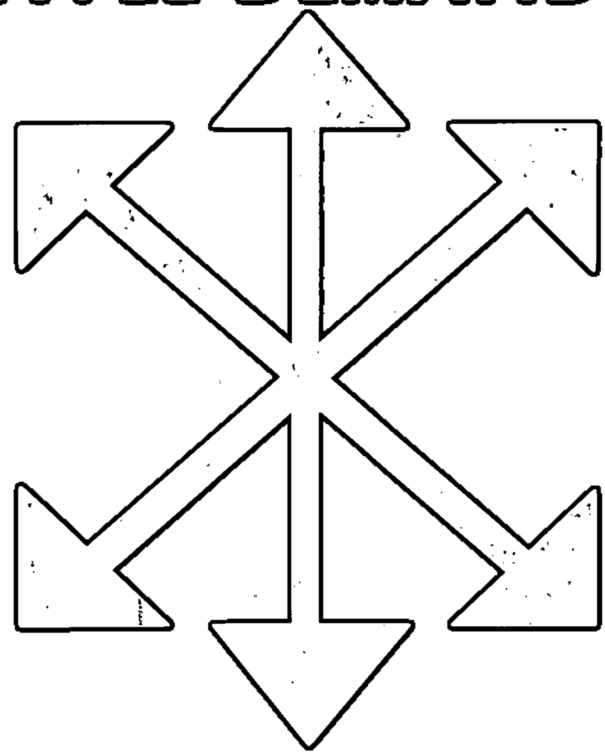
URBAN TRAVEL DEMAND



FORECASTING

URBAN TRAVEL DEMAND FORECASTING

proceedings of a conference held at Williamsburg, Virginia, December 3-7, 1972.

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The members of the committee selected to organize the conference and to supervise the preparation of this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project.

Responsibility for the selection of the participants in the conference and for any summaries or recommendations in this report rests with that committee. The views expressed in individual papers and attributed to the authors of those papers are those of the authors and do not necessarily reflect the view of the committee, the Highway Research Board, the National Academy of Sciences, or the sponsors of the project.

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PREFACE

This volume constitutes the record of a Conference on Urban Travel Demand Forecasting held December 3-7, 1972, at Williamsburg, Virginia. The conference was sponsored by the Office of Environment and Urban Systems, Office of Policy, Plans, and International Affairs, Federal Highway Administration, and Urban Mass Transportation Administration of the U.S. Department of Transportation, The conference was conducted by the Highway Research Board.

Organization and direction of the conference were responsibilities of the Advisory Committee on Urban Travel Demand Forecasting consisting of George V. Wickstrom, chairman, Melvin D. Cheslow, Robert B. Dial, David S. Gendell, Kevin E. Heanue, Thomas E. Lisco, James M. McLynn, K. H. Schaeffer, Joseph L. Schofer, Kenneth W. Shiatte, Edward Weiner, and Richard D. Worrall. Daniel Brand and Marvin L. Manheim assisted the committee as conference consultants, and James A. Scott of the Highway Research Board assisted as staff liaison.

The organization of the report follows generally the organization of the conference. Reports of the chairmen and resource papers are given together under the headings of the respective workshops. Keynote papers and papers by other conference speakers are grouped under the 2 headings of Forecasting and the Decision-Making Process and State-of-the-Art Papers. The remaining material was prepared by the editors after the conference to summarize the discussions and to arrange the workshop recommendations in an implementation program.

Daniel Brand
Marvin L. Manheim
editors

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INTRODUCTION

Decision-makers face a wide range of pressing problems involving transportation. What adjustments can be made to existing transportation systems and services to meet and maintain air quality standards and to conserve energy? How can transportation be provided to groups with limited mobility? What are the most effective means for improving transit service? How can transit operating deficits be minimized?

Answers to these kinds of questions require information about many aspects of the social and economic structure of the community and the engineering capabilities and constraints of the facilities and services. Travel forecasts are an important element of that information base. The estimates they provide of the number and characteristics of travelers for each transportation alternative are used to calculate travel benefits, neighborhood disruption, environmental impact, energy usage, and other items necessary for decisions.

Present travel demand forecasting procedures were developed incrementally during the past 20 years and have been used during that time in more than 250 metropolitan areas in North America and, with variations, in many other cities throughout the world. The issues they address most effectively are those that were most important in the 1960s: long-range, regional transportation plans and information necessary to design the major facilities.

The issues of the 1970s, however, are different and more numerous. Planners must evaluate a wider range of options including not only new transportation systems such as demand-responsive transit but also low-capital options such as parking policy, flow metering, exclusive lanes for buses, traffic control schemes, pricing policy, and vehicle exclusion zones. Moreover, the option of not building facilities is being increasingly selected by decision-makers as environmental and social effects are more thoroughly evaluated.

As energy and resource constraints become significant issues of public policy, more attention must be given to ways of influencing urban travel patterns in order to change energy consumption levels and to reduce the adverse impacts of transportation. Also, policies toward energy in other sectors, such as fuel price increases, will have consequences for urban travel demand.

There are also the issue of equity (Which groups will gain as a consequence of a particular transportation plan and which groups will lose?), the desire of the public to participate in the decision process and to understand the analyses underlying the decisions, and the recognition of the dynamics of change and the degree of uncertainty in planning for the future in many metropolitan areas.

To respond to these important issues of urban transportation planning, decision-makers must have confidence that the consequences of their choices have been ascertained by reasonably reliable methods. What is needed are travel forecasting procedures that are sensitive to the wide range of policy issues and alternatives to be considered, quicker and less costly than present methods, more informative and useful to decision-makers, and in a form that nontechnical people can understand.

It may be necessary to develop a number of travel forecasting techniques to meet all these needs. Some techniques would produce information for many alternatives quickly but produce results at a gross scale. Others would produce more precise results but require greater time and cost to operate. Still others would produce short-range estimates that are 5 to 10 years away.

Within the past few years many suggestions have been made for improving forecasting procedures, and a number of new techniques have been developed that seek to overcome some of the limitations of current procedures. Although there is general consensus that improvements are needed, there is no consensus on what improvements should be made, what new techniques should be developed, or how to proceed to achieve the improvements.

Recognizing the importance of travel forecasts and the need to update the methodology, the U.S. Department of Transportation requested the Highway Research Board to convene a conference of experts in the field. The 5-day conference was attended by some 80 practitioners and researchers. It has the following objectives:

- Determine the information needs of decision-makers relative to transportation issues and problems.

- Determine the appropriate role of urban travel demand forecasting procedures in urban and regional transportation planning processes.

- Review and evaluate current understanding of urban passenger travel behavior and current capability of incorporating urban passenger travel behavior in forecasting procedures.

- Determine the need for improving passenger travel forecasting procedures.

- Determine the analysis process within which travel forecasting procedures operate.

- Determine the performance requirements and limitations of travel demand forecasting procedures.

- Identify directions for new and improved passenger travel forecasting procedures and techniques—including data requirements—that are responsive to the identified needs and requirements.

- Recommend to the U.S. Department of Transportation new procedures and improvements in the existing passenger travel demand forecasting process that are responsive to the identified needs and requirements and that could be made within the next 1 to 3 years.

- Recommend to the U.S. Department of Transportation a short- and long-range program for research directed at developing travel demand forecasting procedures that are responsive to the identified needs and requirements.

- Recommend to the U.S. Department of Transportation the immediate steps toward implementation of the findings, conclusions, and recommendations of the study.

Conference objectives were met largely during the sessions of 6 workshops. Resource papers, prepared prior to the conference, served as a starting point and catalyst for the workshop sessions. The workshops viewed travel forecasting and its present deficiencies from the perspectives of the transportation options being evaluated, the broad range of social, economic, and environmental impacts that depend on traffic volumes and traffic operating conditions, and the requirements and opportunities for travel forecasting that result from considering how people make travel choices. Each workshop produced a summary report of its deliberations and a series of project statements. The project statements describe potential research projects and projects to implement research results already available. The 6 workshops produced 115 project statements, which have been combined into an integrated program of research.

In addition to the workshop resource papers, several speakers discussed what decision-makers want from the planning process in general and the forecasting procedures in particular and where they think deficiencies currently exist. Two detailed and well-documented state-of-the-art papers were also presented.

This report contains the proceedings of the conference both in summary form and in full. Decision-makers and top-level administrators will find the Summaries of Conference Findings and the Implementation Program particularly helpful in their review of departmental programs and budgets. Program managers who have responsibility for initially developing those programs, technicians who must use the methodology, and researchers who must respond to the mandate to improve and update that methodology will undoubtedly want to read the full report.

It is hoped that the report will convey the sense of excitement felt by the conference participants about the new era into which travel forecasting is entering. They could see emerging a stronger behavioral basis for travel demand models, a coherence and unity of the apparently diverse direction of current work, and a tremendous improvement in the practical capabilities for travel forecasting. They recognized, however, that to get from here to there will require substantial amounts of research and the necessary support for that research.

SUMMARY OF CONFERENCE FINDINGS

Travel forecasts are needed for informed transportation decision-making.

Accurate estimates of future travel are essential to identifying which groups benefit most from each transportation proposal; the effects that different facility designs and operating policies have on volumes and quality of service; the costs and revenues to transportation construction and operating agencies; environmental effects such as air quality, noise, and energy consumption; the posibilities for serving particular travel needs through alternative means; and the indirect effects that the pattern of social and economic activities have on land use, employment, and other aspects.

Improvements are needed.

Improvements in travel forecasting methods are urgently needed to supply more effectively the information required for pressing transportation decisions at all levels of government. Present procedures need simplification and streamlining to improve their utility, their policy sensitivity, and their validity: The time required to use forecasting procedures must be reduced to allow more effective response to decision-making; the costs of developing and using forecasting methods must be reduced to enable many more alternatives to be analyzed and to respond to a variety of forecasting requirements; confidence in forecasts of future travel should be improved; and the range of policies for which forecasting methods are valid should be extended.

Information is now available that can be used to achieve immediate improvements in operational capabilities.

Significant improvements in travel forecasting capabilities can be achieved within a period of 3 years and, in some respects, even within 1 year through the use of new techniques based on results of recent research. The new methods are now ready for prototype use in planning and design projects. A small number of pilot studies could be established to test these new techniques.

A repertory of improved methods should be developed.

No simple forecasting method is likely to satisfy all forecasting needs as to scale, time horizon, or speed of response of information for decision-making. Attempts should be made not to develop a single set of methods useful for all situations but to develop very quickly several methods, each appropriate to a particular set of issues. Priority should be given to developing methods for the following areas: subareas and corridors, short-run and low-capital options, new systems and services, mobility of special user groups, and environmental and energy-related issues.

Substantial improvements in forecasting capabilities can be achieved in the future.

A deeper understanding of traveler-choice behavior under a range of conditions will allow researchers to develop forecasting methods that can be more easily transferred from one urban area to another, will create more confidence in forecasts of travel demands for new systems and in identification of travel needs of special user groups, and will result in potential savings in the costs of travel forecasts.

Improvements in monitoring and analyzing the effects of transportation changes will substantially improve the understanding of travel behavior, and that can be translated quickly into improved information for transportation decision-making, especially in the planning of improved transit services and short-run highway system improvements.

Practical methods to implement increased understanding of travel behavior such as equilibration methods, analytical structures, and estimation methods, will allow the overall forecasting process to provide more timely, valid, and useful results at lower cost.

Improved information dissemination and training are needed.

Dissemination of information on new and improved forecasting methods and training in the use of these methods are essential so that staffs of state and local agencies can use the methods rapidly and effectively and provide timely feedback to researchers.

SUMMARY OF IMPLEMENTATION PROGRAM

Improve existing travel forecasting capabilities.

A body of research results already exists that can be used to improve current practice. Almost all of these improvements can be achieved within a period of 3 years, and many can be achieved sooner.

Present procedures should be simplified for easier, faster, and less expensive use. For example, models can be improved so that they can be used with a turnaround time of hours or minutes. Sketch planning capabilities can and should be developed to enable rapid exploration and analysis of a variety of transportation-land use alternatives.

With relatively modest additional investment, capabilities can be added to present systems to substantially improve their usefulness. For example, capabilities can be added to identify those who benefit from level-of-service increases as a result of a transportation improvement; to determine air and noise pollution patterns that result from a particular transportation system plan, and to provide greater sensitivity to policies such as parking and pricing inasmuch as these are important in analyzing effects of travel-mode choices to the CBD.

Several steps that can be taken to improve the validity of forecasts include (a) allowing the same service attributes to be consistently considered in each stage of forecasting (trip generation, distribution, modal split, and assignment) so that, for example, CBD parking prices will influence not only modal split but also distribution and trip generation and (b) improve equilibrium calculation procedures to reach a "true" equilibrium between supply and demand.

Put emerging techniques into practice.

Although recent research has produced a number of promising new forecasting approaches (direct aggregate, sequential, and simultaneous disaggregate), none of these approaches has been suitably tested in real-world applications. Three to 5 urban areas should be selected where these models can be applied in parallel with conventional techniques to provide a basis for comparative evaluation of the advantages and disadvantages of each approach.

The potential of market research methods should be more fully used, for example, to identify the level-of-service attributes that most strongly influence travel decisions. The results should then be used in designing methods for further data collection for use in aggregate or disaggregate demand modeling.

The prototype applications described above can proceed immediately. Data have already been collected or can be collected in special efforts that are relatively small in scope and designed for the specific purposes of the prototype studies. In addition to these specialized efforts, however, more comprehensive data sets should be developed as part of continuing transportation planning activities.

Increase understanding of travel behavior.

Substantial improvement in the understanding of travel behavior is essential to improving the accuracy and validity of forecasting methods. Research is needed into how consumers perceive travel opportunities, particularly the attributes they consider and their choice processes.

Careful monitoring of travel patterns before and after changes in the transportation system can provide major insights into travel behavior and can be very useful in improving travel forecasting methods. In addition, appropriate arrangements should be made for rapid-response funding of well-designed data collection efforts in circumstances where events such as strikes, facility closure due to repairs, or major changes in price provide unique opportunities to observe changes in travel patterns and to gain increased understanding of travel behavior.

Research is required to develop a better understanding of how consumers perceive the attributes of various kinds of transportation services such as personal safety, security, system reliability, effects of marketing programs, comfort, and convenience.

Alternative theoretical models of travel behavior should be developed, including use of economic theories of consumer utility, psychological theories of choice and learning, and alternative sequences of travel choices.

A major impact of transport policy is its influence on location of individuals and firms and on automobile ownership and use; these in turn influence travel behavior. Research is needed to produce improved models for forecasting these interactions.

Provide a basis for development of substantially improved capabilities.

Increased understanding of travel behavior, although essential to improved forecasting capabilities, is not by itself sufficient. This understanding must be transformed into practical demand functions. These demand functions must be part of a coordinated set of models for predicting flows in networks, and these must be related to models for predicting other types of impacts and to the total set of analysis tools supporting transportation planning.

Research should be conducted to explore the structural characteristics of various travel demand models to test alternative structures theoretically and empirically. Particular emphasis should be given to developing procedures to enable more effective use of disaggregate demand models.

Improved methods for calibrating various types of demand models are required and could lead to substantial improvement in reducing data collection costs.

Substantial improvement in procedures for computing equilibrium is also essential and requires theoretical research, development of computational techniques, extensive experimentation with alternative techniques, and development of practical production-oriented computer programs.

Although a single integrated travel forecasting system should not be developed at this time, preliminary explorations of alternative design concepts for such a system should begin.

As more understanding is developed about how consumers perceive the various service attributes of a transport system and operate on it, use of this information for forecasting will require development of methods for predicting those attributes for proposed systems or policies. Such methods could be used to predict, for example, the different levels of travel-time reliability obtained on demand-responsive systems for input to a demand model in which time reliability is one of the level-of-service variables.

Improve methods for priority problem areas.

There are several problem areas in transportation planning today for which present forecasting methods are not fully satisfactory: implications of energy-conservation policies; air quality and traffic noise; mobility needs of special groups such as the elderly, students, the unemployed, and the handicapped; new types of transportation systems and services; subarea and corridor studies; and short-run and low-capital options. Research should be conducted to develop improved forecasting methods responsive to the significant issues in each of these priority problem areas.

Improve information dissemination and training.

Information on successes and failures in the use of new methods reaches the transportation planning field only after several years. The flow of information must be expedited in 2 directions: Documentation of new approaches must go from the research community to practitioners in state and local agencies, and the practical experiences of users of new methods, together with data bases and evaluative material, must flow from agencies back to researchers. Steps should be taken to improve information flow and to promote more rapid adoption of improved procedures.

GENERAL CONCEPTS

DEMAND AND SUPPLY FUNCTIONS

The estimation of the amount of travel on a transportation system is, in principle, a simple application of economic theory. The demand by travelers for a number of trips of a particular type will be a function of the level of service for the trip on a system measured by costs, travel time, and other characteristics. The level of service provided by common carriers or by highways will be a function of the number of trips using the service and the physical and economic characteristics of the system. These 2 functional relations are called respectively the demand function and the supply function.

These functions can be stated and solved much like a set of simultaneous equations in high school algebra to find a level of service that simultaneously satisfies both the demand function and the supply function. This single point in the demand function is often called the "demand" or the equilibrium solution of the supply and demand functions. The relations discussed so far are shown in Figure 1.

If the relations are examined at several points during a period of years, both the demand function and the supply function shift positions because of changes in factors such as population, income, housing, relative costs of equipment and labor for common carriers, land costs, and density. The demand function, such as the one shown in Figure 1, generally shifts to the right indicating increased demand as a result of population growth, income growth, increased automobile ownership, longer trips, and lower densities. If societal values change because of energy and environmental concerns, the demand growth rate may show much greater variability in the future than during the past 20 years and, in fact, may decline in a few areas.

Figure 1.

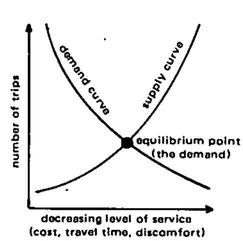
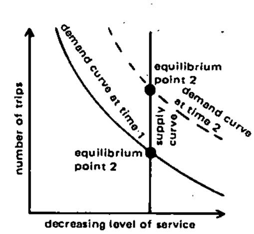


Figure 2.



When the transportation service supplier, such as a highway department, tries to maintain a constant level of service that does not vary over time or in different areas, then the supply function will have little influence on the equilibrium relations shown in Figure 2. Because the level of service does not change, the demand function will depend only on socioeconomic variables. Transportation planning in the 1950s and 1960s used travel demand functions that were generally independent of levels of service in this way. Supply functions were not used. In the future, full social costs of transportation facilities must be considered, and transportation planners will be required to have a deeper understanding of the demand and supply functions.

