a general antipathy to the alternative mode or modes available. While Watson does not expand on the implications of the existence of this bias (if such a bias in fact exists in significant numbers of people), they are nevertheless quite important. Admitting the existence of an antimodal bias implies that, regardless of the characteristics of the mode in question, the modal decision-maker will consistently avoid its use. This can only constitute irrational behavior; conceivably, everything about the mode could change except its name, without changing its attractiveness to tripmakers. For this reason, it seems reasonable to assume that such irrational biases result primarily from the improper specification of variables, or from the exclusion of relevant variables of modal choice. Thus, trip times on alternative modes could be reported as being longer than the actual times on these modes, due to some other, unreported, displeasing attribute of the alternative modes. (Lisco, however, states that his data on mode choice reveal no such bias.¹⁶)

The only other bias Watson mentions, the "reporting" bias, is

roughly equivalent to the "rationalizing" bias discussed above.

These problems exist whether the model is based entirely on "attitudinal" information, or whether only part of the model is so based. Thus, Bock's study of factors influencing modal split, which includes a section on the attitudes of potential system users, reaches conclusions of which the validity can similarly be thrown into doubt. It is asserted that "...the frequency with which comfort was mentioned [as an important transportation system attribute] tended to decrease with increasing income level."¹⁷ It is also stated first, that use of automobiles increases with income, and second, that mention of comfort increases with the use of automobiles.¹⁸ There are only two plausible conclusions that can be reached from the combination of these three bits of information. The first is that only lower income auto users mention comfort, and that these low-income auto users are sufficiently numerous to outweigh the effect of the more stoic, richer auto users. A second more plausible hypothesis is that as incomes increase among auto users, internal comfort comes to be taken more and more for granted.

Several conclusions can be drawn from this discussion. First, the results of interview assessments of transportation system attributes are thrown into question due to the biases discussed above. Some of the problems can be "handled" by making reasonable assumptions about the probable distribution of the resultant errors. For example, the rounding bias can be dealt with by assuming an even distribution from 13 to 17 minutes of people reporting travel times of 15 minutes; or it could be assumed (perhaps more validly) that reported times

represent maximum trip times, such that "fifteen minutes" indicates a range from 11 to 15 minutes. The uncertainties resulting from these assumptions seem ultimately possible of empirical resolution.

The problem of "shortsightedness," however, seems fairly intractable, especially when it is realized that user attitudes are being assessed in a period in which transit service is almost uniformly bad.

There does not seem to be any way of resolving these problems. As a consequence, it is recommended that attitude survey data of this type be used in conjunction with more quantitative, objective measures of tripmakers preferences and attitudes, for while objective measures are useless without some degree of attitude input,¹⁹ still they are not as subject to problems of irrationality.

In common with all models that attempt to approach the problem of modal choice from the viewpoint of the individual decision-maker, the "reported" type of attitudinal model has great potential, in the sense that if the attitude theorists are ever able to accomplish what they have established as their goals, highly significant information will be made available to policy makers, transportation system designers, and modal choice forecasters. However, while the orientation of the approach is unimpeachable, the methodology has not as yet been developed to the point where the problems of the biases in reporting and the measurement of system attributes are amenable to solution. It is in this respect that quantitatively oriented models gain their significant advantages.

2. The Measured Type of Attitudinal Model

A significant attempt to provide the needed quantitative basis for attitudinal models has been developed by Richard M. Michaels;²⁰ his approach seems to be one of a very few quantitative approaches that do not draw directly on economic theory. Michaels instead develops a quantitative basis in measurements of the galvanic skin responses of drivers on various road types. Since the approach thus concentrates on direct user responses to transportation system stimuli, it has been classified as an attitudinal model, even though the "attitudes" surveyed are subconscious, physiological reflexes, rather than conscious objects of reflection.

Several features of Michaels' approach deserve mention; before going into these, however, it will be necessary to review the methodology that was used, and the conclusions that were reached, more extensively. The methodology involved taking a continual reading of the galvanic skin response of various test drivers, at the same time that a passenger in the car recorded traffic events to which significant responses were made. In one series of tests, traffic volumes were measured during the hours the tests were made, so that a relationship between the frequency of tension response and the level of congestion could be derived. It was found that "the events which generated the greatest mean tension response were those involving a maximum difference in speed between the object and the test vehicle.... Turning maneuvers and crossing and merging were the most tension inducing."²¹ Michaels also concludes that "a road generates tension in drivers inversely with the predictability of interferences and directly with the complexity of the traffic situation

with which they must deal."²² A pedestrian stepping off the curb, a stoplight that may or may not change to red, and a car that may or may not yield are all examples of typical tension-inducing traffic situations.