LONG-TERM AND SHORT-TERM FUNCTIONS

When demand functions depend on levels of service, consideration must be given to short-term and long-term functions.

A long-term demand function (the concept can also be applied to supply functions) is used to analyze situations in which travelers have enough time to react fully to new information. For example, they can buy cars, move residences, change jobs, or learn the best routes to travel.

In a short-term function, travelers are assumed not to be able to make major investments. If parking taxes are applied, for example, travelers would not move or trade cars in the short run but would consider changing route choices or mode choices, including car pooling.

Demand functions that are now generally used are neither short term nor long term but can be used for both whenever the level-of-service changes are not too large.

AGGREGATION

Transportation planners are concerned with the actions of large numbers of travelers. Hence, they have had to aggregate the actions of individual travelers to develop mathematical models that use and produce aggregated data. The models essentially describe the actions and choices of the average traveler, who represents a group of travelers in a geographic area, such as a traffic zone. When major changes occur in the transportation system, however, the reactions of individuals in the zone become important, and aggregated data are not adequate.

Recently, analysts have attempted to develop disaggregate models to describe in more detail the expected actions of travelers in a traffic zone by combining the travelers into smaller groups that have similar characteristics such as income or household composition. These models have the potential to improve travel demand forecasts, but their full benefits can be determined only when all planning models are modified to use data at the disaggregate level.

SEPARABILITY OF TRAVEL CHOICES

Because a large task is performed easier if it is divided into smaller tasks that are performed separately, the approach in urban transportation planning has been to divide the demand forecasting model into separate pieces: trip generation, distribution, modal split, and assignment. In addition, there often are land use and automobile ownership models.

The current requirement to find solutions to transportation problems, not by examining long-term investment and construction programs but by developing low-capital alternatives such as environmental and energy control strategies, cannot be accommodated by separate models. The choices cut across the categories that were dealt with separately by previous models. For instance, in a fuel shortage situation, travelers will consider forgoing recreation trips, car pooling, using transit for commuting, buying a small car, reducing speeds, and driving less.

A model that is to provide policy guidance cannot treat these choices independently. On the other hand, if a model treats them simultaneously, it may become unwieldy for more conventional estimation tasks. How to solve this dilemma is the task transportation analysts face.

FORECASTING AND THE DECISION PROCESS

Decision-makers have relied on the skills of analysts and the performance of forecasting models for information to assist them in choosing among transportation alternatives. Three representatives of the planning profession suggest that the confidence in that approach has been shaken and that significant changes must be made to restore it.

Binder warns that planning methodology is in danger of being deleted from the decision-making process because it has not kept pace with changing social values. He suggests several actions to reverse this trend: (a) Inasmuch as transportation problems are wound up with larger social, economic, and political considerations, planning models must be used to develop information on which policy decisions are based but never to make the decision; (b) inadequate and unreliable data should be openly acknowledged; (c) the assumptions of the model and those aspects of the problem the model can and cannot treat should be clearly understood; and (d) models must provide timely information that is sensitive to the political context within which public decision-makers work.

Bouchard cites several shortcomings to current planning models: (a) They are too time-consuming and expensive to operate; (b) they do not examine all relevant points in the decision-making process; (c) their output is not useful in explaining planning strategies; (d) they are geared to 20-year plans and not to current planning; (e) their capabilities are not generally understood; (f) they require too many data. To counter the widespread criticisms that the right kinds of transportation decisions are not being made, planning research must develop models that do not have these shortcomings. Otherwise, they will serve no useful purpose in the decision process.

Hansen suggests that the planning approach of the 1950s and 1960s collapsed internally because of methodological shortcomings and externally because plans were brought to a halt by constituents on grounds of environmental impact, community disruption, and socioeconomic deficiencies. The Boston Transportation Planning Review attempted to address some of these shortcomings of scale, breadth of evaluation, modal bias, and closed-shop appearance. It developed not a single best solution but a wide range of transportation improvement programs. It recognized that questions to be answered are basically political having to do with resource allocation, cost and benefit trade-offs, and distribution among different groups in society. Its methodology was to ensure that all affected by a decision are aware of the consequences and that the decision-maker is aware of the range and magnitude of the public reaction to the proposed action.

MAJOR ISSUES IN TRAVEL DEMAND FORECASTING

ROBERT HENRI BINDER
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I believe that the planning community is at a fork in the road. Unless urban planning quickly becomes more relevant to the needs of decision-makers, it will increasingly be in danger of becoming unresponsive to the decision-making process and will eventually be phased out as a rational approach for analyzing and solving urban problems.

There are a number of reasons why urban transportation planning methodology has reached this point. But they can be summarized by saying that the methodological development has not kept pace with changing values in society and the increasing complexity and interdependence of urbanized and industrialized society.

It is ironical that this credibility gap has occurred with regard to planning. Planners, by the very nature of their work, should be the first group in society to perceive changes and to make recommendations to decision-makers and the community on how best to deal with those changes. The existence of this credibility gap implies that there probably are fundamental changes required in the planning process.

I will, however, proceed with the belief that the planning community can still play an important role in the decision-making process. In fact, it is the responsibility of planners to help policy-makers make intelligent decisions by informing them of the probable consequences of the choices confronting them. This is no small responsibility.

Making intelligent policy choices has become increasingly complex as society itself becomes more complex and as the consequences of various courses of action become more far reaching and intertwined. If one part of the social system is changed, other parts are affected. It is not infrequently that program decisions are made

1. On the presumption of knowledge where none actually exists, or
2. On the basis of a common-sense or intuitive expectation of results that prove to be wrong, or
3. With the aim of achieving a worthwhile objective in one area but with the result of producing quite undesirable results in another area.

More dams may not produce more flood control; more urban renewal may not increase the supply of low-income housing; more highways may not lead to more convenient travel; and more convenient travel may result in intolerable levels of air pollution. It is no longer enough for the policy-maker to choose only on the basis of a quick calculation of the immediate effects. Rather, he must concern himself with the second- and third-order consequences of a particular course of action and with the hidden or indirect policies implicit in any proposed solution. He must weigh immediate advantages in one area against long-term disadvantages in other areas. These cannot be snap calculations. They require a penetrating understanding of the process by which the consequences are brought about. They require sophisticated means of weighing the alternatives. They require new ways of measuring the competing values that have to be balanced. They require an understanding not only of what the trade-offs are but also of what they mean. Policy-makers must be not unlike the ascetic who, upon observing a large jet plane flying over his mountain-top place of contemplation, remarked to his neighbor, "They may have the know-how, but we have the know-why." I am suggesting that we need both.

In the transportation field, planning once consisted of someone sitting down with a map and a set of colored pencils and drawing preferred routes for a road or a railroad or an airline on a map. Although many transportation facilities were built that way, and built well, they were not always economical and frequently had unfortunate social and environmental consequences. Later we improved on the colored-pencil approach by the addition of existing traffic-flow data—cordon counts, tonnages over the line, and so forth. The addition of this information made the planning process for transportation routes and facilities much more precise. Unfortunately the traffic data and the essentially linear projections made from those data were largely static and incomplete and failed to show among other things true origins and destinations. They took little account of the impact on demand of future changes in the transportation system and even more rarely took account of the trade-offs among modes of transportation and between cost and benefits. Seldom, if ever, was consideration given to the possible impact of improvements in transportation facilities on system efficiency, community development, land use, environmental pollution, and utilization of energy. It is probably accurate to say that almost all transportation facilities—passengers and freight, intercity and intracity—were built on the basis of this incomplete information and fairly simplistic planning process.

Within the past 10 years or so, transportation planning has increasingly involved the use of models and systems analysis techniques. These urban transportation planning techniques were responsive to the questions that planners of the 1950s and early 1960s perceived to be relevant to the design of transportation facilities on a regional basis. Today, very different questions are seen to be relevant.

It has now become necessary to integrate into the planning process the environmental, energy, and social effects of transportation facility construction and operation. Also, transportation planning issues have become more numerous and involve a much wider range of alternatives that need to be considered. These include trade-offs between highway and public transit investments; between new construction and low- or noncapital alternatives, such as pricing schemes; between new technological systems and older, still workable systems; and between action programs and do-nothing alternatives. As a consequence of greater involvement by elected officials and citizens in the planning process, it is necessary that information on alternatives be produced expeditiously and in a manner that facilitates communication, particularly among nontechnical people.

Transportation problems in urbanized areas, moreover, are increasingly moving from the category of physical systems, where urban transportation planning methodology has its greatest strengths, to the realm of social and political problems, where that methodology has yet to distinguish itself.

Although significant amounts of money will probably be spent for new transportation facilities in urbanized areas in the future, the need now is to make better use of existing transportation facilities in order to provide quality of service at a cost that travelers and shippers desire, but without unfavorable impact on the environment or community. Plainly, we cannot optimize at the level of a particular mode of transportation nor even at the level of transportation itself. While striving to develop the most economically efficient through-service systems for travelers and shippers, we need to consider the potential impact of improvements in the system on the community, the city, and indeed the social system as a whole. Transportation questions, such as those regarding urban highway congestion and deterioration of local public passenger service, cannot be answered in isolation. They are intimately wound up with larger social, economic, and political considerations such as urban growth patterns. The story of center-city decay and suburban growth is well known. The trend toward urban sprawl has affected and will continue to affect heavily the transport demand of the people living there. If these demands are met only with further capital investments in transportation facilities, the trend toward urban sprawl may be reinforced by those investments. Public policy-makers, therefore, need first to decide whether urban sprawl should continue to occur, and then they can make wise transportation policy decisions.

Transportation planning is plainly needed to help develop the information base on which intelligent policy decisions can be made. And planning methodology has a very important role to play. But as in all things, there are problems, limitations, and risks involved.

For one thing, we must resist the temptation to let the models make the policy decisions. That would be tantamount to reaching a decision without really deciding. The policy leadership cannot delegate this responsibility—nor should the systems analyst attempt to acquire it.

Inadequate data are a persistent problem in transportation. A great deal of the required data of both a physical and an economic nature is simply not available—except perhaps at great cost. (A characteristic weakness of a civilization in which so much is known is that it becomes difficult to admit to ignorance and easy to assume the reliability of information that is anything but reliable.)

Another problem is that of the model itself. It is very difficult for the nonexpert policy-maker to follow the arguments among the mathematical model-makers. In transportation, we are frequently confronted by the argument that the other fellow's model is really unsophisticated, inaccurate, or simply worthless. The assumptions underlying the model need to be made clear to the user. The user should clearly understand those questions that the model can usefully treat and those that it cannot treat. All too often, users have been led to believe that a model can deal with all aspects of a complex problem when, in reality, there are only pieces of the problem that the model or any model could deal with effectively. We must also develop methods to test the utility and validity of various models and to make comparisons among them.

Still another problem is that of timing. Program decisions are being made all the time, and it does the decision-maker little good to be told that in 2 years a systems analyst will have a finished model that will be helpful to him. The decision-maker must have some sort of information today—even if it is of an interim nature. It is unrealistic to expect decision-making to stop until the model is perfected.

Finally, there is the inescapable fact that the design and implementation of a transportation system involve a large measure of political thought, motivation, and action that may multiply the variables. Any systems analysis risks divorce from reality unless it provides information that is useful in the context of day-to-day political decision-making.

Clearly, the forecasting of urban travel demand is a critical step in the planning process. The forecast travel is an input to the determination of benefits and cost and many external effects and the evaluation of transportation alternatives. These results are essential items on which major investment and policy decisions rest. In short, the forecast of urban travel drives the major technical portion of the urban transportation planning process. This is true at the federal, state, and local levels of government. It is therefore incumbent on the U.S. Department of Transportation and the transportation planning community to ensure that travel forecasts are sufficiently accurate and timely for decision-making, sensitive to the important issues facing the decision-makers and community, and communicated to nontechnical people in an understandable manner. And we must ensure that the forecasting methodology is adequate to meet these needs.

Much of what I have said is not entirely new. Paul Cherington, a former Assistant Secretary for Transportation Policy and International Affairs, expressed much of the same sentiment before the Transportation Research Forum in October 1969 in a speech that was critical of the use of systems analysis in transportation policy-making. I cannot see that we have gained significantly on the problem since that time. It is significant that this conference was called and attended by such a group of competent professionals. What is required from the conference is a set of recommendations to plot the future in this critical area of transportation planning, that is, methodology for the forecasting of urban travel. This can be accomplished by making recommendations as to how existing forecasting techniques can be better used and how new research directions can be set for improving existing forecasting techniques and developing new ones.

RELEVANCE OF PLANNING TECHNIQUES TO DECISION-MAKING

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During the past 10 or 15 years we have spent more than $250 million nationwide on planning transportation facilities. Nevertheless, the critical decisions on transportation are still made external to this process and to the techniques used in the process. And there is good reason for that: There are serious shortcomings in the models that we now use. Some of these shortcomings are clear, and we have known about them for years but have not responded with improvements. During the past 4 or 5 years there have been repeated warnings to modelers about those shortcomings from citizen groups, elected officials, and even transportation experts, but to no apparent avail. What are the shortcomings?

First, the models are too time-consuming and too expensive to operate. I can recall a situation in a western state not so long ago where the chief engineer of a very large transit operation requested one of the regional planning groups to give him some help on revising the routes and schedules for the area's bus system. He wanted to make the revisions to accommodate some of the expected increase in visitor traffic because of an upcoming social event. The event was 3 months from the date of the request. The answer he got from the regional planning group was that his problem would take about 6 months to analyze and could not even be started until he provided $20,000 for the computer analyses. You can imagine his answer; he will likely never again ask the planning group to help him make a decision. Most decision-makers today are hampered by 2 key constraints: They do not have time to analyze and debate all of the salient issues that surround a particular problem, and they certainly do not have the cash in hand to have somebody else assist them. So models must be more responsive to time and money constraints if they are to be useful to decision-makers.

A second clear shortcoming is that models fail, in many ways, to examine all relevant points in the decision-making process. They certainly cover the demand elements and the capacity elements, but they do not do a very good job of covering the impact elements or the total cost elements of the alternatives under consideration. They do little to trade off one impact with another in the decision as to which of several examined alternatives should be built. The sophisticated models that we now have deal with those elements in the decision-making process that are perhaps not the most important ones. We spend a great deal of money refining and further defining the travel-demand forecast, even though urban expressways are clearly either 4, 6, or 8 lanes wide and making that choice on the basis of geometrics and flexibility is not too difficult. What we seem unable to do is to account for the impacts among those 3 widths and other choices.

Third, existing models really box us in. I am sure each of us has been in meeting after meeting where some modeler goes through his song and dance about his sophisticated model and spends three-fourths of the time allotted for his presentation explaining the workings of the model and only a fourth explaining what that means in terms of either the demand for travel or the impact of the facility to meet those demands. In other words, we think too much about the models and too little about the maps and charts and photos and common sense that sell particular planning strategies.

Fourth, present models are geared to the 1990 situation or the 20-year situation when in fact transportation problems are now and projects are now. The average time span of the term of the local or state official is 2 or 4 years or certainly 8 years at the most. A mayor wants to know whether he should proceed with a particular transportation facility. Modelers tell him what the situation will be in 1990. The mayor finds it difficult to respond to the criticism of his constituents as to why he either does or does not proceed with a particular project. Models fail to give him the information he needs on today's situation.

Fifth, the technicians themselves may not always understand the models. Two modelers may argue the merits of an experimental finance factor of 1.2 versus 1.8 related to the distance factor, which may account for only 5 or 10 percent of the sensitivity of the model. We get so wrapped up in technical aspects of a model that too often we fail to view it in its overall perspective.

Sixth, models are just too data hungry. Regression equations that describe the trip-making rate per household are sometimes composed of as many as 30 variables. At the same time that we use those equations, we make the statement that trip-making is predictable. In my mind, those 2 actions are just irreconcilable. Increasingly, policy-makers side with the view that trip-making is predictable, and increasingly model-makers pump more variables into the equation. In other words, we tend to scoop up the data as though they were going out of style while losing sight of the generalizations that we make and also of the extreme costliness of collecting the data.

How did these shortcomings develop? Back in the early 1960s when computers came into wide-scale use, many transportation people immediately selected a course that led to the development of models that were complicated, time-consuming, expensive, and research-oriented. At the same time, other groups were predicting travel by using much less sophisticated models. Neither one of those was satisfactory for urban transportation planning purposes, and so we settled for something in the middle. We have ended up with a set of models that are almost useless for both research purposes and decision-making, and we have lost all the way around.

What we really need is 2 sets of models, one for use in research and one for use in solving practical short-range transportation problems. I have no doubt that, given free rein, technicians could develop such models.

I would like to devote the remainder of my remarks to the decision-making models, not because they are more or less important but because I think enough attention has been given to the research side. Unless immediate attention is given to these models, we in the transportation planning business may well find ourselves in the back seat—or in the rumble seat because we may already be in the back seat when it comes to assisting decision-makers make critical transportation decisions.

It is no secret that transportation decision-makers are increasingly coming under attack from local political leaders, environmentalists, and all sorts of groups, young and old, from east and west, north and south, rural and urban. The criticism on all fronts is that the right kinds of transportation decisions are not being made. If our techniques are not responsive to pressures that decision-makers normally find themselves subjected to, then our usefulness is outlived.

The total technique models that I am talking about will have to have the following key features.

First, they will have to deal explicitly with the issues of the day and be oriented toward answering questions that decision-makers face today. That gets back to the impact question and to the question of dealing with 1990 or dealing with today. The models must frame answers in terms of today's time schedule. That is, they must explicitly measure present impacts of all the alternatives from the standpoint of build or no-build so that the impacts can be objectively debated and discussed within the public arena. In other words, I am not suggesting a series of regression equations that compute the impact of building highway A as being the introduction of so much air pollution into the air, so much loss in tax value, and so much reduction in time and cost to the automobile user; match the value of those negative impacts with the value of the positive impacts; and then come out with a decision as to whether or not highway A should be built. I am suggesting that the analysis of the impacts of highway A on air pollution, economic base, travel considerations, and a host of other factors be framed in terms of the kinds of data that elected officials, citizens, and technicians alike can use in public discussions. That is difficult to do, but I suggest that, if we expect models to have impact on decisions, then we have to meet that objective.

Second, the models do not have to do everything. There are some repetitive and highly complicated analyses that models can do, but they do not include things like travel demand, impact on parks, and impact on historic sights. Photographs, maps, and field surveys can be used to answer many of the kinds of questions that are being asked by elected officials and by citizen groups and answer them perhaps better than models do.