By examining a situation wherein drivers chose between alternative routes, and comparing the galvanic skin response measures produced during tests on those routes, it was found that "the route subjectively preferred by drivers induced an average of forty percent less tension response per minute than did the other route."²³ An analysis of the variance demonstrated that the "differences between routes were statistically significant."²⁴ From these results, and from the results of similar tests reported on six years later, Michaels draws the conclusion that "...total stress incurred in driving is a more important determinant of route choice than either operating costs or time costs."²⁵ It is further concluded that "...drivers evaluate alternative highways in a rational, though subjective, fashion...."²⁶ From all of this, it is concluded that "no economic determination [of route selection] seems feasible without knowing the scale of value drivers use and its relation, if any, to dollars."²⁷

There are certain problems with the approach that tend to detract somewhat from the strength of these conclusions, however. First of all, as Thomas points out, "...there are a number of difficulties with the use psychophysical measurements. Many measurement techniques produce results that vary widely from person to person and for the same person from day to day. The galvanic skin response technique is particularly faulty in this regard...."²⁸ Other problems relate to the appropriate use of statistical measures of

the level of tension generated by the roadway environment, that is, whether it is more important to avoid large mean tension responses, or to avoid extreme tension responses, associated with lower mean levels.

Additional problems of the applicability of such measures to the comparison of modes with high external discomfort (congested auto trips), and modes with high internal discomfort (transit trips); of the interdependence of these measures with the variable of travel time; and of the contrived nature of the experiment. In addition, it should be noted that Thomas reached opposite conclusions (if it can be assumed that traffic impedances are roughly equivalent to tension generators) relative to the importance to users of impedances.²⁹ It is therefore concluded that the use of the galvanic skin response is not immediately applicable to transportation planning situations.

The objective type of attitudinal model nevertheless seems to have a good deal of potential, especially if (as Michaels suggests³⁰) it can be related to economic considerations. It is clear, however, that the basic unit of comparison must be economic, rather than psychometric, due to the difficulties outlined above. Michaels' neglect of factors other than those directly associated with user attitudes (and reflexes) indicates an assumption that user preferences and attitudes are the sole determinants of route choice. This is clearly not the case; in order to develop a more valid model, it will be necessary to relate these attitudes and preferences more closely to system characteristics, and to limitations deriving from socio-economic characteristics of the user.

This is a criticism that may be applied to the attitudinal models in general. In concentrating on user attitudes and preferences, they have developed one-sided models that generally fail to consider other important factors of mode and route choice. Income, for example, is seen solely as a determinant of user attitudes, and not as a budget constraint. In using proxy variables such as residential distance to the central business district, they have missed the opportunity to relate user preferences to actual differences in system characteristics. As a result of this oversight, the policy information they generate is less reliable.

A final major problem (relating more particularly to the subjective type) stems from the assumption of constant user attitudes and preferences (rendered untenable by the short-sightedness bias). It would seem desirable in such models to devise a way of modeling changes in user preferences, relating these to changes in transportation system characteristics and changes in socio-economic characteristics. A cross-sectional model accounting for these characteristics completely could be quite useful in terms of policy direction. The absence of such an orientation, in addition to the biases in the subjective type and the measurement problems in the objective type, render attitudinal models inadequate to the task of modal choice modeling.

B. Econometric Models of Modal Choice

The final category of modal choice model to be evaluated is made up of the econometric approaches. Developing in response to the same basic problems motivating the development of attitudinal

models, the econometric modelers have been a major source of criticism of the conventional modal split models,³¹ and have done a great deal to stimulate both the improvement of travel forecasting models, and the search for attitudinal underpinnings to some of the behavioral assumptions incorporated into models of modal choice.³²

The models that are herein classified as econometric models "...share the characteristic that the various modes or destinations are regarded as commodities, each with its own price and among which the consumer chooses so as to maximize...some index of satisfaction."³³ Aside from a common basis in economic theory, and from a mutually held concern with the consumption of transportation goods and services, however, the types of approaches reviewed in this section have little in common.

Two broad types of econometric models have been identified, termed in this thesis the "demand models" and the "choice models."³⁴ Demand models operate on the basis of the economic theory of demand and price elasticity relationships applied to urban areas at a zonal level of aggregation. While none of these models are as of yet fully operational, nevertheless significant developments in theory have been made. Choice models operate from the levels of the individual consumer, in attempting to specify measures of the utility function of urban travel. These models therefore operate on a probabilistic basis, at a disaggregate level of analysis (hence the term "disaggregate stochastic" models). Young³⁵ has demonstrated that a demand function for urban travel can be developed from a utility function; similarly, Manheim has demonstrated³⁶ that both model types are sub-types of a general equilibrium model, as

seen above. Consequently, it is likely that both model types will ultimately find uses in transportation modeling. Manheim, in fact, suggests that both model types be used in conjunction with each other, the demand models for accurate large area analysis, and the sequential implicit models for those analyses for which a greater degree of control over the process is desired.³⁷ A general equilibrium model can also be developed so as to be given a probabilistic interpretation, potentially providing "...an explicit bridge between disaggregate stochastic models and aggregate models."³⁸

As a consequence of these interrelationships between the two model types, it is felt that there is no need to determine ultimately which of the two models is to be preferred. While the short-term significance of the trade off between the improved functional form of the explicit demand models and the more causally efficient data base and orientation of the choice models will be briefly reviewed, it is presumed that ultimately research into both areas of analysis will prove rewarding, perhaps in terms of disaggregate stochastic models providing the causal basis for simultaneous demand functions incorporating probabilities of travel movements.

1. Demand Models

The first of the demand models to be developed was the series of models developed by Kraft, Wohl, Domencich, and Valette. Based on the notion that "the variables identified by the theory of consumer behavior as relevant in a study of demand are the price of the good or service being investigated, the prices of competing or complementary goods or services, and income,"³⁹ it was determined that the

variables relevant to the prediction of travel demand include the time and money requirements of subject, complementary, and competing travel commodities, as well as the usual attraction variables and trip generation variables (age, occupation, family size, ethnic background, and so on). Then (translating the equation⁴⁰) the number of round trips of a given purpose by a given mode is a simultaneous function of the socio-economic characteristics of the origin zone, the socio-economic and land use characteristics of the attraction zone, the round trip time and cost for the given purpose by the given mode, and the round trip times and costs, of round trips by alternative modes for the same purpose. The fact that it is a simultaneous model requires that interzonal movements be measured in terms of round trips; this is what is referred to in Reichman and Stopher's criticism that "although these models are conceived only as generation and modal choice models, to make them operational... requires that trip distribution be included. This is necessary because... the specific trip interchange must be known before values can be obtained for the system characteristics operating on modal choice and generation...[since] a combination of modal choice model and generation model is not defined operationally."⁴¹

The main focus of these models, however, is on the elasticities and cross-elasticities of travel demand by alternative modes. It is argued that "...the use of demand relations and cross-relations permits both the total amount of trip making and the split among modes (for example) to be altered as the price or travel time for any mode is changed...with demand models of the sort proposed (in form at least), tripmaker decisions about whether to make a trip, where to

take it, and by what mode and route to take it are treated as simultaneous and interrelated decisions..."⁴² instead of separately as in the case of sequential implicit demand models. This is made possible by the concentration on relationships between competing modes.

Although the model accounts for such variables as the time of day of the trip, in its most expanded form, and although changes in trip cost are immediately reflected in reduced trip generation rates, the model nevertheless has two flaws. First, although the relationships used as the basis of the model equations are developed on a disaggregated basis,⁴³ it is expected that the complexity of the model will require the use of values representing entire zones, "... such as the median, simple mean, or weighted average of the [travel times, prices, and socio-economic characteristics values], for all individuals in the zone."⁴⁴ The problems with this sort of aggregation involve questions dealt with above in Chapters II, IV, and VI.

The second flaw in the model is the lack of a perfect equilibrating mechanism, stemming from the failure to include travel volumes on both sides of the equation⁴⁵ (so as to better account for the effect of congestion in one hour on trip making in other hours, for example), and the lack of land use variables. The assumption of constant future land use is necessitated by the extremely cumbersome nature of the model, and by the lack of an adequate land use theory.⁴⁶

Another contribution to the theory of modal choice is R. E. Quandt's concept of "abstract modes." As developed by Quandt and Baumol⁴⁷ and refined by Quandt⁴⁸ and Mayberry,⁴⁹ the concept replaces sets of cross-elasticity relationships with a perfect

substitution model, based on theoretical work by Lancaster,⁵⁰ who in revising economic utility theory has changed the locus of utility from goods and services to characteristics of goods and services. Quandt and Baumol's significant contribution lies in the improvement made to the theoretical foundation for predicting the effect on travel demand of innovative modes. Thus, the abstract mode concept improves the theoretical basis of the assumption that individual biases exist relative to each mode characteristic, rather than on the basis of total system characteristics. This implies that extrapolations of trends relating to declining transit usage cannot be considered valid unless it can be shown that the characteristics of transit against which passengers were biased are likely to remain unchanged; in short, "total travel must not depend on the names given the modes."⁵¹ Thus, "...an abstract mode is characterized by the values of the several variables that affect the desirability of the mode's service to the public: speed, frequency of service, comfort, and cost..."⁵² and as a consequence "the theory...presupposes that individuals are characterized by modal neutrality...."⁵³ This assumption has been empirically verified, to a certain extent.⁵⁴ The abstract mode concept provides a basis for assuming general "rationality" of mode choice, provided that all relevant mode characteristics are specified.

Quandt and Baumol have operationalized the abstract mode type of demand model,⁵⁵ but have applied it only to problems of inter-city modal split, so that there is no real basis for comparison in terms of level of aggregation. It seems likely, however, based on Mayberry's axioms establishing rules for formulating demand

functions to be applied to homogeneous income groups,⁵⁶ that the level of aggregation will be rather high; this is only appropriate for a model that attempts to predict aggregate effective demand in toto.

The abstract mode models of travel demand thus have the advantages of policy adaptability and greater behavioral validity, combined with the disadvantages of reliance on factors such as the weighted average of per capital income in origin and destination zones, in addition to the failure to account for the affect on land use of transportation systems, and thus the failure to determine validly the equilibrium flows. (These failures are not nearly so critical in intercity modal choice situations however, for which these models were originally designed.)

Demand models in general are characterized by aggregation problems, to the extent that the requirement that models be developed from the orientation of the individual is neglected. Thus the abstract mode model accounts for relative and absolute differences in travel time and travel cost, without attempting to develop causal relationships between user characteristics and the relative importance of either of these two variables; such relationships are to be determined at an aggregate level by an examination of the mode choice data to be reproduced in the statistical testing phase. It is in this sense, that is, in the greater validity of disaggregate equations, that the disaggregate-stochastic models make up for their reliance on a sequential implicit demand model.