Third, the models must produce results quickly and simply, even at the expense of accuracy. A decision is going to be made regardless. Whether the model is the basis for the decision depends primarily on whether the model can be responsive in terms of the financial and time constraints that decision-makers operate under. A serious credibility problem has developed with regard to models because they do not address the right issues in a timely and politically sensitive way. We have got to build models that do.

Fourth, the models must deal with all possible options—from low-capital-intensive programs to high-capital-intensive programs, from existing technology to new technology, from what happens if we do to what happens if we do not. We cannot afford to have a screening process that knocks out these alternatives before they get ample public discussion and ample public hearings. For example, if patronage of a system of buses operating on existing congested facilities is forecast by current modal-split models, the figure will not be much lower than one for a rail rapid transit system that costs billions of dollars. The models are incapable of dealing in a rational way with the full range of options.

Fifth, and I touched on this earlier, the models must make it possible for trade-off analyses to be made among the impacts of any individual alternative. We should not try to develop a formula for doing this, for it is a matter of values, of goals, of objectives that may be different for each individual or group. The model output has to be sufficient so that those analyses and judgments can take place in the public arena. The model need do no more.

Sixth, the models have to be tied more readily to available data sources so that the need for new data collection is minimized. Governments and private sources collect literally millions of data bits every day. The national census, the state data collection activities, and many other data collection activities are not fully exploited. Major efforts must be made to reduce the need for new data collection and maximize the use of the existing data.

There is a vast difference in the types of questions that are asked by decision-makers at the various stages of planning. One overall series of models cannot be all-inclusive in terms of answering all the questions at the various stages or times in the planning process. The model that determines air pollution at the system level is quite different from the model that determines air pollution at the corridor or engineering design level. The questions of the past are almost irrelevant today. We do not quite know what the questions are going to be tomorrow, but right now we have to get today's questions answered.

THE BOSTON TRANSPORTATION PLANNING REVIEW

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The urban transportation planning approach developed in the 1950s and 1960s in the United States is practically dead. Where it has not suffered internal collapse from its own methodological shortcomings, the transportation planning process and the plans it spawned have been brought to a halt by its very constituents. Organized interest groups, municipalities, and private citizens displaying remarkable sophistication have successfully challenged their planners on grounds of environmental impact, community disruption, and socioeconomic shortcomings. The early promise of a systematic methodology based on firm quantitative grounds leading to the rational formulation of urban transportation policy has been the casualty of the so-called urban highway revolt.

From coast to coast, plans based on this planning process have collapsed when the facilities they recommended reached the implementation state. In each instance, examination of the implications of the plans exposed issues far outside the scope of the original planning process: conflicts in user needs, complex external effects on communities and the environment, and conflicts between long- and short-term impacts.

During the past 3 years, this conflict has gradually become embodied in federal legislation and procedural requirements dealing with air pollution, noise pollution, historical preservation, and so on. The essential elements of the planning process that is emerging are

1. Full consideration of alternatives, with the advantages and disadvantages of each analyzed rigorously and in writing,
2. Inclusion of a no-build alternative as a way of focusing on whether the facility is really needed, and
3. Public hearings and other opportunities for participation for the purpose of exposing the above analysis to criticism and public controversy prior to commitment on the part of the government to proceed with a project.

Although they set general goals for a new planning process, the federal, state, and local legislation and guidelines offer no new techniques or tested processes for dealing with what is rapidly becoming a typical planning problem. Often planners are finding themselves uncomfortably in the middle of political, institutional, and community-interest groups. In Boston, an attempt was made to overcome these gaps in the metropolitan planning process.

Late in 1969 Governor Sargent appointed a task force to advise him on the growing highway controversy. The task force recommended a moratorium on nearly all highway construction within 12 miles of Boston—approximately $1 billion of construction.

The Boston Transportation Planning Review (BTPR) was initiated in July 1971 and is now drawing to a conclusion. It has tried, successfully I think, to address some of the weaknesses of the previous planning process. These shortcomings are concerned with the scale, breadth of evaluation, modal bias, and closed-shop appearance of past planning studies.

SCALE OF PLANNING

In the past, transportation studies proceeded for the most part sequentially from broad regional analyses through subregional, subarea, or corridor studies to facility design at the project scale. The decisions made at each step constrained the scope and flexibility of the steps that followed. As a result, transportation and nontransportation impacts and design issues at the subregional or project scale were rarely considered in the development of the regional system plan.

Conversely, because of predetermined or implemented regional system constraints, insufficient latitude remained at the subregional scale to permit joint consideration of transportation service and transportation-related impacts. Whether the transportation service improvements were worth the imposed nontransport impacts has consistently been outside the scope of previous studies and a question that was rarely addressed at any stage of the planning process. Nowhere in this process was there an opportunity to display the full range of costs and benefits of a particular facility to permit a fully informed decision.

This shortcoming and the need to expose a broad range of costs and benefits associated with potential transportation improvements led the BTPR to focus its major effort on definitions and evaluations of alternatives at the subregional scale. A key finding of the BTPR has been that a design scale of 200 ft:1 in. is necessary to test a facility for impacts at the corridor or subregional level.

The time scale as well as the areal scale of past planning studies also created several problems. The high degree of abstraction contained in the planning for the 25-years-from-now future—"the magic land of 1995"—was simply not concrete enough to attract the attention of the interests that, in fact, might be affected by it. In addition, that long-range focus blurred the real problems of implementation of the long-range plans and practically blotted out any concern for today's transport problems.

The BTPR focused its concerns on today's problems. A particular facility must be justified in terms of its near-term benefits, not simply that it is in accordance with a long-range plan. The philosophy followed recognized that we have a transportation system today and that the objective of the planning process is to augment and improve that system through time rather than replace it at some future point in time.

EVALUATION

The second shortcoming of past transport planning is that it has been largely directed by a concern to aggregate regional user benefits and capital costs rather than to distribute them among areas, activities, and socioeconomic groups. Metropolitan transport plans were evaluated primarily in terms of total travel-time saving at an average value of time for all users. This has led to many plans that

1. Neglect the transport needs of many transportation minorities;
2. Allocate the impacts, costs, and benefits of transportation system changes without regard to the distribution of transportation benefits they provide; and

3. Leave some people worse off than they were before the proposed transportation improvements without compensating them for their losses.

It is clear to me that this focus on the "average" person, particularly when average is defined in transport demand terms, has led in many instances to a subtle but significant transfer of benefits to the upper and middle income groups of urban areas and a corresponding transfer of costs to the lower income groups.

To respond to this shortcoming, BTPR focused its concern not on the development of a single best solution but rather on the description and evaluation of a wide range of potential transportation improvement programs. Such a process permits participants with a wide range of values to judge the desirability of the various alternatives according to their own values. Some 50 evaluation categories were developed with the participants. The traditional engineering benefit-cost analysis was only one of the 50 categories, and it was given no greater attention than the other 49.

In addition, the impacts were further disaggregated by community. The matrix formed by community versus evaluation category permits locally based interest groups to estimate the goodness or badness of an alternative with respect to specific local values.

The implication of the inclusion of a broad set of evaluation categories makes it increasingly clear that the absence of a single objective function or even a set of static objective functions deprives the planner of the ability to deliver to the decision-maker a single best alternative to any transport problem. Therefore, the study did not result in recommendations. The key technical act in the BTPR was to generate alternatives and expose their characteristics (the facts) to the broadly varying points of view of the participants.

Judging the relative importance of transportation service improvements as balanced against the inherent community disruption caused by such improvements is necessarily a political, not a technical, decision.

MODAL BALANCE

The issue of modal balance is increasingly appearing as the paramount technical-political issue. Many participants see highways not only as being impact villains but also as providing service to the "haves" in society and diverting resources from transit improvements that would serve those groups most in need of improved mobility.

CLOSED-SHOP PLANNING

The closed-shop appearance of transport planning stemmed on the one hand from the participants' assessment of their traditional professional prerogatives and on the other from an isolation resulting from the seeming irrelevance of transportation studies as perceived by residents or urban areas. The long-range and regional focus of past studies blurred the ability of both the profession and a general public to see the short-range and concrete implications of transportation planning. Private citizens and interest groups and often municipalities themselves saw little reason to be deeply involved.

The crisis out of which the BTPR grew stemmed from a deep conflict of values, conflicts that are felt in society at large and that emerge into the public spotlight in the form of battles between citizen groups and equally committed governmental agencies. Battles increasingly end in paralysis and stalemate rather than in creative reconciliation and decisive implementation.

The Boston Transportation Planning Review was an experiment in attempting to channel those conflicts into a process where people feel they are being heard and are in fact being listened to. In the BTPR, the functions of participation were fourfold.

First, a clear understanding of the issues around which transportation improvement must be planned can be developed only through close association with users or those who will be affected. A community inhabitant has a better sense of the issues in his community than a regional transportation planner can ever have.

Second, people who are not full-time planners but who represent communities, business, environmental groups, or labor are not any less "professional." They have ideas. These ideas extend the imagination of planning professionals. In the case of BTPR, experience shows that participation forced planners to consider more seriously alternatives at the edge of what they might initially call "feasible," and that those alternatives finally emerged as serious candidates for selection.

Third, implicit in a multivalued transport planning process is the admission that transport benefits, to many people, are not more important than other effects of transport improvements—positive or negative. Individuals and groups value housing relocation, time savings, ecological disruption, and aesthetics quite differently. There is no common preference order—in short, there is no single public interest; rather there is a variety of public interests. The new planning process, therefore, depends on making available to participants complete information, which they in turn use to make up their own minds based on their own value systems.

Fourth, the participatory process serves as another channel by which public reaction to the facts can be channeled to decision-makers. Although most public and private groups and some individuals have their own traditional communication channels to decision-makers, the BTPR process provided another formula procedure for those reactions to be made known to the decision-maker.

In summary, a participatory approach to planning, as developed by the BTPR, recognizes that the questions under review are basically political questions, having to do with resource allocation, cost and benefit trade-offs, and distribution among different groups in society. Therefore, the decisions are political and not technical, and only elected officials have the mandate to make those types of decisions. The role of the planning process is to ensure that all those affected by such a decision are aware of the true consequences and that the decision-maker is aware of the range and magnitude of the public's reaction to the proposed action.

OUTCOME

What has the BTPR produced? What have been the outcomes of this combined technical-political approach that

1. Looked for solutions for today's problems rather than tomorrow's benefits,
2. Was concerned with who got what rather than some short-hand measure of total society benefits,
3. Was concerned about all transport impacts both positive and negative rather than travel demand, and
4. Was concerned with making all information broadly understandable to all parties rather than precisely understandable to a few.

After almost 2 months of deliberation, the Governor announced his decision. The moratorium on expressways within Mass-128 is now a permanent institution in Boston. Boston will pursue an increased transit program and a highway-oriented transportation management program. More important than the decision is the reason behind it.

It is not possible or desirable to try to provide sufficient highway capacity for all those who "demand" it. The costs, in terms of community disruption, housing relocation, and damage to natural environmental assets are too large; and the benefits, in terms of increased mobility, are too small.

Our limited highway, rail, and transit transportation corridors represent the only real physical opportunities to improve both our mobility and our environment. Therefore, we must focus our efforts on developing institutional mechanisms and physical facilities that allow the public to better manage the abundant resources of transportation supply already possessed to better serve Boston.

In effect, the Governor said:

1. There is no such thing as absolute demand;
2. It is always constrained by supply; and
3. At least with regard to highways, we already have a sufficient supply if we just learn how to utilize it properly.

Although Boston is only one case, I know it has had its predecessors and am sure it will be followed by others. To be of use in what I think will be the wider emergence of the technical-political transportation process used in Boston, the planning models, techniques, or whatever must produce broadly understood information. That information must be

1. Quicker, even at a sacrifice in accuracy (in fact, directions of change may be much more useful than elements of the absolute magnitude of change);
2. Broader in scope, particularly the effects of increased mobility (traffic numbers and accessibility supply are not enough, but must be connected to terms people understand, such as decrease in employment, increase in sales, and required labor base); and
3. Comprehensive at a point in time rather than during a period of time.

CONFERENCE WORKSHOPS

Conference participants were assigned to 6 workshops to explore in depth various aspects of travel demand forecasting. At the opening workshop session, prepared resource papers were given to provide background information as a basis for the discussions. Out of these sessions came the recommendations that form the implementation program.

The reports of the workshop chairmen and the resource papers are given in this section. Given also are the names of the participants and the objectives and options for each of the workshop topics: short-range and low-capital options; long-range and contemporary options; new options and technology; social, economic, and environmental impacts of transportation systems; travel behavior; and analytical structures.

Workshop 1

DEMAND FORECASTING FOR SHORT-RANGE AND LOW-CAPITAL OPTIONS

OBJECTIVES

Identify, review, and evaluate current and proposed travel demand forecasting techniques and procedures for use in assessing short-range and low-capital options in urban transportation.

Recommend new and improved forecasting procedures that are responsive to requirements of using the travel forecasts

Develop a recommended program of research that is responsive to the identified requirements of using the forecasts.

OPTIONS

Short-range options include all actions or projects that may be planned, designed, and implemented in fewer than 5 years. Therefore, spatial distribution of land uses may not be considered, but changes in the time distribution of activities may be as may changes in the cost of travel or methods of operating the system. Examples of low-capital transportation options include traffic engineering and operations improvements, priority lanes for high-occupancy vehicles, pricing policies for automobiles, transit operating improvements, transit-fare policies and operating subsidies, transit marketing programs, no-build alternatives, parking restrictions and regulations, automobile-restricted zones, and transit service cutbacks. Examples of nontransportation options are staggered work hours, longer shopping hours and Sunday shopping, and a 3- or 4-day workweek. Examples of short-range options include the above plus certain high-capital options that can be quickly implemented such as construction or reconstruction at specific locations such as bridges, freeways, rail and bus rapid transit facilities, and parking and terminal facilities, and transportation demonstrations projects.

PARTICIPANTS

W. Bruce Allen, Joel Ettinger, Charles Hedges, Stanley J. Hille, Gerald Kraft, Robert McGillivray, Albert I. Pierce, Richard H. Pratt, David Quarmby, Donald V. Revello, James Schmidt, and Joseph L. Schofer (chairman)

Report

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Workshop 1 was concerned with the travel forecasting needs that are generally or uniquely experienced by decision-makers attempting to make choices among alternative short-range and low-capital transport options.

Options of this type are important and perhaps are predominant elements in transportation system development porgrams in most urban areas because such modifications amount to routine system maintenance activities and their costs are within the feasible range for most cities.

In addition, because of widespread citizen opposition to major capital-intensive transportation investment programs, low-capital options may represent the only way to preserve and improve transportation services in the coming decades. Such a restricted spectrum of transportation options may force consideration of ways to provide basic mobility services with the existing roadway system, and small modifications to it, and may also require limitation of the growth of (private mode) travel demand.

Furthermore, short-range options are of special concern to elected decision-makers, who generally find it difficult to place high priority on longer term planning, preferring instead to focus on more immediate ways to solve problems.

ROLE OF FORECASTING

Organized procedures for estimating the response to short-range and low-capital changes in transport services are needed for effective and responsive decision-making. Yet, decisions are often made with no information at all about the potential impacts that might result. Such information that may be available through the use of inexpensive travel forecasting techniques is often unreliable or of unknown reliability, inaccurate, or based on forecasting techniques that are essentially insensitive to the major attributes of the options being considered. Some information may be provided through the use of traditional, long-range, regional forecasting tools that have questionable validity, are always made at great expense in time and money, are usually made at a level of detail far too general to be meaningful, and, again, are based on forecasting techniques that are insensitive to the major attributes of the options themselves.

SOME ATTRIBUTES OF SHORT-RANGE AND LOW-CAPITAL OPTIONS

If forecasting techniques are to be responsive to the planning of short-range and low-capital transportation options, they must be capable of predicting user response to changes in a variety of measures of levels of service that are not now explicitly included in contemporary forecasting models. These might include frequency of service, travel time reliability, comfort, convenience, access time and distance, crowding conditions, availability of information about services, parking constraints and policies, level of crime on the transport systems, exact fare pricing, waiting area conditions, parking availability, number of transfers, transfer times, regulation of taxis and jitneys, car-pooling policies, and area-wide vehicle restrictions.

Furthermore, those dimensions of service change associated with short-range and low-capital transport options and represented in current models are not effectively treated. These elements include monetary travel costs, transit routing patterns, and travel times. Contemporary models cannot efficiently treat responses to changes in such variables at a sufficiently detailed level, and they are frequently not realistically sensitive to small changes likely to be important to users of transportation.

SPECIAL INFORMATION REQUIREMENTS

Because of the nature and the scale of many short-range and low-capital transport options, planners are faced with the need to provide decision-makers with specific information that is generally not accommodated by contemporary forecasting techniques. For example, information is required on the sensitivity of travel demand to a variety of level-of-service measures common to the relevant options, but not explicitly treated in the current models. Furthermore, demand characteristics for travel modes not normally considered in the data collection and analysis phases of typical urban transportation planning studies may be important for short-range and low-capital planning. Such modes include bicycles and pedestrian trips. Special attention may also be necessary for "no-mode" (unmade) trips as well as for potential trips by modes having currently restricted usage because of regulatory policies, such as taxis and jitneys.

In some urban contexts where social and environmental pressures are very great, it may be necessary to provide information on the relations between travel demand and environmental impacts. More specifically, there are needs to estimate demand in response to traffic management (limitation) schemes designed to respect "environmental capacities." Information on the trade-offs among levels of service, travel demand, and environmental impacts has become essential in some situations. It would be desirable, for example, to have a rapid and efficient capability to estimate such trade-offs among the "go-around," the "go-through," and the "don't-go-at-all" options to respond to public suggestions and complaints and to speed up the search and choice process in planning. It is important to recognize that rapid analysis and decision-making not only may lower planning costs and make it possible to implement decisions sooner but also may facilitate making more choices in a given time period, leading to transport services that are more responsive to current needs.

Recognizing that transportation is a supporting service, and not an end in itself, the planner may appropriately develop demand-supply analysis techniques that allow him to specify environmental capacities initially and then determine both the characteristics of feasible transport services and the equilibrium demand. This synthesis approach places special requirements on demand forecasting techniques in terms of sensitivity to service-level variables and speed of response, which are not met by available methods.