If, as Manheim⁵⁷ asserts the problems with the current sequential implicit demand model (the Urban Transportation Planning Package series) can be resolved by introducing requirements of

activity and levels of service consistency, and by carrying out a number of iterations, then the advantages of causal efficiency, individual orientation, and so on that the disaggregate stochastic models demonstrate warrants concentrating the analysis of modal choice in this area of methodology; for if demand models develop to the point where it will be possible to deal with disaggregated data bases, then the existence of an established body of theory and analysis will be helpful. Over the short term, in fact, modifications in the existing sequential implicit demand model seem to be both more feasible and more acceptable to transportation planning bodies. On this basis, it is possible to turn finally to the discussion of disaggregated stochastic models of modal choice (choice models).

2. Choice Models

Choice econometric models of modal choice are those that incorporate behaviorally oriented micro-economic analysis into the study of individual travel patterns. In effect, these models attempt to derive individual utility functions, related to user characteristics such as income. There are several advantages to this approach, related to the nature of the disaggregated data base and to the analysis techniques used. One of the most important is the ability to test a potentially large number of measures of user preferences not amenable to aggregate analysis; this is a characteristic shared with the other type of "behavioral" model, the attitudinal models. Another advantage deriving from this first attribute in part, is the ability to "...provide a basis for inferring the relative values that people place on various characteristics of the transportation systems."⁵⁸ Thus, by approaching the problem of modal choice

"...from the standpoint of what it is that motivates an individual to choose one mode over the other,"⁵⁹ the disaggregate-stochastic model provides a basis of efficient causes from which can be derived the policy mechanisms of interest to transportation planners. The advantage that these models have over the attitudinal models is that they have incorporated the element of money cost and micro-economic theory into their models, so that a quantitative measure of the relative importance of various system characteristics is provided.

The choice models thus have the advantage of a strong basis in two research strategies. Warner, for example, (who can be considered the first disaggregate-stochastic model theorist) was able to base his analysis of modal choice on micro-economic theory, asserting that "elementary economic considerations often lead to useful hypotheses regarding consumer choice,"⁶⁰ while Stopher and Lisco⁶¹ base their modifications of economic theory on modern theories of discrimination and choice. Thus, "...since there is a minimum variance in discrimination and there are dynamic changes in preference, every human decision is in essence, probabilistic. [Two conclusions stemming from this fact are] ...that the number of variables required to predict probability of choice is finite and rapidly approaches the limits of human discrimination; and...that as a set of alternative choices becomes equivalent in subjective characteristics, the probability of [a given specific] choice approaches a limit, $1/n$, where n is the number of alternatives."⁶² All of this justifies a limitation on the number of variables necessary to produce good predictions that is indefensible in terms of pure economic theory, where the postulate of economic rationality requires perfect knowledge

of all relevant cost and utility variables. (Such an approach would assume that each tripmaker performs a benefit/cost analysis every time a trip is anticipated, which assumption entails difficulties in terms of such problems as determining the correct user evaluation of the "cost" of fatalities, for example.)

As a result of such behavioral theory-derived considerations, all of the choice modelers have limited the number of variables considered to be efficient causes to a relatively small number. Thomas, for example, has developed a model of route choice based on variables of trip purpose, income level, travel time difference, and total tolls, for route choice problems involving decisions between toll roads and comparable free routes.⁶³ Lisco,⁶⁴ on the other hand, takes into consideration the additional factor of comfort, as do many others. In none of the models, however, does the number of variables constitute a sufficient basis for benefit cost analysis; in fact, for most of these models the number of instrumental variables is less than five.

Choice models have the additional advantages (due to their exclusive concentration on individually-oriented, efficient causal variables) of geographic transferability. In addition, the causal relationships developed in these models are not distorted by problems of sensitivity to zone size, nor to problems of ecological correlation. Furthermore, the disaggregated data base provides flexibility in terms of the later choice of aggregation levels for further applications of the data.

The usual approach in disaggregated stochastic models of modal choice is to analyze data on mode or route choices according

to the income of the tripmaker, the purpose of the trip (usually work), the ratio or difference between the travel times on alternative modes and the ratio or difference between costs on alternative modes, with the addition sometimes of other less universally used variables. Relationships among these variables are then determined through use of either discriminant-classification techniques, logit analysis, or probit analysis.

The measurement of many of these variables is the subject of some considerable debate among choice theorists, due to disagreements on the nature of the data base that should be included (e. g., between perceived and measured data), on the question of the development of measures of comfort, and on the issue of the appropriate nature of the value of time. These issues are all related (and in fact develop from alternative means of deriving a value of time), and are in addition quite crucial to the problem of modal choice.