Work-trip travel has been the focus of attention in long-range forecasting because it represents a large—and easily understood—fraction of all urban travel. Although work trips may be of primary importance for the evaluation of many proposed short-range and low-capital transportations, other trip purposes may require special consideration in this context. For example, special off-peak transit services designed for disadvantaged travelers and oriented toward shopping, medical, and recreational purposes fall into this option category. Too little is known at present about the non-work travel market. In the case of the increasingly important weekend recreational trips, for example, forecasting capabilities are limited by the policy of collecting (long-range-oriented) origin-destination data on weekdays only.

Because short-range and low-capital transport options are often focused on a particular segment of the travel market, forecasting techniques may be called on to provide specific information about the market areas of proposed services and about the response to those services of different types of travelers. Generally, the requirement for highly disaggregate analysis places special pressures on short-range and low-capital forecasting processes.

THE DECISION-MAKING ENVIRONMENT

The uniqueness of the information needs for decisions about short-range and low-capital transport options does not lie only in the dimensions of service changes likely to occur. Certainly it is becoming increasingly more common to be faced with decisions about service changes not well described in terms of travel time and costs alone. Yet, such changes may well be proposed to meet long-range urban travel needs. Furthermore, the impacts of such changes may be widespread and long lasting.

It is apparent that the fundamental conceptual and theoretical bases for performing short-term travel demand forecasting must ultimately be consistent with the bases for long-range forecasting. The decision-making environment within which choices about short-range and low-capital alternatives are made serves to differentiate the characteristics of long- and short-range forecasting problems.

For example, the decision-makers involved in choices about short-range and low-capital options are often not the same ones concerned with long-term choices. They are often closer to the "operating" level and, thus, may hold narrower perspectives and be less favorably inclined toward dealing with complex information sets. Furthermore, the transportation planners concerned with these choices are likely to be different, in terms of skill levels and viewpoints, from those concerned with long-term decisions.

Who are the decision-makers? They include federal, state, and regional transportation professionals, local government officials, system operators, and ordinary citizens. The role of citizens in decision-making regarding short-range and low-capital options is likely to be large because of the immediacy of the choices, the rapidity with which some of the impacts arise, and the probable localization of those impacts. Citizen-participants have special information needs because they do not possess technical backgrounds and because they are likely to be directly affected by choices. Similarly, decision-makers, as laymen, present a special challenge to travel demand forecasters. This is amplified by the extreme time pressures common to short-range decision-making. The characteristics of the short-range decision-making environment lead to some very specific performance requirements for demand forecasting techniques. Among these are the following:

1. The need for rapid response to questions about reactions of the travel market to proposed transport changes;
2. The need for preparing impact estimates at low cost;
3. The need for a strong, simple, and obviously credible basis for forecasting;
4. The need for preparing detailed, disaggregate user-response estimates at the microlevel;
5. The need for providing easily understood measures of expected equilibrium service levels in terms meaningful to citizens and decision-makers (this requires measures that are trip oriented, perhaps describing door-to-door travel times for specific

trips, volumes on local streets, and delays at particular intersections); and

6. The opportunity in some cases to provide impact estimates with relatively high error margins when proposed service modifications are (essentially) reversible or easily adaptable.

All of these requirements might not apply to every short-range and low-capital decision situation, but they are all relevant to the general environment that forms the context for such options.

The importance of building and using forecasting capabilities responsive to such decision-maker needs is critical. Special concern must be placed on the linkage between planner and decision-maker if good choices and, perhaps, if any choices are to be made about the maintenance and development of urban transportation systems.

STATE OF THE ART

Forecasting capabilities that can meet the needs described above are not in general use in the United States today. The standard, long-range planning techniques are typically unresponsive to the issues and options, the scale, and the variables involved in questions about short-range and low-capital options. Long-range forecasting techniques clearly do not meet the time and cost performance requirements of typical short-range and low-capital options.

Yet, a reasonable amount of relevant information that would be useful in this decision-making environment does exist. This includes information on demand elasticities derived from previous experiments with changing transportation services. Such information may be in the form of case study results or in terms of the parameters of models calibrated in a variety of special forecasting studies. Advanced formulations of long-range models, such as those used in the United Kingdom based on generalized costs rather than travel time alone, may also have applicability in the study of short-range and low-capital options.

Unfortunately, the link between this information and its potential users is very weak. Many planners and decision-makers do not recognize the need for forecasting capabilities in this context. Those who do are often unaware of available information and techniques or are unable to put them to use because of inadequate documentation. Furthermore, there is a strong tendency to apply unresponsive and inappropriate long-range forecasting techniques because they are relatively well documented. It is apparent that these long-range methods have been unintentionally institutionalized, having acquired the appearance of the only way to estimate travel demand. The danger of institutionalization of techniques in the context of short-range and low-capital planning is very great, and steps are needed to foster continuing innovation.

The fact that some potentially useful approaches to short-range and low-capital forecasting do exist suggests the immediate need for a program of information dissemination. This program might include the assembly and codification of results of experiments, calibrated and special purpose models, and proven methods for expanding the sensitivity of existing, long-range models. In this manner, and without additional research, a greatly improved—but still very limited—capability for predicting the use of proposed short-range and low-capital transportation options could be structured and made available at low cost and in a very short period of time.

At the same time, a continuing research effort must be undertaken to improve these techniques in the context of both the needs stated previously and the experience with the use of off-the-shelf methods. Documentation of such experience with existing and innovative techniques in the context of carefully controlled surveillance of the actual impacts of short-range and low-capital transport improvements is essential for the development of a meaningful forecasting capability in the next few years.

DIMENSIONS OF AN ACTION PROGRAM

Improving operational capabilities to forecast response of the travel market to short-range and low-capital transport options should begin with identification, codification, and dissemination of available techniques. Initial results of this effort can be made available within 6 months. The state of the art will not remain stagnant, of course, and so this information collection and dissemination process must continue. The flow of information must move in 2 directions: Documentation of viable approaches must be provided to users in the field, and the experiences that users have with these methods, along with applications of their own innovative methods, must be returned to identify research needs, to provide data bases for research, and to make it possible for others to use locally developed approaches.

In the short term, at least, it is likely that 2 classes of short-range and low-capital options might call for 2 distinct approaches to the forecasting problem. These are differentiated by the scale of their impacts.

The first category includes options that produce only relatively small and highly localized facility or route-oriented user effects. Such alternatives might be dealt with by applying knowledge from existing data, special-purpose models, and case studies and presenting them through written reports, nomographs, or tables.

The second category includes those options that produce larger impacts on an area-wide basis. It is likely that the time and budget constraints applicable in such situations would be less limiting than those applied to the first category of options. Larger scale, more costly forecasting procedures might thus be used. Introduction of generalized costs and application of currently available behavioral models of mode choice should receive high priority. Prediction of mode- and route-choice shifts alone may be sufficient for short-term evaluation of some of these options. Yet, it is well known that even some apparently small changes in characteristics of transport services can result in shifts in destination choice, trip generation, and even the spatial arrangement of activities. Every effort must be made to anticipate such impacts. If available models cannot respond to such changes effectively and efficiently, research needs should be clearly documented.

It is patently obvious that existing models, modified in light of available knowledge, will not fulfill all of the requirements of the short-range and low-capital forecasting environment. An organized research program is badly needed. In particular, efficient models that are appropriately sensitive to level-of-service changes common to short-range and low-capital transport modifications must be developed. To accomplish this requires a reliable, disaggregate data base describing market responses to real changes in these variables. The collection of such a data base might best be accomplished through add-on studies as a part of existing federal and state transportation improvement funding projects, with case studies selected for special data collection efforts by an interdisciplinary research advisory council. This will require the precise specification of research needs and the careful monitoring of opportunities for data collection and analysis. Such an approach will make it possible to learn from the planned changes in transportation services that occur daily throughout the nation. It amounts to taking appropriate advantage of existing opportunities. Recent developments in disaggregate modeling suggest that large volumes of costly data will not be required. Instead, it will be of critical importance to collect the right data in the right situations, based on the nature of the hypotheses to be tested and the models to be calibrated. Data collection methods and format specifications should be uniform across case studies to promote maximum use of collected data and to facilitate intersituational comparisons for the purposes of extending the range of known demand elasticities.

Special arrangements should be made for rapid-response funding of highly specialized data collection activites in the context of infrequently occurring targets of opportunity, including strikes, extreme environmental conditions, accidents, facility closures due to repairs, and price or service changes. All collected data should be made relatively available to any researchers who wish to use them and to those agencies funded to perform analytic research in order to maximize the benefits derived from the collection efforts. In particular, this may offer universities an opportunity to perform unfunded, exploratory research directly relevant to forecasting needs faced by planners.

Specific model development efforts should focus on improving existing techniques and testing and developing emerging behavioral models. Near-term research (1 to 5 years) should seek to quantify the traveler-type-specific elasticity of travel demand with respect to typical short-range and low-capital option attributes, as listed above. Longer term research should seek to define the more fundamental characteristics of travel behavior. Such research is of critical, direct relevance to the solution of the forecasting problems faced by transportation planners, decision-makers, and citizens on a daily basis. Forgoing basic research entirely in order to meet short-term needs alone is clearly a form of disinvesting and will result in an even more critical situation in transportation planning in the coming years.

Data collection and research efforts must continue, perhaps at a lower level of effort, after initial research projects have been completed. This will ensure that future forecasting methods are timely and responsive to the evolving needs of decision-makers, the changing characteristics of travelers, and the emerging characteristics of transport options. Furthermore, monitoring of the efficacy of operational forecasting techniques, through the surveillance of the actual response of the travel market to implemented changes in service, will make it possible to validate existing forecasting methods. An organized monitoring program is particularly appropriate for many short-range and low-capital options, the impacts of which may be felt very rapidly.

Beginning immediately, it should be possible to organize a family of forecasting techniques appropriate for evaluating short-range and low-capital transport options. Each of the methods within this family might be appropriate for a particular forecasting situation, defined in terms of the travel market characteristics, option characteristics, and impact characteristics. Just as the range of the complexity of the forecasting environment might be quite broad, so might the range of the forecasting methods. The need for establishing consistency between methods is, of course, essential and must be the subject of continuing research. The search for a reliable, behavioral basis for forecasting models is likely to ensure this consistency. In the immediate future and for less complex forecasting environments, the codification of existing knowledge in the form of tables, charts, and nomographs is a reasonable direction to pursue.

The product of these efforts might be prepared and distributed in the form of a set of loose-leaf guidelines that permit users to quickly identify one or more appropriate forecasting approaches, based on the characteristics of the problem at hand. Documentation of these techniques, including specifications of the limits of their validity and applicability, should be thorough. The loose-leaf form is recommended for easy updating. Guidelines should be prepared and distributed in such a manner that institutionalization of methods is discouraged. It should be recognized that the current state of the art is sufficiently limited to make institutionalization very dangerous. Innovation in demand forecasting should be encouraged and, where appropriate, actively supported.

MARKETING REQUIREMENTS

Along with development and organization of appropriate travel-demand forecasting capabilities, it will be important to recognize and to meet the need for marketing these capabilities to potential users. This includes educating the analyst about his forecasting needs, the techniques to meet them, and the limitations of those techniques. It includes providing both the analyst and the decision-maker with information about forecasting needs and methods so that they can work effectively together. Finally, there is a need to provide the analyst with a basis for communicating to lay citizens not only the results of the forecasting process but also the philosophy, validity, and meaning of the forecasting process itself.

Resource Paper

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Travel demand forecasting can and should be used in the planning and design of short-range and low-capital options. The degree and manner of use may vary, but either direct or indirect application of appropriately structured demand analysis is essential to responsible project design and implementation.

To back up this premise and to provide a framework for identifying appropriate research and development, this paper starts with a discussion and classification of applicable travel demand forecasting needs. Requirements imposed by the nature of short-range planning and the actors involved are then outlined. This provides a basis for delineation of desirable demand forecasting and analysis characteristics. Following a brief evaluation of the present state of the art is a statement of research and development needs.

JUSTIFICATION AND USES

Need for Forecasting

Discussion of demand forecasting requirements and applications in the context of planning short-range and low-capital options should start with recognition that there is disagreement as to the usefulness of such demand analyses. The argument supporting omission of demand analysis is that "short range" and "low capital" by their definitions denote projects inexpensive enough to approach on a cut-and-try basis. It is argued that skipping demand forecasting saves money and precious time in project initiation—money and time that could better be spent in responding to the real-life project results as determined in the field.

It seems reasonable to acknowledge that there will be project options of a scale not justifying any more forecasting than the qualitative evaluations implied by good project design. However, good project design itself can benefit from demand analyses structured to produce travel market response information of general applicability.

The state of knowledge regarding effects on transit ridership of service, price, and advertising was recently described by the general manager of a progressive transit operations as, "We don't know" (1). This statement is symptomatic of not just a communication gap but a very real need for demand-analysis information applicable to optimization of transportation service priorities and design criteria.

Many short-range, low-capital projects deserve direct application of project-specific demand forecasting. Such forecasting may be done to aid preliminary project design, to use in selecting the best of several alternatives, or to provide a basis for feasibility determinations.

The project design application of demand forecasting in particular involves processes that are not extensively developed. As a result, the planner is often better able to evaluate a proposed transportation option than he is to design one in the first place. Yet it is surely a basic requirement that we be able to conceive and structure effective transportation options.

Use of demand forecasting in comparison of alternatives is not at all diminished in importance by the current short-range and low-capital orientation of the transportation planning climate. The increase in citizen participation in the planning process places greater demand on the planner and the administrator to produce an array of information, including forecasts, for use in citizen evaluation. The forecasts must be easily explained and readily defendable.

Although capital investment is not so much an issue with short-range and low-capital options, there are other types of investment, risks, and need for justification that equally require demand forecasting. One of these is the investment in institutional change required for many of the policy options currently receiving attention. Another is the substantial risk of project failure that may jeopardize a transportation improvement program. There is also the real or imagined cost of change in the way of doing things, as exemplified by disruption of public travel habits and operating agency procedures.

Classification of Forecasting Uses

Given the forecasting needs discussed above, a categorization of travel demand uses can be outlined as follows:

1. Demand forecasting for design purposes
   a. For project-specific design
   b. For general design guidelines
2. Demand forecasting for project evaluation
   a. For comparison of alternatives
   b. For feasibility analysis

As outlined, use of demand forecasting in design can either be project specific or have more general applicability. Project-specific applications involve using travel forecasting models and techniques in preliminary design to identify the potential and the preferred characteristics of a short-range or low-capital option. Results are specific to study area characteristics. The demand models may be used to produce preliminary usage estimates, to identify areas of feasibility, and to evaluate alternative operating parameters in the search for optimum transportation service combinations.

Use of demand forecasting as a more general design tool implies making available a service planning handbook containing design guidelines and criteria recommendations derived from demand analysis. This would necessitate answering the basic questions about traveler response to alternative transportation system attributes, relating findings to a comprehensive array of typical planning options, and thereby deriving a series of suggested design approaches and evaluation criteria.

Demand forecasting for the purpose of evaluating concrete transportation proposals divides neatly into the subcategories of forecasting for alternatives comparison and forecasting for fiscal evaluation. The 2 processes are essentially similar, but with some difference in emphasis.

In a comparison of alternatives, demand forecasting provides relative measures of the degree to which each alternative meets facility-usage goals. For valid comparisons, the forecasting procedures and assumptions must be fully consistent among the tests of alternative concepts. Ability to differentiate among substantively different alternatives is of paramount importance, and thus demand-model sensitivity is a virtue.

In fiscal analysis, given a chosen plan, the basic concern is reliability. A degree of conservatism is generally desirable. The ideal best estimate for purposes of fiscal planning, seldom obtained, would in fact be a set of estimates, each prepared according to different procedures and assumptions and, thus, bracketing the full likely range of actual results.

PROCESS AND USER REQUIREMENTS

Planning Process Characteristics

In comparison with long-range forecasting, travel demand analysis for short-range and low-capital options generally involves fewer unknown elements. Most of the land use, population, and travel characteristics not directly subject to project impact can be described by means of trending or minor adjustment of data on present conditions. This on the one hand limits the scope of the demand-forecasting problem and on the other hand places greater demands on the planner for findings fully consistent with currently observable conditions.

Land use and development can generally be considered fixed. The potential change in trip generation can often be judged minor and either omitted from consideration or accounted for as a percentage. One exception is where a secondary mode is to receive order of magnitude improvement or a primary mode is to be curtailed, for example, the introduction of viable bus service into a currently unserved area or the institution of a major parking tax or vehicle use toll. For this type of option, quantification of effects on the absolute amount of trip-making activity would definitely be desirable.

Trip distribution falls in the same category as trip generation: Changes should be of minor significance except in the special cases just mentioned. Travel-mode choice, however, is a demand element of major interest and concern in planning most short-range, low-capital options. Almost any undertaking involving more than traffic-operations improvements will require mode-choice analysis if there is to be any formal demand forecast.

Route-choice forecasting is the other travel demand element consistently of interest. Route selection, reflected in the planning process by sub-mode-choice analyses and travel assignments, is significantly more sensitive to service changes than choice of prime mode itself. As will be further discussed, accurate demand forecasting at the transit route level of detail is particularly important in meeting informational needs of the transit operator.

Demand forecasting for short-range and low-capital options thus emerges as having primary concern with either mode choice or route selection or both. Consideration of change in land use, trip generation, and trip distribution can in many cases be omitted or simplified, with certain important exceptions where induced demand is of special interest. Availability of comprehensive and up-to-date base-year travel data is a corollary requirement of particular importance.

Geographic Areas of Application

It is probable that most short-range, low-capital demand forecasting will involve projects best evaluated by concentrating on some appropriate subarea of the metropolitan region. The subarea may be an entire transportation corridor, a major political jurisdiction, an operating division, or the area tributary to a specific transportation terminal or station.

Projects justifying demand forecasting may only involve a single street or transit route, but normally a larger area will require study to identify pertinent side effects.

Need for full metropolitan region forecasts will in certain instances be encountered, particularly in reference to evaluating policy alternatives. Travel analysis for short-range and low-capital options clearly must have a flexible structure applicable to a broad range of geographic area sizes and levels of analysis detail.

Requirements of Specific Users

Each potential user has specific needs and requirements of demand forecasting for short-range and low-capital options. These are not necessarily conflicting requirements, but they must all be accounted for in seeking techniques with broad applicability.

The metropolitan transportation planner represents users including the transportation planning arms of federal, state, and local governments; regional land use and transportation planning agencies; and consultants to those groups. His demand-forecasting requirements are fairly all-encompassing. A major concern, reinforced by environmental legislation, is to have a reliable capability for estimating and comparing mode shifts that may take place when alternative programs and policies are implemented.