One of the most important considerations in the development of a utility function of travel (as was pointed out in the section on attitudinal models above) involves the specification of variables in terms of which other variables can be stated; this identifies the relative importance of each variable, and permits the prediction of the effect on consumer choice of new transportation modes altering the quantities of each attribute available. In an economic model, the translation of variables into a common standard is accomplished by developing money "costs" for each variable; differences in philosophy and technique related to the solution of this problem have led to the development of two distinct approaches to time valuation, identified in this thesis as the "wage-related" approach on the one hand, and the

"variable-value" approach, on the other. The variable value approach has been developed in relation primarily to problems of route choice, in a series of studies carried out by the Stanford Research Institute. Although this approach is contrasted with the wage-related approach, the approach taken is nevertheless not unrelated to variables of income. The Stanford Research Institute studies have developed a complicated set of time value curves for eight income classes and five trip purposes. The distinction between the wage-related and the variable-value time valuation schools is therefore made on the basis of a theory of a constant value of time as a percentage of income, on the part of the wage-related theorists, as opposed to a theory of a value of time that varies with the amount of time saved, on the part of the variable value theorists.

The difference cannot be explained on the basis of a difference in technique, since both groups of theorists develop their models on the basis of the same sorts of procedures; the distinction is purely the result of theoretical disagreements. Thus, as Thomas and Thompson state in their rejoinder to Lisco's criticisms of their study of time value for commuting motorists:

Two research groups studying the value of travel-time savings used data on individual traveler's transportation choice. Both arrived at a constant (marginal) value of time within a few cents of each other. Both had a large intercept term favoring one route when there was no difference in travel time between the different routes. One study found one route to be preferred over the other by about \$2.00, while the other found a preference of about \$0.40.

The first study (Lisco) used mode-choice data. It concluded that it was reasonable to assume that the full estimated \$2.00 preference of an average motorist for the automobile over rail rapid transit could be explained by convenience, scheduling, and other factors. The second study (SRI) used route-choice data. It could not see any

reason why the average motorist would have to be paid \$0.40 to use the toll route given no time difference between routes, because the engineering quality of the toll route was higher than the free route.⁶⁵

The Stanford Research Institute study bases its variable value of time on the observation that "for very small amounts of time saved, empirical evidence indicates that motorists are insensitive to reductions in trip time, while economic theory suggests an eventual diminishing marginal utility of time saved as the amount of time saved continues to increase."⁶⁶ Income then enters into the relations only on account of the greater ability of higher income individuals to pay for desired time savings. It bases its later division of benefits according to trip purpose strictly on willingness to pay (that is, on empirically observed payment) criteria.

The wage-related theorists have not argued these points on theoretical grounds. Nevertheless, taking each of these points in order, it is possible to justify a wage-related approach on the order of those developed by these theorists, with the following arguments.

(1) It can be argued that the fact that route choice variables need not include comfort while mode choice variables should, is the result not of perverse theoretical viewpoints on the part of mode choice analysts, but on the very great differences between the levels of internal comfort of an automobile and rail rapid transit. That the intercept in the route choice model was much smaller thus does not necessarily indicate a higher degree of statistical validity.

(2) The fact that the toll road has a higher quality of engineering than the free route may merely indicate that engineering quality is not a determinant of route choice. Factors such as congestion,

impedance, and so on, may make more difference than travel time alone; Michaels, it will be remembered, asserts that "...total stress incurred in driving is a more important determinant of route choice than either operating costs or time costs...."⁶⁷ Though this is probably overstated somewhat due to problems of collinearity and the artificial environment of the study (see above), nevertheless such a factor may have been overlooked.

(3) The fact that motorists are insensitive to small savings of time may be the result of sampling problems. The large amounts of time savings shown in the chart accompanying the paper⁶⁸ indicate that the sample may be somewhat biased. In order for time savings of thirty minutes to be possible, trips of considerable duration must be being taken; in trips this long, questions of the risk of being delayed may be more important than questions of the opportunity to save small amounts of money. Thus, even though the actual time saving is small, it is the risk of time loss that is avoided. This is even more likely in the case of vacation trips, where the additional factor of unfamiliarity with the areas being driven through may account for the willingness to pay tolls more than the value of time to vacationers. In either case, small time savings will be foregone due to factors of the risk of time loss and uncertainty. For the unsampled shorter commuter trips, small time savings may be more important.

(4) A related factor is the possibility that planning to account for differences in time may require more time than will be saved. Then although searching for time savings would constitute a potential loss of time, such that such searching would tend to be foregone,

the providential receipt of small time savings would not be valued at less than the normal time rate. (This is one of those areas wherein attitude data can aid the development of behavioral models.)

(5) The consideration of income as budget constraint is inconsistent with the notion of the diminishing returns to greater time savings. A more plausible way to include income in the time valuation problem is as some fraction of the wage rate, reflecting the fact that for different income levels, time costs constitute different proportions of the total family budget. Thus it may be that the money costs of travel by the quicker route will be worth more if spent on other items than if spent on time.

(6) Thus the concept of a constant wage-related time value is defensible on theoretical grounds. The theoretical basis of the variable time value approach is weak, however, since it is based on an indifference curve approach that in effect derives user preferences as givens, without deriving the causal factors behind the empirically observed values. The approach thus lacks a sound behavioral research strategy, though it is superficially founded in economic theory.

The use of a wage-related approach makes possible the concept of the derived demand for time implicit in the development of different time values for different purposes. According to such a view, time spent in travel would be valued more or less highly depending on the pleasure to be derived at the destination. These sorts of considerations, however, can be treated separately from time value considerations, in the same way as the value of "comfortable time" is separated into the value of comfort and the value of time.