The planner is concerned about the effect of comfort, convenience, reliability, time, and cost. He needs measures for special services such as door-to-door bus passenger pickup, demand scheduling, and car-pool priorities; he needs to assess multimodal effects such as the impact on transit demand of fringe parking facilities. Special requirements are imposed by the need to assess transportation service impact on various socioeconomic groups and the need to take into account specific capacity restraints such as limited parking availability. Finally, because the transportation planner represents the party charged with producing travel analyses, he needs techniques that can be applied within reasonable time and expense limitations.

The first priority need of transit operators as demand analysis users is travel forecasts that they can believe in and feel comfortable with. This is not likely to happen until the planning profession can produce computer assignment output for present travel with transit line loadings close to observed loading. Even though corridor volumes may match, the operator has difficulty understanding how a process that cannot produce accurate line loadings without extensive hand adjustment can really have any validity as a short-range planning tool.

Not only are accurate line-by-line passenger-loading estimates necessary for credibility, they are needed by the transit operator for technical reasons as well. In particular, the schedule department needs such estimates to prepare schedules for major transit routing changes. Indeed, it would be desirable for transit assignment output to be adequate and sufficiently comprehensive for direct input into automated scheduling processes.

Other transit operator requirements include the need for basic marketing information on traveler response to service and fare changes. When specific proposals are being tested, operators would like to see detailed information on both favorable and unfavorable effects on riders. They would like to know the effectiveness of service changes in attracting new riders, but do not want this mode-shift information to mask impacts on the existing transit users. Lastly, operators of multimodal transit systems require the facility to examine effects of fares, parking charges, feeder service, and terminal facilities on mode of arrival at stations, station choice, and revenues.

Demand-forecasting requirements of the highway operator relate primarily to those instances where a proposed option impinges on the traffic operation of an existing freeway or street. If the option is transit oriented, the highway agency will desire demand forecasts to determine whether the highway capacity relinquished will result in a net transportation gain or loss. Reliable demand forecasting pertaining to highway vehicle route choice can be a useful tool in evaluating changes in traffic operations, but the analysis costs and accuracy obviously must compare favorably with manual techniques.

Political decision-makers and citizen participants in the planning process are the ultimate users of much of the demand forecasting done by planners and transportation operators. They depend on forecasting reliability and need clear statements defining the range of uncertainty inherent in each demand analysis finding. Citizen participants, in particular, are concerned with questions of basic demand forecasting validity. They are best served by models that have an obvious, easily explained correlation between model structure and some inherently logical travel-making decision process that the public can relate to. Finally, political decision-makers and citizen participants desire prompt response to the "what if" question, placing a requirement on the travel analysis process for quick response to testing of alternatives.

OBJECTIVES AND PRESENT STATUS

Desirable Features and Characteristics

The short-range, low-capital applications of demand forecasting, the specific needs of forecasting users, and the characteristics of the short-range planning process all serve to define desirable features and attributes for the applicable demand analysis methodology. In this section, a position is set forth as to what the key features of this methodology should be.

As previously discussed, it is the mode-choice and route-choice travel decisions that consistently bear most directly on short-range forecasting. This suggests an advantage to using sequential models for most short-range planning activities. Sequential modeling will allow bypassing of the generation and distribution stages of forecasting in those numerous projects where the theoretical advantage of considering all factors is clearly outweighed by the benefits of simplified analysis.

Use of mode- and route-choice models alone does imply availability of travel-interchange volumes from surveys or forecasts. Unfortunately these are not always available in suitable form. For such situations and for projects where latent demand is of critical importance, there is definite place for direct-demand transit-rider estimation techniques.

Two major considerations call for use of models with a clear, logical structure open to examination and study. First, use of the inscrutable "black box" type of formulation hinders the planner in explaining and justifying his processes to the ultimate users: the transportation system operator, the political decision-maker, and the citizen participant. A process with inherent logic that can be effectively illustrated provides more salable forecasts than one that nonstatisticians must take on faith. Second, models with a logical structure provide a basis for understanding mode-choice decision-making processes in a way that can be applied toward designing more attractive transportation alternatives. Sensitivity tests of any type of model can be used to determine that model's statement as to how travel will change as transportation service parameters are altered, but only a model structured on theory can significantly contribute to answering why. For these reasons, short-range demand forecasting appears best served by models based on the concept of describing actual human behavior with probability statistics.

Part of the analysis package should be a carefully derived and structured handbook setting forth demand forecast findings relevant to system design. Translation of these findings into service criteria and optimum service combinations under various conditions should be provided. The basis for such a handbook should clearly be the broadest possible array of well-substantiated behavioral modeling and sensitivity testing.

Requirements for analysis of alternatives obviously call for forecasting techniques that provide internally consistent comparisons, realistic sensitivity to the differences among options, and reliability in the absolute forecast. The ideal model should have the capability to analyze not only time and cost factors but also comfort, convenience, reliability, and various subcategories within each, such as walk time versus wait time. The ideal forecasting package must cope with special transit services involving boundary conditions, such as no-walk or no-fare; effects of incentives and special information services, such as in organized car pooling; and impacts of capacity constraints, such as capacity limits on station or downtown parking.

Part of the short-range demand forecasting package should be an assignment process capable of realistic passenger loadings on individual transit routes. This assignment capability should extend to systems containing mixes of express bus, local bus, rapid transit, and commuter railroad services.

It is desirable that the analysis package include capability for isolating the impact of service change on various socioeconomic and transit rider groups. In the instance of short-range transit alternative evaluation, it would also be desirable to provide for analyzing the known travel patterns of existing riders while at the same time to provide for calculating mode shifts associated with transit improvement. This capability would presumably be manifested in a technique for manipulating and analyzing detailed transit-rider survey data while retaining access to travel information and models required for mode-choice forecasting.

With all this, the ideal short-range and low-capital demand forecasting package would still have to be operable with considerably less expense and elapsed time than is characteristic of current efforts. The desirable goal would be to have no significant project forgo demand forecasting because it would require too much money and time needed for other aspects of project initiation.

State of the Art

Sequential demand models, identified in the previous section as appropriate for most short-range planning, are fortunately the most highly developed. Nevertheless, present examples do not provide all characteristics outlined as being desirable.

Disaggregate models structured to relate mode choice with human behavior give excellent promise for better understanding of user response to transportation system characteristics. The development status of this type of modeling has been covered recently in a comprehensive paper by Reichman and Stopher (2). At this point, there has been little production use of disaggregate stochastic models in transportation planning practice or in the translation of research findings into descriptions of preferred transportation system characteristics.

Concepts closely paralleling the probit analysis type of disaggregate model, but intended for use with aggregate data (3), have been recently applied in developing new mode-choice models for the Washington and Philadelphia regions. Direct-demand transit-rider estimation procedures developed by Kraft and others (4) are being employed in Boston, but have not at this point been adopted for production use in other urban areas.

Assessing the consistency and reliability of current models is made difficult by the fact that most "testing" is limited to replication of the same survey data as were used in model calibration. There have been all too few rigorous comparisons of modeled travel demand with actual before-and-after data.

The Traffic Research Corporation diversion curve mode-choice model for Toronto is one that has been examined by using comprehensive survey data from 2 points in time. The results indicated good stability where high levels of transit service were involved and some significant shifts in modeled response to lower levels of service (5). Tests of a mode- and sub-mode-choice model chain developed for the north suburbs of Chicago indicated an ability to forecast, within the range established by 2 separate surveys, the usage and mode shifts associated with opening a rapid transit branch (6). In both cases the models involved were of the sequential type. This author is not aware of any such comparisons made with urban applications of direct-demand modeling.

There does not exist any handbook of transportation service design based on knowledge of desirable system characteristics as derived from mode-choice model interpretation and sensitivity tests. There has, however, been some limited sensitivity testing along this vein in system-specific analysis. One such application was the use of direct-demand estimating models in an effort to describe desirable service characteristics for metropolitan Boston transit service (7). A second application was use of mode-choice models developed for the Chicago north suburbs (6) to examine local bus-rider sensitivity to fares and service frequency (8). This latter work also involved use of modeling in system design to establish basic ranges of feasible service coverage.

All of the currently operational demand forecasting techniques and related models are sensitive only to a limited range of transportation system characteristics, although obviously those parameters thought to be of critical importance are included. A current Washington, D.C., study of short-range, low-capital options available for reducing automobile travel (9) serves to illustrate present capabilities and needs. Forecast results are not available, but study design has identified the new Washington, D.C., choice models as being directly sensitive to effect of policies concerning parking fees, transit fare, road pricing, and increases in transit service as described by coverage and frequency. Policies under consideration that cannot be examined without supplementary modeling include car-pooling incentives and expansion of commuter fringe parking. Neither will direct examination be possible, should it be desired, of certain other service attributes including standee policy and service reliability. Hard data are lacking for rigorous development of supplementary models to address such questions.

The major available work concerning importance of mode-choice factors other than those directly related to time and cost is the Chicago area research done by the Illinois Institute of Technology (10). Factors investigated include considerations such as privacy, ability to read a newspaper while commuting, and likelihood of obtaining a seat. Certain of these considerations were identified as being of importance. However, for whatever reason, the findings of this study do not appear to have engendered consideration of more factors in operational demand forecasting models. The recent Purdue session on transit operations research needs concluded that "much more research on the determinants of demand for transit service is absolutely essential to rational planning" (1).

There exists one example of forecasting demand for special transportation services by using disaggregate mode-choice modeling. The travel modes considered were private automobile, rental car, taxi, and limousine as used for access to airports in the Baltimore-Washington area (11). The authors of a paper on the project, which used a multimodal logit model, indicate this initial work to be promising. It is pertinent to note that the architects of this analysis, as so often happens, also report being severely hampered by incomplete survey data on the characteristics of current transportation service use.

There are a number of other models or estimating procedures that have been developed for forecasting special transit service demand. However, these tend to be structured on unverified hypothetical user response pending availability of better information.

The first and major use to date of the HUD transit-planning package for short-range transit improvements provides an instance where impact of service changes on existing transit-rider groups was specifically looked at. This use was in the investigative UMTA demonstration project undertaken during 1968 in conjunction with the Washington Metropolitan Area Transit Commission and D.C. Transit, Inc. (12). Travel time and transfer reductions (or increases) were quantified in terms of origin and destination areas of transit-rider trips, with no socioeconomic stratification. The techniques on hand then and now required substantial additional data processing to obtain this information. The data for this particular project were a detailed survey of existing transit usage, but the work suffered from inability to make statements about mode shifts that might be occasioned by specific service-improvement proposals.

It was in this demonstration project, which used the HUD programs, that the need for more realistic transit route assignments was first identified. Although satisfactory manual adjustment techniques were developed, they were time-consuming and not easily transferable to significantly altered routing systems.

The success of recently implemented multipath highway assignment techniques (13) in providing realistic highway vehicle loadings gives indication that realistic transit assignments should be possible to achieve. Work in the areas of transit submode choice and highway route choice gives evidence that models applicable to multipath assignment can be readily structured (14, 15). Transit sub-mode-choice modeling to date, however, has been based on limited data. There has been no known investigation of transit-route choice within an all-bus system.

The present overall picture of demand forecasting for planning short-term and low-capital options is one of an activity that holds significant promise, but of practical applications and achievement to date that have been limited in number and scope. For any major growth of accomplishment in this activity, there needs to be more basic understanding of market forces and demand forecasting, more dissemination of knowledge, and introduction of analysis program mechanisms designed specifically to meet short-range forecasting requirements.

SUGGESTED RESEARCH AND DEVELOPMENT

The suggestions that follow comprise a position and preliminary statement on specific research and development activities thought to be of particular importance in the development of demand forecasting for short-range and low-capital options. Obviously many of the suggested projects have direct input into other areas of demand forecasting as well.

Travel Data Surveys

The need for survey data is an aspect of research that too often leads to projects that gather data and do little else or that structure elaborate data-dependent models on the thinnest of observations. Moreover, there is often only one chance to obtain survey data pertinent to important before-and-after situations.

It is suggested that a program be initiated with the explicit purpose of obtaining and processing empirical travel data structured specifically to meet mode- and route-choice modeling requirements. A key initial step in such a survey program is establishment of a board of control or a similar structure for use by the researchers to specify data needs and oversee survey design. This board of control should comprise practitioners and researchers with demonstrated experience in using survey data for mode-choice model research, development, calibration, and application. The board should have representation from each of the principal schools of thought concerning model structure.

Under direction of this board of control, special surveys would be commissioned. In addition, survey designs would be specified for pertinent UMTA grant projects.

In the area of special surveys, it would seem particularly useful to initiate sets of closely controlled surveys directed at obtaining travel behavior information for circumstances where only one variable changes or is different. For example, it is doubtful that the effects of walking distance on transit usage or submode choice can be adequately described without observations obtained when other factors are held under close control. Appropriate data should be obtained from areas with relatively isolated bus routes and transit stations. Separate large-sample, microlevel surveys or survey sets could be directed to assessment of response to various potential determinants of mode choice, route choice, and mode-of-access choice.

The obvious purpose of a rigorous survey program in connection with UMTA-grant projects is to obtain before-and-after data. The effects surveyed need not be dramatic to be important. It is said that the transit-riding population on Chicago's parallel Lake Street and Eisenhower Expressway rapid transit lines has for years been shifting from one route to the other in response to schedule and equipment changes. Time-sequence surveys in this narrow corridor, had they been taken, would be invaluable to those concerned with comfort and time factors. As with the special surveys suggested above, before-and-after surveys should be carefully selected and controlled to produce a maximum of pertinent traveler-response information.

Model-Testing Procedures

Procedures and means for independent testing of demand models need to be made an integral part of the research and development process. Models or model chains thought or intended to be of general interest and utility should be examined for transferability from one data set to another and for capability to predict before-and-after travel characteristics. This is not to say that a choice model developed in Pittsburgh should necessarily be rejected because it cannot reproduce St. Louis transit riding; a correct reproduction of relatives might be judged sufficient for given purposes. My opinion is, however, that if a choice model is not transferable it is because some specific and ultimately quantifiable determinants have not yet been properly accounted for.

Initiation of a demand forecasting test program need not await development of new models and techniques, but could move forth in 2 stages. The first stage could be to provide a better understanding of the strengths and limitations of those current demand models that have received or deserve more than local attention. The traditional transit operator rules of thumb for estimating ridership potential might well be similarly examined. The evaluation program could then move on to a second phase of testing new model developments as they become available.

This testing program should provide funds specifically allocated for such calibration and adjustment as the authors of each model might specify as being appropriate. Funds should also be available for actual assistance and review by the developers of a model under examination. It should be stressed that this testing program is not suggested as a punitive control measure. Certainly one key purpose would be self-education of the planning profession. Further, it should be understood that an open and publicized validation program would be invaluable in gaining the confidence of transportation operators and public decision-makers where that confidence is deserved.

Market-Response Analysis

Analysis of demand-model structure and conduct of sensitivity tests to establish market-response relations are fully deserving of research and development status. As with model testing, analysis of market-response relations could move forward in 2 phases. In phase one, some half dozen existing models found to have merit in the validation process could be applied in parallel to service- and policy-parameter sensitivity tests by using a series of data sets. The results, and such findings as could be inferred directly from the model structure, could then be assembled into a preliminary market-response statement. In phase two, the work would be expanded by using new and advanced modeling techniques as they become available.

In addition to more general informational reporting, one specific product of market-response analyses should be the previously suggested design handbook for short-range, low-capital options. As with the precursor analyses, this handbook could be developed in stages as information becomes available. The purpose of the handbook would be to distill findings of travel demand analysis into concrete service design and marketing guidelines and recommendations.

Such a handbook might well contain nomographs and other manual design aids to better allow translation of recommendations to fit local conditions. Design information should be accompanied wherever possible with concrete examples of actual applications and their successes and failures. The handbook should be structured for use by all those involved in transportation service design, planning, and marketing, but with specific attention to needs of those projects where it would likely be the only demand-forecasting information input.

Mode and Route Choice

Implicit in the above recommendations is an assumed major program of mode- and route-choice modeling research. Such a program should be closely structured and directed to obtain pertinent results. A substantial portion of the research should be done under performance specifications having near-term application in mind.

A demand-modeling research program should obviously not put all of its eggs in one basket. On the other hand, it would appear that primary funding should go to mode-and route-choice modeling in the behavioral school with preference for efforts with clearly structured theoretical bases. Within this scope there is room for aggregate and disaggregate modeling, as well as for network modeling and modeling independent of specific network processes.

A key element of mode-choice research should be further investigation into the determinants of mode choice including the many comfort and convenience factors not yet well accounted for. For full utility, such research must be conducted within the framework established by model development. The results need to be readily transferable into the demand modeling context, not just independent statements of relative parameter importance.

A share of the research effort should go into direct-demand modeling to meet those needs for such models as have been outlined in previous discussion. It is hoped that such direct-demand modeling can draw on the findings of sequential, behavioral modeling such as to allow a comparably logical structure. In connection with developmental work on direct-demand techniques, it would be useful to obtain better information and forecasting ability concerning the secondary effects of induced transit ridership. Specifically needed are a better understanding and quantification of the social benefits that accrue from improved service to the transit-dependent individual.

Impact-Analysis Techniques

In the development of both model and analysis packages, attention needs to be given to isolation and examination of transportation service impacts on special user and socioeconomic groups. Work pertinent to this need may only be practical to undertake as part of specification and development of a broader analysis package. This circumstance does not in any way diminish the importance or urgency of such impact isolation capabilities. Perhaps there should be a task force established to define reasonable requirements for user-group impact analysis and to pursue its inclusion in the development of an overall analysis package.

It should be possible to accommodate the important special interest in accurate handling of existing transit-rider groups by development of relatively straightforward techniques. The need is for a program package allowing analysis of short-range transit improvements with primary emphasis on existing transit users but, nevertheless, providing appropriate estimates of mode-shift potential and risk. Such a package would use existing transit-rider trip data as the primary basis for route-specific volume and rider-impact analysis. Adjustments for mode shifts would be calculated on the basis of differential shift modeling that could be either direct demand or sequential as applied in conjunction with a separate total person-trip table.

Multipath Transit Assignment

The existing unmet requirement for accurate line-specific forecasts of transit riders has already been highlighted. This is a clear-cut and major program development need.