This constitutes a more valid basis for modal choice analysis than the aggregation of different factors into a single summary variable. According to such a view, for example, the value of time for work trips as empirically derived by Thomas would be composed of the actual base time value, and an additional factor expressing the effect of the penalty for tardiness incurred by late arrivers at the work trip destination. This would tend to explain the difference between the high value assigned to work trip time and that assigned to, say, shopping trips. This would also account for the large discrepancy between perceived and measured benefits to travelers, validating Thomas' statement that the use of non-perceived data should be considered a specification error in time valuation,⁶⁹ but for a different reason: the faulty perception of a system characteristic is held to result from the use of that characteristic as a summary variable, and thus from improper specification of system characteristics.

While the concept of separating out the derived demand value from the total "empirical" value of time constitutes a considerable step away from the wage-related approach, it is nevertheless felt that this is compatible with the approach; Lisco, for example, has separated discomfort from the value of walking time, and comfort from the value of automobile riding time.⁷⁰

In conclusion, it is felt that the wage-related choice theorists have the greater potential to determine the interrelationships among user preferences for system characteristics, by virtue of their more rigorous research strategy. The addition of the concept of a derived demand for time may permit the better integration of attitude

survey data into choice models, thereby permitting the quantification of significant attitudinal variables. Choice models as a whole thus present the possibility of greatly improving the validity of the modal choice modeling procedure.

C. Conclusions

The benefits of the conceptual approach are evident primarily in the improved ability to handle the effect of changes in the characteristics of transportation systems induced by policy, on the use of alternative modes. This indicates a greater adaptability to situations of advancing technology: the abstract mode concept, and the concentration of the choice theorists on individual choice problems, permit the description of any new mode in terms integral to these models. While attitudinal models have the drawback of the various biases cited, nevertheless the concentration on an efficient cause, user preferences, provides useful inputs to other models (in particular, the choice models). Conceptual models have greatly increased the theoretical soundness of modal choice modeling, by improving the consistency of the models overall, and by concentrating on causal relationships and causal variables (though demand models are forced to use proxies for these variables). The causal emphasis of the behavioral and economic research strategies greatly increases the confidence which can be placed in these models' results.

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PART III

CONCLUSIONS

CHAPTER VIII

CONCLUSIONS

Certain points which have been discussed should be reemphasized. The first is that the a priori criteria of the need for variables with an orientation towards policy, causal efficiency, and individual behavioral units, and of the restrictions placed on the specification of proxy variables have proved useful in the evaluation of the modal choice models reviewed.

The second is that the conventional system of travel demand modeling lacks a considerable degree of validity and accuracy, and should be improved to the point of accounting for the various feedback loops now neglected, and of reflecting a consistent set of causal variables in every step of the process. This means that feedback processes such as the relationship of levels of congestion to the demand for travel, and the effect on land use of travel behavior in general, must be accounted for. This can be done either through the use of explicit demand models, or through an iterative procedure with sequential implicit models. In addition, regardless of the overall model system that is used, requirements of consistency must be met. Thus, for example, variables that are used to predict modal choice must relate conceptually to the variables used in distribution, generation, and assignment. If time and cost are important in

explaining mode choice, they should apply as well to the other travel decisions predicted.

The third is that conventional modal split models are weak in causal structure, and that as an initial step in improving the process, they should be replaced within the structure of the Urban Transportation Planning Package series by disaggregate stochastic models. Suitable modification in the rest of the models in the series should also then be carried out.

The fourth point is that research into attitudinal modeling, into simultaneous equation travel demand models, and into other equilibrium models should continue, with an effort being made to incorporate probabilistic relationships and causally efficient variables into the analysis. These improvements will serve both to enhance the usefulness of the models as policy tools, and to increase the causal structure and long-term reliability of the models. A greater emphasis on efficient causes will yield a greater potential for predicting the effects of transportation system changes induced by policy. Stating model conclusions in terms of probabilities will increase the validity of the model, as well as providing a more useful basis for policy decisions.

Finally, economic and behavioral research strategies should be more closely interrelated, so as to better explain the "economic rationality" of the tripmaker. The "economic man" concept, and the related one-dimensional "economic determinism" of many of the models considered, should be foregone in favor of a more broad theoretical basis in psychology and culture theory. Where large percentages of people appear "irrational," it should be assumed

that the model is incomplete in its consideration of the influences on behavior.

In general, it has been seen that the need for a means of inputting the effects of policy changes or changes in transportation system technology has motivated the search for a stronger basis in causality for explaining and predicting modal choice behavior. This has led to the renunciation of trend extrapolation techniques prevalent in the earlier stages of the history of modal choice model development, in favor of more behaviorally-oriented approaches. The process of improvement has been halting, however; it is for this reason that the contribution of this paper may be significant.

Various reasons for the incorporation of causal structure into modal choice modeling have been suggested, including the need for a research strategy, a policy orientation, an emphasis on efficient causes, and an individual orientation. This thesis has organized the various criticisms of various approaches into a more structured, sound theoretical basis for modal choice modeling. The success of the conceptual approaches may point out the dangers of the too great reliance on statistical verification techniques that has characterized the empirical approaches to the modeling of modal choice, and to the evaluation of models.

In the actual evaluation of the models in the second part of this thesis, the combination of criticisms made amounts to an outline of an ideal model of modal choice, within the constraints of the modeling process as a whole. Such a model would include a basis in behavioral and economic theory, a concentration on efficient causes

determined at an individual level, and the consequent ability to account for policy changes. In addition, adequately accounting for equilibrium processes of both land use and travel demand natures would lead to geographic transferability and universal applicability. Such a model has yet to be devised; these are the directions in which future modeling efforts should go, however.

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APPENDIX

APPENDIX: GLOSSARY OF TERMS

The terms included in this glossary are organized for purposes of clarity into three groups, representing roughly the area to which they are most related. These are the areas of economics, of modeling in general, and of transportation. An attempt has been made to translate these special terms into language understandable to planners not specializing in these areas.

A. Economic Terminology

complementary--referring to goods or services among which there is no possibility for substitution, and among which an increase in the demand for one yields an increase in the demand for the other; this can be a onesided relationship, such that, for example, an increase in the demand for cars creates a demand for gasoline, while an increase in the demand for gasoline need not lead to an increase in the demand for cars. Bread and butter are complementary goods, butter and oleomargarine are not complementary goods.

demand--a functional relationship between the quantity of a good or service that will be consumed or purchased and its price.¹ This economic concept of demand is thus equivalent to a combination of the layman's concepts of the need or desire for a good or service, and the ability to pay for a good or service.

derived demand--the demand for those goods or services

that are characterized by a high degree of complementarity with other given goods or services.² The demand for travel is said to be a "derived demand" since travel is demanded jointly with other goods and services; shopping trips generate a demand for travel that can be "derived" from the demand for, for example, food.

econometrics--the combination of economic theory with statistics and/or probability theory and methodology. According to A.A. Walters³ "[the econometrician] must take the theory of economics and provide some measures of the magnitudes of parameters...[and]... should then use his parameters to predict events." Econometrics can thus be seen either as the statistical testing of economic theory, or as the application of economic research strategy to statistical or probabilities problems.

elasticity--a dimensionless measure defining the relative sensitivity of demand to a change in the value of a variable, "...defined as the percentage change in the quantity demanded due to a percentage change in the variable."⁴

cross-elasticity--the relative sensitivity of the demand for a good to a change in the value of a variable directly affecting another, competing good.⁵ A rise in the price of gasoline will have an effect on transit use dependent on the cross-elasticity of transit with respect to automobile user cost.

substitution--the partial or complete replacement of a good or service in the market by a competing good or service; or the replacement by one individual of one good or service for another good or service. Goods (such as butter and oleomargarine) are said to be "substitutable" if such replacement can occur.

B. Modeling Terminology

disaggregated--referring to a set of observations that has not been grouped, and that thus represents the actions of a number of individuals, rather than the "average" actions of a group of individuals. The grouping of observations of behavior on the part of non-homogeneous individuals leads to problems of hidden variance and wide confidence limits; hence disaggregate data bases are generally recognized as being desirable. Thus Quandt,⁶ who has been treated as an aggregate-base theorist,⁷ states that "...considerable advances may be achieved by improving the data used for estimating travel demand functions. It seems reasonably clear that the most important achievement in this respect would be the creation of a reliable and highly disaggregated data base."

group ("ecological") correlation⁸ --the (usually high and misleading) correlations achieved as the result of the aggregation of heterogeneous individuals into larger units for analysis. The term commonly used in the social sciences is "ecological correlation."

model--a theory expressed as a set of mathematical relationships, providing a systematic statement as to the interrelationships among forces in the real world.⁹

behavioral model--a model grounded in the theory of individual decision-making, with the basis of the theory either psychology or micro-economics. Behavioral models are therefore inherently disaggregated and stochastic.

empirical model--a model developed from the projection of correlations and trends for which causal explanations have been adduced on a post hoc basis, or for which the basis in causality is weak.

stochastic model--"[a model] in which at least one of the operating characteristics is given by a probability function."¹⁰

A stochastic model thus predicts the occurrence of a given phenomenon (such as the choice of the transit mode, for example) in terms of a probabilistic relationship of independent to dependent variables.¹¹

structural model--a model based on a structure of causal relationships thoroughly grounded in social or behavioral theory, including the theories of macro-economics, micro-economics, psychology, and sociology in particular.

specification--the process of identifying the relevant variables and their interrelationships in a model. While it is rarely possible to specify all pertinent variables, a priori theorizing about the direction of the bias resulting from excluded variables will aid in the establishment of appropriate confidence limits.¹²

variables--factors in the real world actually or potentially entering into a model, that do not remain constant in the relevant universe considered in the model. Thus, "holding a variable constant" constitutes a limitation on the universe of the model.

dummy variable--a variable representing a non-quantifiable real world entity in a model, by means of an arbitrary assignment of alternative values. Thus race could be included as a variable by assigning a value of unity for the characteristic "nonwhite," and a value of zero for the characteristic "white."

exogenous variable--a variable excluded from the universe of a model, assumed to be either constant or only slightly changing, or assumed to be irrelevant to the processes being modeled. The failure of either assumption generates "exogenous shock,"¹³ which

is a shift in the relationship between the independent and the dependent variables, but not in the relationships among independent variables.

fitting variable--a variable used in the testing of models against present-day data, that has the quality of improving model correlation coefficients more than it increases the error. Fitting variables in transportation studies typically include socio-economic and demographic characteristics such as sex, age, race, and tenancy.

proxy variable (surrogate variable)--a variable that is used to represent another, presumably more causal and more difficult to measure, variable. For comparative purposes, for example, total pounds of food eaten per day might be a useful proxy variable for daily caloric intake.