The problem could be approached in stages if appropriate for technical reasons. The problem element requiring the most immediate attention is the need for accurate assignment within the transit mode. This capability clearly requires multipath assignment responsive to sub-mode- and route-choice characteristics. The other principal problem element is that of obtaining realistic multimode loadings with full consideration of the automobile-driver and automobile-passenger means of access to transit service. The ultimate objective would be to have a program package allowing, for example, accurate estimation of line and station volumes for changes induced by collection and distribution changes in transit service, fee manipulation of fringe parking, and adjustments of line-haul service.

Time and Cost

Again it must be emphasized that time and cost of analysis are critical factors in the usefulness of demand forecasting in planning short-range, low-capital options. Improvements and elaborations to analytical capability will not be of value if they cause undue added expense, time, or necessity for special expertise. Indeed, requirements for these items must be reduced if advanced demand-forecasting techniques are to find broader acceptance and applicability in short-range planning. Program development activities must thus be vitally concerned with time, cost, and ease of program use.

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Workshop 2

DEMAND FORECASTING FOR LONG-RANGE AND CONTEMPORARY OPTIONS

OBJECTIVES

Identify, review, and evaluate current and proposed travel demand forecasting techniques and procedures for use in assessing long-range urban transportation options that use contemporary technology.

Recommend new and improved forecasting procedures that are responsive to requirements of using travel forecasts in assessing the options.

Develop a recommended program of research that is responsive to the identified requirements.

OPTIONS

Long-range options include all actions or programs that use contemporary transportation technology or institutional procedures and that may be planned, designed, and implemented in 5 years or more. Examples that use contemporary transportation technology include freeways and expressways on new or existing rights-of-way; new or reconstructed arterial streets; new bridges, major interchanges, or other major link improvements or bottleneck relief; rail or bus rapid transit lines on new rights-of-way with or without supplemental feeder modes; new terminal facilities such as consolidation of transit terminal facilities or major new parking programs involving new construction or demolition or both; and demolition or reconstruction to a smaller scale of an existing urban expressway. Examples of options using contemporary institutional procedures are land use controls such as zoning, water, and sewer service regulations; direct development such as renewal, purchase by eminent domain for open space, or government installations; and increased operating subsidies.

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Report

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Workshop 2 reviewed many current problems and issues within the context of the methodological procedures that were developed in the late 1950s and the early 1960s, for they form the basis for many current techniques. Discussion ranged from the view that long-range target-year planning was no longer valid to the view that long-range target year planning should be extended to cover even longer study periods of 30 to 40 years.

Out of these wide-ranging discussions a concensus emerged that it was possible to get more out of existing technical processes. Present processes have great flexibility and adaptability for solving problems not considered in the past. For instance, plan staging and its implications on the selection of the recommended plan requires only more time sequence analysis and perhaps a faster iteration process (through simplification of coding techniques so that more alternatives can be studied. Better use of existing techniques can also be obtained by developing better summarization routines for the models involved and by making greater use of graphic outputs.

Workshop 2 not only considered the present technical processes but also took a look at where major improvements were needed immediately as well as during a longer period. Three types of improvements are needed: On-line improvements that can be made immediately, near-term improvements that involve only the application of current research findings to actual problems and require no further research and, long-term improvements that require basic research.

Participants identified the following 3 areas as being those where improved techniques are most needed:

1. We must be able to make timely responses as issues are raised. Some capability already exists for doing this, but a great deal more is needed.
2. Most region-wide system plans are being closely scrutinized on a corridor basis, and new tools must be developed that will provide precise information on volumes, passengers, costs, and environmental impacts within the corridor. Generalizations from the regional level will no longer suffice.
3. Although current processes do provide rudimentary analysis of land use and

transportation relations, more precise information is needed.

With regard to the current state of the art of long-range transportation planning, participants concluded that (a) projects are conditioned on what went before and what current issues are; (b) the target-year approach to developing a transportation plan does not indicate whether such a plan can be achieved and does not stress incremental evaluations of the long-range system; (c) impacts cannot be modeled in detail so that benefits and consequences can be easily identified; (d) even short-range solutions take as many as 10 years to implement; (e) energy consumption, which will become a major consideration in transportation planning, has not been considered; and (f) models are not sensitive to activity systems so that the effects of transportation decisions on land use and vice versa can be predicted.

Workshop 2 identified several issues that researchers must address in improving long-range and contemporary travel demand forecasting methodology.

1. It is generally insufficient to use a fixed land use plan as the basis for forecasting travel demand and its impacts. Long-range transportation planning implies land use changes resulting from the implementation of transport plans. In addition, a land use plan conceived in isolation of the location, timing, and design of transport improvements may not be unachievable. Thus, a fundamental issue in long-range planning is, How can the effects of transportation on land use and land use on future travel demand be incorporated?
2. The emergence of a "systems view" of transportation problems within urban areas has enabled the planner to greatly improve his conceptual tools for evaluating plans consisting of 2 time-staged sequences of projects. However, the political process as well as the operational necessity of reviewing, programming, budgeting, and construction dictates that projects be addressed and their analysis and justification be carried out one at a time. How can these 2 divergent viewpoints be reconciled?
3. Long-range plans have been criticized for their failure to deal with existing and short-term problems. Preoccupation with complete systems has obscured the benefits to be obtained by implementing partial systems. How can travel demand forecasts be made to address these short-run projects?
4. Travel demand forecasting has always been concerned with flows on individual facilities. Yet, flows by themselves have neither a beneficial nor a detrimental meaning. Decision-makers need to know the consequences of particular courses of action, and thus models must go beyond flows to impacts. How can models be so designed?
5. Can forecasts be produced by streamlining the process, e.g., by using abbreviated coding devices; simplified representation of proposed projects, corridors, or system elements; and a summarization of data depending on the decision to be made?
6. Can incremental forecasts be made to provide 5-year time series information and to examine for each succeeding increment the numerous possibilities and their implications on the previously committed elements of the system? Such techniques should deal with population, employment, land use, and the associated travel demand.
7. Can geographic identification be built into forecast information to permit ready correlation with housing, population, business and employment, recreation, and social indicators?
8. Can graphic devices be developed to quickly show areas where future travel demand will create problems on the existing system? Can areal summaries of vehicle-miles of travel and capacity provide similar insights, and can measures of performance be developed to indicate on an area basis the mileage of highways or transit routes required to provide needed service?
9. How can travel information be used to describe the impact of an action or lack of action to a policy-maker? These impacts should be stated in terms of costs (fares), congestion, opportunities for business (CBD) employment, health care, and the like.
10. Can the effect of tolls, fares, and other charges or restrictive regulations be adequately modeled so that their effect on travel demand can be estimated with reasonable accuracy?

11. Can travel distribution be estimated by time of day? Can peak loads be estimated directly on links?

12. Can the error of estimate be readily ascertained in a simulation process so that this factor can be considered in evaluating impacts?

13. When a new facility of limited capacity is put into the system exogenously, can its impact on other facilities be measured?

14. Is there really an opportunity to make significant changes in land use and to evaluate their impact on travel demand? Are these changes isolated within a region? What is the extent of their impact?

15. Can the forecasting process produce data for evaluating noise, pollution, accidents, and mode choice on a project, corridor, or regional basis?

16. Can we estimate or model the immediate effect of a minor transportation facility improvement? Does this have to be done by a regional model?

Participants decided that transportation impacts should be classed by groups affected rather than by type of measure. The consensus was that this was an important distinction because the measure used or the category of impact is viewed differently by each of these groups and that one level of detail might suffice for one group but be totally inadequate for another. Table 1 gives the 5 groups identified and the impacts.

Workshop 2 discussed specific areas for methodology improvement and research based on a hypothetical urban area. The urban area has a population of 1,000,000+, has been the subject of a conventional comprehensive land use-transportation study of the 1960s, is now experiencing problems not only with the overall regional system, has had several major corridor controversies, and has problems associated with the local transit system with regard to how many buses to purchase and what headways should be used on certain routes.

A summary of the discussion is given below. On-line recommendations cover those improvements that can be made with present capabilities; near term covers those for which knowledge now exists but its method of application must be developed; and long term covers those for which basic research is required.

ON LINE

Disaggregate Household Data

Better use of existing travel survey information can lead to improved travel prediction. The condition of existing home interview files should be reviewed, and specific recommendations should be made for use of the data on a disaggregate basis.

Parking

Present assignment models are not sensitive to changes in parking policy or pricing. These factors greatly affect travel mode choice to the CBD, and assignment processes should be improved to reflect changes in parking conditions.

Transit

Improvement in present capabilities is needed for the analysis of transit service in both large and small urban areas. In large areas, major route changes or implementation of new service is often considered in specific corridors of the region. In small cities, new local service or the tailoring of local service to meet specific requirements may be proposed. Transit analysis for either of these areas must be detailed and quick, and both are difficult with existing methodology.

Table 1. Transportation impacts and groups affected.

Group	Impact Type	Factor Impacted
User	Direct cost	Fuel, parking charge, tolls, other pricing mechanism
	Indirect cost	Accidents, insurance, depreciation
	Service	Travel time, accessibility, comfort and convenience, frequency, safety, availability, regularity, diversion
	System staging	Availability, circuity, cost
Nonuser	Displacement	Economic and social costs
	Environment	Noise, air quality, aesthetic impact, impeded access, congestion, accessibility, land use
	Urban structure	Density, public utility cost, open space, taxes
	Travel generation markets	
	Staging of system	
Carrier	Direct cost	Capital investments, revenues, operation
	System operations	Type of technology, major facilities location, type of operation, station location, headways
	Sensitivity	Errors in predictions of ridership and cash flow
	Risk analysis	Based on above
Noncarrier	Direct cost	Accessibility for employees, customers, products, buyers, and sellers
	Development	Neighborhood viability, opportunity for development, relative attractiveness of areas
	Risk analysis	Use above factors to review cash flow situations
Government		
Federal	Direct cost	Capital, operation, revenues
State	Direct cost	Capital, operation, revenues, operating assistance
Local	Direct cost	Capital, operation, revenues, operating assistance, tax base, capital grant program

Macromodels

The transportation system plan (transit and highways) for each metropolitan area should be checked for appropriateness of size, that is, the number of miles of major facilities or frequency or level of service. Capability to do this now exists with macromodels, but specific application techniques need to be developed for typical urban areas.

Land Use

Existing land use growth allocation models are sensitive to transportation network changes. However, these models have not been used in most transportation studies, and their capabilities have not been fully used in measuring the effect of proposed transportation systems on land use. Standard methodology should be developed to ensure that land use implications of proposed transportation plans are studied in each urban area.

Implementation

Too often, long-range transportation system plans are developed without a thorough review of the sequence in which the plan elements should be implemented. Based on the number of plans that have been rejected in recent years because certain links were no longer acceptable to the public or to elected officials, strategies must be developed for using existing models to make incremental forecasts and analysis on staging of transportation plans. If these techniques are used, the plan that is most economical 20 years hence would not necessarily be the plan that is most economical when a time series analysis is made on the implementation of its incremental parts.

SHORT TERM

Direct Demand Models

Direct demand models appear to be one means of obtaining better forecasts for transportation corridor projects. A set of specifications for data requirements should be developed immediately for use in such models. One method of developing these specifications is to bring together the practitioners who are about to initiate general travel surveys for their urban areas and the researchers who desire to do direct demand modeling so that data requirements for both can be obtained simultaneously.

Model Documentation

Too often models are developed and used without documentation of input requirements and the types of output that can be called for. Specifications are needed for present and future models so that users may fully exploit the model and have all necessary inputs available before the model is brought on line. Effective evaluation must also be based on statistical fit of the model to data for both present and future conditions.

Pilot Study

A method to analyze corridor travel is urgently needed. Current tools have been designed for regional analysis but do not address many of the detailed questions within a specific corridor or subarea. Workshop 2 proposes that problems of this type be identified within 3 urban areas and that applied research projects be initiated to develop specific analysis techniques.

Equilibrium

Present assignment models do not necessarily reach equilibrium between traffic flow and system capacity. This condition must be achieved if network flows are to be realistic in simulation models. Therefore, present assignment techniques should be modified, particularly for peak-hour analysis, to achieve a condition of balance.

Peak Hour

Investigation should be undertaken to find the length of the appropriate peak period for network travel analysis. Most analysis is now done on an ADT basis, and conversion to peak hour is approximated after the network assignment has been made. Current microassignment techniques should be reviewed, and the appropriate time period should be determined that is representative of peak-volume conditions on transportation networks.

Application Time

Current transportation models require weeks and, in may instances, months for their application. Methods to shorten the application period should be developed so that models can be applied more frequently to evaluate many more alternatives than are currently considered.

Tree Trace

In minimum time path algorithms, present tree techniques use either time or distance. A tree trace algorithm should be developed that can use a number of different parameters (including cost) and permit these parameters to be used in combination, i.e., weighted average if deemed appropriate.

LONG TERM

Management

Many urban transportation planning studies have not exhibited a full understanding of the planning process or the management of its individual parts. A management planning program should be initiated to ensure that study directors as well as key technical staff members have adequate training to manage efficiently and productively.

Monitoring

A specific program of monitoring must be established to ascertain the change in trip-making and other key parameters on which travel demand forecasts are made. This program must be instituted in enough cities so that change can be monitored on a geographic, political, and social basis.

Total Impacts

The transportation planning process and its technical tools must be sensitive to and responsive to environmental, housing, and other social needs. New tools must be developed to permit more detailed analysis of the impacts of transportation at the subarea or neighborhood level where these factors are most significant.

Urban Structure

Present land use models measure the impact of transportation system change on land use but only at the regional scale. Models should be developed to measure the effect of land use changes and transportation system changes on each other.

Traffic Volumes

The end product of transportation planning is the provision of travel volumes to the designer of the facilities. Present techniques require much hand adjustment of regionwide travel volumes and in many instances do not provide enough detail for the designer. Improved methods of developing design parameters are required.

Resource Paper

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Travel demand forecasting has proved to be an elusive art, widely practiced, but increasingly difficult to believe as more and more projects are opened to traffic that exceeds all forecasts, sometimes even those of the design year. Other projects, such as the Massachusetts Turnpike or the Chesapeake Bay Bridge-Tunnel, have not reached their estimated volumes and consequent revenue generation. The next big project to open is the BART system in the San Francisco area. This project is one that will be watched carefully. Will actual volumes exceed the estimates, or fall short? If past prediction is any guide, there is little chance that they will come close to the mark.

This Achilles heel in the urban transportation planning process is a problem that is not likely to be solved by one conference. It will take research money, creative effort, and lots of hard work to bring long-range travel-demand forecasting to the state of being a science. What we must do are identify some of the reasons why we appear to have failed in the past and put forward ideas for future research.

NEED FOR LONG-RANGE FORECASTS

The first, and perhaps the most important, point I want to make is that there is a mistakenly perceived need for accurate long-range forecasts of traffic volumes. It is true that the transportation projects associated with most cities are large and expensive. The South Station section of the Boston central artery cost more than $75 million per mile. This is too large an investment and too important a facility to build without a careful estimate of demand. When one considers the effect on the area as a whole, including the secondary investments, the impact of this transport investment is enormous, affecting the land use patterns of the urban area literally centuries into the future.

How then can I say that accurate long-range demand forecasts are not needed? First, I believe that we are kidding ourselves to think that demand estimated by present methods will be accurate in the long range. Even if we were to develop very good demand models, travel is only one part of the complex overall urban process that includes changing land use and urban structure. Changes in the transport facilities system will themselves affect the equilibrium of the system. The new levels of the activity system that will result will influence the travel demand forecasts and render thei inaccurate. Thus, I would argue that demand models considered in isolation of this process of change are necessarily short range in nature.

The conclusion that demand models are short-range prediction devices derives from the fact that the forecast volumes computed by the model depend on the validity of the inputs and, because these will be changing during time as the economic-activity system changes, the outputs will only be valid during that period for which we can accurately predict values for those input variables. At the moment we are not very facile at developing those inputs. One reason is that the urban transportation planning process has devoted very little time and effort to the construction of operational activity-system models of land use, housing, industrial location, and so on. Another reason is that the models are hard to develop. As a consequence, demand models will remain accurate only during the short range, not the long range, until these models have been implemented.

Beyond the practical realization that at the moment we do not have satisfactory activity-prediction models and therefore currently are not going to get long-range demand predictions, my original point was that there is a mistakenly perceived need for accurate long-range forecasts of traffic volumes in the first place. One current use of such demand forecasts is in the economic justification of a project. Long-range forecasts are needed because projects are typically capital intensive and require long lives for their economic amortization. This leads us to believe that accurate volumes are needed in the computation of the benefit stream. The fact is that in networks the flows over the system are changed by investments in new facilities in such a diffuse and subtle way that it is impractical to compute benefits external to the transportation/activity prediction system. Rather, what must be done is to integrate into the models the ability to compute the disutility incident to travelers or commodity movements as the result of each trip. Over time, as the activity system changes, those utilities will also change; and, as they do, accounting systems set up for the purpose will record them. One such measure is the gross national product. Urban equivalents to GNP could be formulated. Plans could then be evaluated by comparing time series of such measures. Volumes would be output merely as an afterthought.

An attractive alternative when we get good land use models will be the examination of the changes in land use that have occurred as the result of the changes in the transportation system. In fact, the goals of the urban transportation planning process might well include specifying the land use pattern being sought. Clearly, this would remove some of our current obsession with traffic-flow figures.

For the time being we should spend more time looking at the levels-of-service attributes that exist on important links in the system and between typical origins and destinations at equilibrium. The fixation on volumes is understandable, for they provide a readily comprehensible measure that is in many instances directly observable, at least in theory. In practice, they begin to get complicated: Hourly volumes, average daily traffic, thirtieth highest hour, practical capacity, and design volume all require elaborate explanation. With higher level objective functions, our concern can properly turn to other matters.

However, before we can do this we will have to address the concerns of our brethren whose job it is to design transportation facilities. They have for some time been looking to these forecasts for numbers to use in the sizing of facilities. I believe we should cut them off with nothing more elaborate than a statement that the figures we can furnish will not be appropriate to their use anyway without further discussion. Typically, the numbers needed for economic justification will not be the same as those needed for sizing and design. This is not to say that there is no relation between the two; however, the needs of the former are concerned with total flows, whereas the design concern is with conditions during the often-repeated peak period. The capacity-related figures frequently used for design are difficult if not impossible to get from present approaches. The design of the facility should probably be based not on traffic forecasts literally interpreted in any event but on consistency principles with as much future flexibility built in as each case will allow. For large projects it may be desirable to develop simulations for each of several designs to determine the consequences of each. In essence, I am suggesting that one first establish the facility design and then determine how traffic will use the facility provided.

Increasingly, the forecasting of demand will be in support of some notion of what one would like to see the city become in the future. This means that city goals must be well thought out. It also means that the task of designing future systems is greatly clarified. Designing systems without such a statement of desired goals is much more difficult, for there can be no measures of goal achievement except very narrow measures of traffic efficiency, which I contend are totally unsatisfactory.

There are at least two other reasons why I would like to debunk the importance of accurate long-range forecasts. The first is that the most important years from an economic point of view are the first years, not the later ones. The higher the appropriate rate of interest is, the truer this is. Our concern therefore should be primarily with the short-run effects of changes in the system. Many of these may be interim in nature. They may represent conditions before the system is "finished." As designers we have tended to be over-concerned with the design year, with the grand plan, and with symmetry of the finished system. Increasingly we have been frustrated by systems that, it has become embarrassingly obvious, will never be finished. We might be more convincing if we stuck to short-range forecasting and emphasized solutions that have more immediate payoff.

The second reason is closely related to the first. That is, long-range forecasts associated with a target year insidiously undermine rationality in the planning process. If the activity system changes in response to changes in the transport system, then it would appear to be patently absurd to attempt to jump ahead to some final year and predict activity levels at that time without working up to it gradually in steps that allowed one to make midcourse corrections. Actually, the target-year concept in conjunction with the needs approach to public works planning has been the device by which we have fooled ourselves for years. We have merely specified activity variables that would support the travel patterns for the facilities that we sought to supply in the first place. Whether these travel patterns could actually take place was not debated. We could then hide behind the comment, "We only build what the public needs."

This leads us to consideration of what is involved in forecasting long-range travel demand for urban transportation facilities. Clearly, the discussion thus far indicates that more than mere demand models are involved, though they are at the heart of the process. What is at issue is the whole urban transportation planning process and the entire system of models. Current methods do not recognize this, though there are many individuals around who do and have said so.

The problem as I see it is that the entire process must be revised to make it more interactive and interdependent and to integrate the currently missing elements. Others have criticized the faults with currently employed methods more extensively and carefully than I propose to do; nevertheless, I will point out those aspects that I find most in need of correction if we are to plan intelligently.

The approach that I will take is to address 4 interdependent topics: problems with the current UTP process, problems with the travel demand forecasting models of the UTP process, some proposals for improving the forecasting models, and some proposals for improving the overall UTP process. It will be difficult to separate my discussion of the nature of the problems with current methods from the prescription for their solution, but I will attempt to do this to achieve what clarity I can.

PROBLEMS WITH UTP PROCESS

It may be useful to clarify what I mean by the current UTP process. Basically, I am addressing the process of urban transportation planning and the associated travel demand forecasting models endorsed by the Federal Highway Administration and embodied in its package of urban transportation planning programs (1). Although these are not the only programs in current use or the most advanced ones, they do represent a sort of current state of the art and for a variety of reasons they must be "eclipsed" before they can be replaced.

The overall planning process for a given urban area is shown generally in Figure 1. I have the following problems with this overall approach:

1. Insufficient recognition of the interdependence of the elements in the process,
2. Absence of transportation-responsive activity-system models,
3. Use of a target-year approach to planning,
4. Obsession with predicting traffic volumes,
5. Seeking of accuracy when what is needed is a range of uncertainty,
6. Lack of appropriate objective measures with which to measure the effectiveness of the process, and
7. Insufficient integration with the decision-making process.

Some of the topics have already been alluded to, but it is useful to focus the arguments for each.

Insufficient Recognition of Interdependence

The basic problems here are a lack of explicit simultaneity in travel demand determination, an apparent reticence to compute equilibrium between supply and demand, and an almost complete failure to model the feedback between the transport system and the socioeconomic activity system. The real-world system clearly involves a high degree of interdependence; yet, the UTP process attempts to deal with it as a sequential process. It fails to recognize transportation as part of an essentially self-regulating equilibrium process. Thus, we have the thrust to provide enough capacity in the new freeway system, the attempt to answer the problem of growing congestion, and the failure to consider the do-nothing alternative.

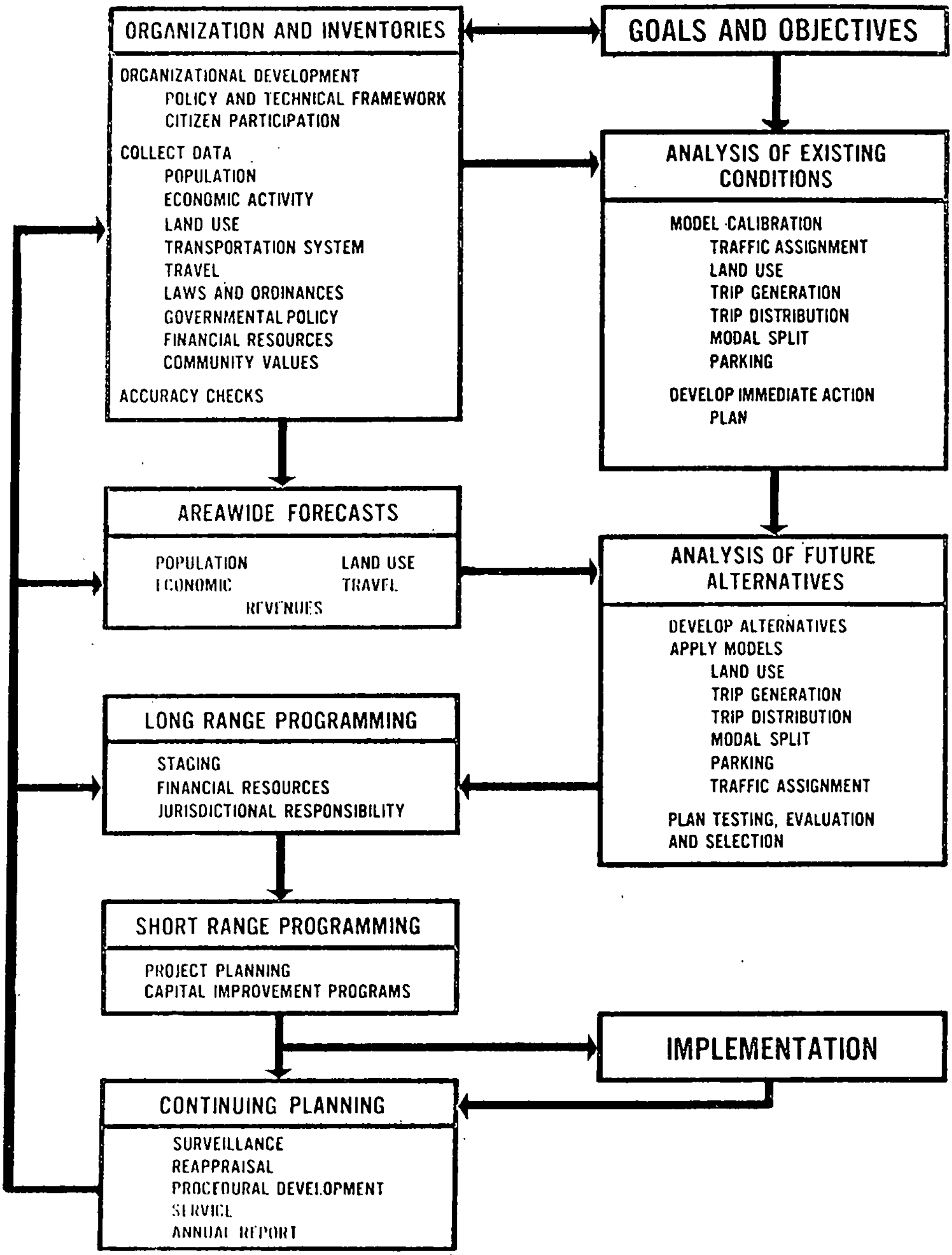
Absence of Transportation-Responsive Activity Models

The typical UTP process forecasts or projects area-wide population, land use, and economic activity. In only a few cases have socioeconomic-activity models of any type been used, and in almost no case could they be considered to be fully responsive to changes in the transport system. This may be too harsh a judgment to levy against all studies, for the National Bureau of Economic Research has reported on land use models developed and used in 5 different urban areas (2). It is no exaggeration, however, to assert that adequate models of economic activity for use with the transportation planning process still do not exist.

Use of Target-Year Approach to Planning

I feel that the target-year approach is the single most detrimental aspect of current planning. It basically ignores the question of how we get from here to there. It also ignores both the problems and the benefits associated with the staged introduction of improvements into the system. Benefit streams are badly misrepresented by this process, which assumes that all projects will be on-line by the target year. The benefits achieved in this year must be linearly applied from "zero" at the outset to "full" in the target year. This is clearly unrealistic. If, in the real world, it is possible to bring an important project on-line in the early years, the discounted present value of the benefit stream is greatly enhanced. Yet, this is ignored by the existing approach. Improper consideration of intermediate years also means that disruption during constructuion is not addressed directly. Finally, the shortcomings of the forecasting process are placed in the most unfavorable position because in essence the whole value of the project is determined based on extremely tenuous estimates of the far distant future.

Figure 1. Urban transportation planning process.



Obsession With Predicting Traffic Volumes

Overconcern with traffic volumes could be construed to be an indication that objectives have not been well thought out. Traffic volumes on the links of a network (especially a complex network) bear little or no direct relation to benefits. It is difficult to look at the volumes on most networks and infer anything about objectives. Our interests in flows come about because of the correlation with equilibrium levels of service on the network. Level of service is a legitimate concern, but it is hard to determine the incidence of changes in level of service from those on individual links. The aggregation that is of more interest is the equilibrium level of service between zones and the consequent impact of the activity system.

Seeking of Accuracy Instead of Range of Uncertainty

We are not now, nor will we ever be, capable of making accurate forecasts. Accuracy in this undertaking is a myth. We should understand, however, that there is uncertainty associated with all forecasts. The real point is that we should understand the range of uncertainty implied by a particular forecast. It would also be useful if we also knew how the range of uncertainty changed with each choice variable. This will take a change in our current thinking, but it is essential to proper assessment of the impact of individual projects.

Lack of Appropriate Objective Measures

We really have done very little to define suitable objectives and to program the capture of the appropriate measures into the existing models. The plan and the traffic flow volumes on it have been viewed as the final answer. For those studies that have attempted to do more, a variety of approaches have been used in practice with obviously different objectives. This is probably as it should be. There will always be a variety of objectives that one would like to observe in making the decision, and a decentralized decision authority will want to see all of them. I feel, however, that at the moment in the planning stage we show the decision-maker almost nothing except the plan and the flows. I will have some suggestions as to the objective measures we should be using at a later point.

Insufficient Integration With Decision-Making Process

It is difficult, given the present structure of urban government, to interface with the decision-maker, for there is typically not one person or even one decision-making body but literally dozens. The UTP process as currently structured is ponderous. It cannot respond quickly to requests by local mayors or citizen groups to investigate local changes or to develop scenarios that could be presented to the people involved to show them what it will be like after the change is made. This lack of responsiveness to participatory planning makes the process less useful than it would be if it were less expensive, more quickly done, and more illustrative in output.

PROBLEMS WITH FORECASTING MODELS

Difficulties with the process as a whole are repeated in the models making up the system; however, I will make every effort not to repeat myself as we turn to the models themselves. The particular focus of this section will be on those components of the overall system that deal directly with the demand and network equilibrium portions of the process. I am acutely aware of the very fine job that others (3, 4) have done in summarizing the faults with the process; I will merely review the basic faults that I find with the models.

Although it cannot be considered to be a complete statement of the details of the UTP process, Figure 2 shows the basic thinking underlying the process (1). The 4 basic steps are trip generating, trip distribution, modal split, and traffic assignment. Economic activity and land use are essentially projected into the future without feedback from the transportation system, though feedback to future land use is shown here with a dotted line, indicating that "though we now know there should be interconnections, they have not been routinely implemented to-date." Trips are generated without concern for the supply of transportation or its effect on the level of service offered. Trip distribution is typically constrained by its calibration to maintain the existing trip-length distribution whether or not the network can support it or the land uses have changed to accommodate it. And, neither generation nor distribution is typically brought into the equilibration process with network flows. Finally, the future-system or target-year approach is indicated as the recommended approach.

The problems with these models can be listed as lack of policy responsiveness, improper selection of attributes for modeling demand, inadequate determination of equilibrium flows, and importance of activity-system models to long-run demand.

Lack of Policy Responsiveness

The most obvious problem with the models is that they are not policy responsive. That is, they are not designed to answer the questions posed by a particular agency or to understand the response of the system to particular controls held by that agency. The urban transportation system in a large metropolitan area is rarely under the control of a single authority but typically jointly controlled by a variety of transportation agencies and an equally large number of nontransportation agencies. One cannot overly criticize the designers of the models for failing to identify a particular decision-maker. The major problem here, however, is that the current model design does not properly reflect the trip-making response of the system to changes made in the system itself. As pointed out in another report (3), the models are nonbehavioral and noncausal as well. The model system also suffers from lack of ability to account for transportation-related features such as differentiated tolls, parking fees, and bus schedules; and it is unresponsive to the possible changes in public transportation offerings, vehicle exclusion, parking restriction, and signalization that might be imposed by a policy-maker.

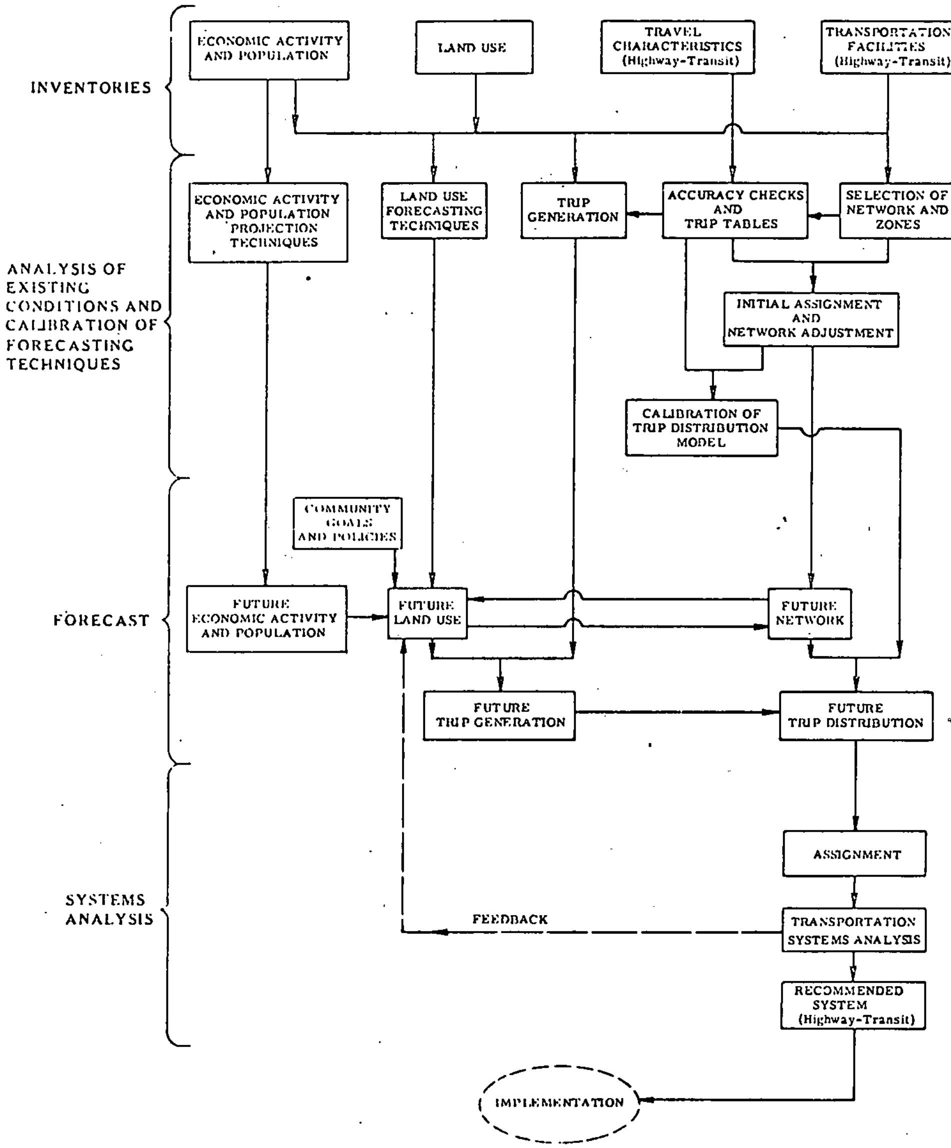
The most basic problem, therefore, is failure of the process to consider trip-making as responsive to travel conditions. This is a direct consequence of the fact that, in current versions of the travel demand forecasting package, trip generation is accomplished prior to and separately from both trip distribution and capacity restraint. The decision on where to travel, and, in fact, whether to travel at all, cannot be separated from the travel time, cost, and other travel consequences. Yet, existing programs do not even iterate on trip distribution, much less on the whole process.

The argument usually advanced for treating trip generation and distribution as given is that work trips are inelastic with respect to travel conditions. This may be true to a large extent. However, in the short run, the workbound traveler may vary his time of departure, his routing, and his travel mode. Travelers with nonwork purposes can also change their destinations and their frequency of travel.

Time of departure is not treated by any of the currently operational models. Yet, earlier departure times are clearly one way in which individual travelers in the system continue to cope with the capacity bind. For shopping and recreational trips, the opportunity to shift destinations, frequency of trip-making, and departure time increases with the construction of each new suburban shopping center. If travel demands are to be properly predicted by demand models, the equilibrium computation must be responsive to short-term changes in mode choice, routing, departure time, trip destination, and frequency of trip-making.

The activity system must likewise be responsive to a larger number of intermediate- and long-term variables. In the longer run, the traveler may decide to purchase a motor vehicle (or a second one). Over a still longer term, he may decide to change his

Figure 2. Urban travel forecasting process.



place of residence or even his job. These trade-offs are not appropriately modeled at the level of the daily travel equilibrium. Yet, they might be reflected in the changing income of an area, the aging of its population, or a change in its housing market.

Improper Selection of Attributes for Modeling Demand

The UTP demand forecasting models are extremely limited in the variables available. The trip generation and attraction phases can, and typically do, make use of a variety of socioeconomic-activity variables. It apparently was not convenient to use transportation level-of-service variables for either trip generation or attraction, for none is ordinarily used. This is equivalent to saying, "It doesn't matter how bad the traffic gets; I'm still going to the ball game." Once trips have been generated and attracted, they are typically pushed around by use of the distribution model, ordinarily the gravity model. This model typically uses travel time as the only variable. It is possible to weigh travel time by its average value and to add certain out-of-pocket costs such as parking fees or tolls and to use this as the variable affecting distribution of trips. This is sometimes done. The modal-split models have made use of a few more variables, but even here the number of variables that can be used to influence modal choice is limited.