C. Transportation Terminology

disutility (generalized cost)--the sum of all the "costs" incurred in travel, including discomfort, inconvenience, time losses, opportunity costs, and money costs. Those models that have been classified as econometric choice models attempt to specify the consumer's disutility function;¹⁴ that is, they attempt to identify the generalized cost of travel.

impedance--in gravity and other spatial distribution models, the constraint on travel, seen as increasing with some form of generalized cost or disutility, in theory, but usually reflecting a single aspect of cost, that of time.

modal choice model/theory--in general, any model developed as a forecasting and analysis tool for the purpose of explaining and predicting rates of use of alternative means of transportation. The

term thus includes such terms as modal split, mode choice, route choice, auto occupancy forecasting, and mode use forecasting.

In its more specific usage, the term refers to those types of mode use forecasting models developed along the lines of behavioral and/or micro-economic theory, and that therefore emphasize the individual decision-making process, in explaining and predicting present and future choice of mode.

modal split model/theory--any model developed to explain or predict the aggregate percentage or absolute division of person-trips among competing modes, and operated with the use of data aggregated by zone, district, or study area levels.

mode--any means of transportation, including walking, bicycles, buses, trains, one-man back-pack rocket kits, and so on, but usually referring to either automobiles, buses, rapid transit, or railways.

abstract mode--Quandt's term, representing a set of attributes describing a real or imaginary mode of transportation, in terms of, for example, its relative and absolute speed, cost, comfort, and so on, and necessary to the development of his perfect substitution model of modal choice. The construct has been implicit in the work of a large number of the more recent transportation theorists, who typically assume that an individual's decisions on modal choice are made on the basis of his separate evaluation of several characteristics of his alternative modes.

D. General Terminology

a priori --developed on the basis of theoretical considerations, and not relying on the results of data analysis. A priori criteria for choosing variables in a theory, for example, are thus contrasted with "empirical" criteria. These latter rely entirely on the basis of data analysis and the "maximum correlation criterion." In many respects these terms parallel the distinction between deductive and inductive thought processes.

causal --a variable is said to be "causal" if its occurrence is associated with the subsequent occurrence of the observed phenomenon, and if it can be deemed causal on a priori grounds of theoretical logic and structure.

efficient cause --a causal variable constitutes an "efficient cause" of a phenomenon if, in the chain of causal variables leading to the occurrence of a phenomenon, it occurs most immediately prior to the phenomenon. Thus, for example, reduced residential density causes transit service to be less efficient, which causes transit trip times and costs to be less favorable than auto trips, which leads to a high probability of auto use. In this sequence, the difference in trip times and costs by alternative models is deemed the "efficient cause."

conceptual --a "conceptual" model is one that is soundly based on theoretical considerations. It is distinguished from "empirical" models, which are based on an ad hoc collection of successful correlations.

FOOTNOTES

1. Kraft, Gerald and Martin Wohl, "New directions for passenger demand analysis and forecasting," (RAND Corporation, Santa Monica Calif., June 1968), 6.
2. Oi, Walter Y. and Paul W. Shuldiner, An Analysis of Urban Travel Demands (Northwestern Univ. Press, Evanston, 1962), 12.
3. Walters, A.A., An Introduction to Econometrics (W.W. Norton, New York, 1970), 21.
4. Kraft and Wohl, op. cit., 9.
5. Ibid., 14.
6. Quandt, R.E., "Introduction to the analysis of travel demand," in R.E. Quandt (ed.), The Demand for Travel: Theory and Measurement (D.C. Heath, Lexington, Mass., 1970), 15.
7. Reichman, Shalom and Peter R. Stopher, "Disaggregate stochastic models of travel-mode choice," Highway Research Record 369 (1971), 93.
8. Oi and Shuldiner, op. cit., 51-53.
9. Voorhees, Alan M., "The nature and uses of models in city planning," Journal of the American Institute of Planners XXV, 2 (May 1959), 58.
10. Naylor, T.H., et al., Computer Simulation Techniques (Joseph L. Wiley and Sons, New York, 1968), 17.
11. Stopher, Peter R and Thomas E. Lisco, "Modelling travel demand: a disaggregate behavioral approach--issues and applications," Transportation Research Forum--Papers of the Annual Meeting XI (1970), 199.
12. Oi and Shuldiner, op. cit., 57.
13. Fisher, Franklin M., A Priori Information and Time Series Analysis (North-Holland Publishing Co., Amsterdam, 1962), 4.
14. Quandt, op. cit., 9.

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