Obviously time is an important factor, and it has been used in almost every study. However, not everyone has recognized the variety of time-related factors there are and their relative importance. Time is frequently separated into travel time and access time. It has been further differentiated by mode into walking time, wait time, line-haul time, transfer time, parking time, time variability, interarrival time, and schedule delay. Recent research has shown that these variables should have different values (5). For example, walking time appears to be 3 to 4 times more onerous than in-vehicle travel or transfer time.

A variety of other variables, including cleanliness, comfort, convenience, out-of-pocket cost, ability to carry packages, safety, schedule reliability, ability to read, privacy, and ease of carrying wife or children all may be important for the various modes. Very few can be routinely handled by the present process. A principal reason is that, although the attributes associated with the various modes may be available at the link level, they are difficult to determine from origin to destination over the network. This could be easily overcome by using the minimum path tree-tracing algorithms in more creative ways. For example, it is possible to use the concept of a travel resistance or impedance where

$$R = \sum_i c_i L_i$$

and where L_i is the level-of-service attribute found on the link, c_i is the cost per unit associated with encountering attribute i, and R is the consequent disutility of traveling over the link (6). Manheim (7) shows this relation in terms of utility functions, and Blackburn (8) refers to this concept and uses utility theory as the "inclusive price" of travel on the link. If R is determined at the link level, minimum R paths can be computed or minimum time paths can be traced and their consequent summed attributes determined simultaneously. None of this is typically attempted in the present programs.

There has been, as well, a notable lack of interest on the part of researchers working with the UTP package to develop more extensive supply attributes or supply models at the link level. I would reason that this is because there did not appear to be a way in which the information could be used in the process even if it were to be developed. Based on the methods described above, the information flows of such extensions become perfectly clear. Traffic volumes determined during a previous assignment could be used with variables describing transportation supply to determine level of service that, through valuation by an inclusive price scheme, is then used for tree-tracing of attributes in the next demand computation. Such a scheme does not limit the number of attributes to be used in describing transportation supply or demand functions as do the present UTP models.

Inadequate Determination of Equilibrium Flows

For practical purposes, there is almost no feedback in the present system of models. The modal-split portion is the most interactive, and equilibrium between modes joining the same origin and destination is achieved in some cases. The same cannot be said for network travel conditions and trip generation, attraction, and distribution. Obviously, the more simultaneity that can be reflected in the models, the better. In the real world, one observes a certain equalization of impedance over the network, at least as reflected by travel times. There are typically a larger number of possible paths between origin and destination than can be conveniently modeled. As the network becomes increasingly loaded, more and more of these paths are used. Travel times on the expressway approach those on city streets. Where there is disparity between the two, queues may build on the expressway because travel times on the freeway are still better than those on city streets—especially for the long-distance travelers or those without perfect information about the local street system. The transit system may share in this impedance equilibrium, if value of time to the travelers could be properly evaluated.

Achieving this equilibrium in the models appears to be a very difficult task. Even this understates the problem, for trip production is still intimately related to level of service on the network in spite of my attempt to present the parts as independent. A first attempt to solve the problem of simultaneity might do it by considering the parts independently and iterating. This has been done on occasion but not routinely. The criterion for equilibrium is typically stability on the network. Figure 3 shows a scheme for improving this equilibrium computation, but it should be viewed only as an improvement, not the answer.

Although current practice is variable, the FHWA package suggests that speeds measured on the present network should be used in building the minimum path trees used in trip distribution. Trip travel time distributions are then built up by using the origin-to-destination pattern actually observed and travel times computed from the minimum path trees. For the future, travel times on the network are assumed for the purpose of building trees for use as input to the distribution model. Then, the iteration between capacity restraint (if it is used) and travel conditions on the network is assumed to affect only choice of mode and routing. This is obviously simplistic.

A major problem facing those of us who are attempting to explain travel behavior is the sheer size and complexity of the network. Early models used several hundred nodes. For large urban areas, several thousand nodes are currently being tried, and the desire for more grows with every increase in computer capacity. The fact of the matter is that we will probably never have enough. We must somehow be able to model the volume-delay function of the corridor as a whole, while it is flowing in all directions at once, for it is apparent that, as major transport links become congested, flow is diverted to facilities of ever-decreasing levels of service. Perhaps the answer is the use of a spider-network plan that is rather different from the type we have tried to date or, alternatively, the consideration of the local streets as a sort of plain of impedance. My view is that bigger networks are not the answer. They merely lead to bigger computers, longer computer times, and increased complexity and expense.

Actually, travel-making behavior is considerably more complicated than the process shown in Figure 3 suggests. The complicating factor is related to the phenomenon known as peak-spreading. For inelastic trips, the one dimension of flexibility is time of travel. Everyone is familiar with the statements: "Better leave early to get ahead of the peak" or "It's too late now—might as well have another cup of coffee and wait for the traffic to clear." In fact, travel times may be relatively consistent throughout the peak.

Peak-spreading is partly due to the diversity of starting times and appointment hours and the randomness of schedule that may be found in any urban area. It is also the result of travelers having a choice in their schedules so that their travel does not coincide with peak-hour travel. For those employees who have starting times at 8 or 9 o'clock, there is still another factor influencing their decisions on when to travel. That is the variability of travel time as measured by the cumulative probability of travel time. If it is extremely important that you be some place on time (for example, at work), then you must allow enough time not only for average travel time but also for the extreme tails of the distribution to the desired probability. It is probably this additional factor that pushes the cautious employee to commute to work early and have breakfast downtown.

All of these factors make the prediction of the full set of network conditions affecting travel much more difficult and involved than present methods would even suggest, much less replicate. Obviously, if the previous discussion is to be believed, there is a need to predict peak-hour as well as average daily flows. And perhaps even more important there is a need to know the length of the peak as well. Our ability to do these things is currently extremely limited.

Importance of Activity-System Models to Long-Run Demand

The difference between short-run and long-run demand prediction is a distinction that was made in a before-and-after study (3) and it is useful to extend here. Because demand models are a function of both equilibrium level-of-service and activity-system variables,

$$V = d(L, A)$$

it is useful to ask how the FHWA process will deal with each of these inputs over time. If one feels that the activity-system variables are also a function of transport level of service,

$$A_t = a(L, A_{t-1})$$

then a basic problem exists with how to predict these variables several time periods out. One way is to assume that there is no relation between transportation and economic activity or that it is not significant and to merely project these variables by extrapolation. This is what has been done in the FHWA process. To do otherwise requires the use of an activity-system model. For the transport level-of-service attributes, there is conceptually no problem with keeping up with L because it is a direct function of the transport-system variables and the volumes, both of which are available from the models in the process.

$$L = s(T, V)$$

This poses a problem only in the sense that the FHWA process does not now do it—not that it could not be rather easily done.

For the short run, both level-of-service variables and activity-system variables are directly observable from the real world. For the long run, we have to either construct activity-system models or be prepared to make heroic assumptions.

PROPOSALS FOR IMPROVING FORECASTING MODELS

It is far easier to criticize the present set of forecasting models than to offer constructive proposals for improvement. I do believe, however, that it is possible to make a quantum jump in our ability to make short-run forecasts by merely implementing a number of the research advances that have been made during the past few years and by following up suggestions made by others. Furthermore, I am confident that a greatly improved short-run forecasting capability will carry us a long way toward being more effective in our advisory roles to decision-makers. The specific recommendations are summarized as follows: use the available demand-model knowledge to develop policy-responsive, behavioral, causal, short-run demand models; integrate supply and demand models in better equilibrium computations; develop activity-system models that can be used to support longer range use of demand models; and develop and incorporate performance measures useful in decision-making.

1. Use the increased knowledge of demand models to develop better models.

It is not difficult to improve demand models dramatically by merely implementing research already completed to date. This will ultimately improve long-range as well as short-range forecasting. Brand (9) has summarized the state of the art. The first, and perhaps the most, significant change that could be made is to a direct demand model instead of the multistage process in the FHWA package. Because a direct demand model handles generation, distribution, and modal-choice simultaneously within a single model, there is no need to think in terms of 3 separate steps. A variety of these models exist including those of Kraft (10); McLynn and Watkins (11); Quandt and Baumol (12); and Domencich, Kraft, and Valette (13). Another advantage is that the parameters of those models can, for the most part, be interpreted fairly easily as elasticities and therefore have an intuitiveness and a meaning that are useful in their own right.

Manheim (7) discusses the interrelation of these models and his general share model and shows how consistent direct models can be "disaggregated" into indirect models without loss of generality. It appears that, with the expenditure of a bit more time and effort in attempting to clarify the approaches that are available as well as their advantages and disadvantages, significant understanding will occur.

In listing problems with the current models, I mentioned the need to expand the set of variables available for use in the demand models. The use of the inclusive price technique appears to be the way to do that efficiently. Not only does it tie in the concepts of utility theory but it is useful from a computational point of view, for it can be readily implemented with existing minimum path algorithms. It is also useful from the standpoint of calibrating the model, reducing the difficulties caused by multicollinearity, and so on. The variables ordinarily used in CRA's disaggregate behavioral demand model (5) were greatly expanded, including several types of time and a variety of others expressing comfort and convenience characteristics.

That study also explored the possibility of calibrating a disaggregated or sequential model that first determines frequency of travel and then mode, time of travel, and destination. The model form used was the logit model calibrated by maximum likelihood techniques. The results were exciting. It appears that the methods for handling both choice of destination and time of day were satisfactory and that the results, particularly the elasticities, were quite significant. Although time of day was divided into only peak and off-peak travel, this may be the breakthrough needed to consider the equilibrium-over-time computation more fully.

2. Integrate supply and demand models in better equilibrium computations.

The subject of equilibrium in networks is one that has been badly neglected. The FHWA package makes only a limited effort at producing equilibrium flows through the use of a capacity-restraint routine. Conceptually the idea is that, if flow on a given link exceeds the "capacity" of that link, then some of the flow must be diverted to other routes or modes. To think this way, one must carefully define the time domain during which the model simulation is representative, the demand for flow during that period, and the capacity (or, better still, level of service) defined during that same period. The problem has been that, if overall levels of service get too bad, demand will decrease (or shift to the off-peak). Typically, the models have ignored this point and have simulated either peak-hour or all-day flows. Both have problems. Peak-hour figures are hard to estimate, and all-day capacities are meaningless.

Even ignoring these problems, we have had problems with equilibration procedures that we have wished would go away. The most difficult has been oscillation of flows on the network instead of convergence of our iteration procedures. This has made the assignment algorithms long-running, which has been the reason why we have failed to feed back all the places in the computation we should have. Weighting schemes where flow from the last iteration is weighted with flow from this iteration have been tried with only palliative success.

The most promising work in the equilibrium area has been that of Manheim and Ruiter (14) on DODOTRANS. This very flexible demand-computation and network-assignment package can do anything the FHWA package can do plus incremental assignment in conjunction with direct demand computation. The incremental-assignment technique, developed in 1962 (15), assigns an increment of travel demand over an increasingly loaded network with periodically updated computations of level of service. The result is an exact equilibrium of demand with supply done in somewhat the same way as the real world.

Integrating peak and off-peak travel into this system is something that will still require some effort, but a really computationally efficient version of this system should be programmed and implemented in a test project that could also include the best available demand techniques.

If this were done, there are still 2 areas in the equilibrium computation that need more conceptual work. The first is in the area of supply models. Almost no attention has been given to constructing simple supply models for use with the demand computation and assignment package. These could include the effects of number of lanes, curb parking, edge effects, traffic lights, left turns, and pedestrians.

The second area is that of working with big networks. I discussed this previously and will not belabor the point, but I think that our ability to model real situations is badly impacted by the fact that we seem to have to model the whole world before we can adequately represent the ability of the local street system to absorb or give up flows. Perhaps the answer is the use of aggregate models such as those of Koppelman (16). We can explore the use of spider-background networks that represent in a very general way the volume delay characteristics and volume response of the local street system in all areas except the one on which we are currently focusing our attention. This will require more research, however, for we do not now know how to do this adequately.

3. Develop activity-system models.

As I indicated earlier the entire travel demand forecasting process is incapable of moving beyond short-run demand prediction unless or until activity-system models are integrated into it. This is probably not the forum for a full-scale discussion of the development of these models. Yet, their importance must be immediately apparent. The expectations are not for immediate fulfillment of this need. There has been steady progress in this field since Lowry, however, and recent work may be imminently useful.

In general, the process of predicting the activity system is closely related to predicting the progress of the economic system. There are, of course, stocks of both transport facilities and buildings. The construction process because of its commitment of resources and time is a good place to separate the long-term changes in these stocks and the short-term use of these stocks by the economic system. The process shown in Figure 4 attempts to set out in a general way the relations between these stocks and the processes that decide their fate (the various demand processes and markets). The actors in these processes are individuals, firms, and governments. As in travel demand forecasting, the viewpoint of the individual and his choice is a good place to start. The family income sets an upper limit on the overall budget, but the amount used for items such as housing, clothing, food, and transportation is essentially flexible. The higher the income is, the more trade-off possibilities there are. The utility concepts applied in demand forecasting also can be applied here.

Obviously, the housing stocks and the housing market determination are the largest single group accounting for the largest amount of land and dealing with the most number of persons. A recent and landmark contribution to this area is Ingram's work (17), which is part of an overall urban simulation effort undertaken during the past few years by the National Bureau of Economic Research (18). The larger effort involves also industry and commercial location studies, but models that can be implemented are not yet at hand. Much research remains to be done in this area.

We should note in passing that we have not yet really addressed the problems of predicting urban freight flows. In view of the impact of those flows on urban street

Figure 3. Network equilibration process.

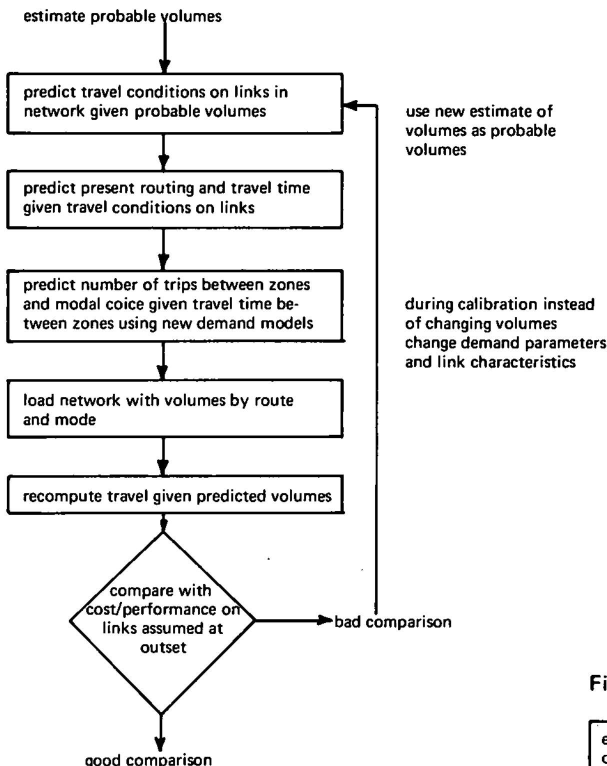
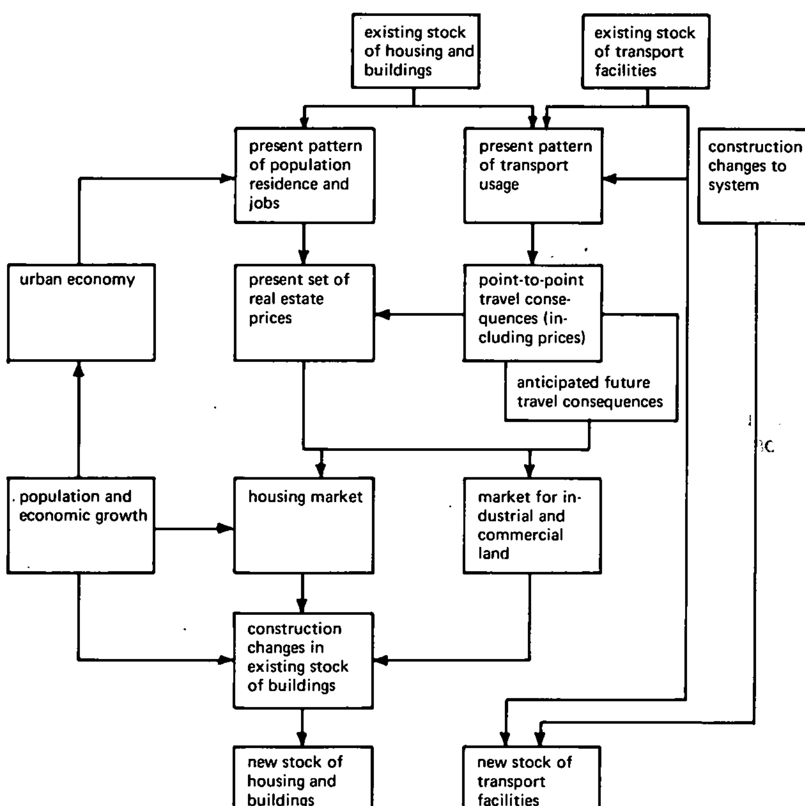


Figure 4. Urban growth process.



movements, it seems to me extremely important to begin to incorporate freight-movement factors into the system as well.

4. Develop useful performance measures.

The most important thing to keep in mind in the evaluation of transportation-system changes is that the final decision is basically a political and not a technical decision. Therefore, it is essential that performance measures properly reflect this. The actors in the political arena are likely to group themselves in any one of literally thousands of different ways. However, there are some basic building blocks that are common to a variety of groupings. These are firms and governments. They are typically referenced by resident location, affiliated locations, income, transport expenses, housing expenses, and mode. They may be aggregated by mode, industry, area, and income category. The relevant performance measures may be sorted or aggregated in a variety of ways for display purposes.

A major design issue, however, is the set of basic performance measures that will be developed by the models for use in evaluation. Clearly, costs of all types fall into this set. The factors in the inclusive price vector are all candidate costs, and the demand model weights indicate the way in which these attributes are traded off against money. This establishes their relative marginal values for use in evaluation. Within the modes, there are short- and long-range costs that are typically passed on to the shipper or passenger through the transport price or tariff. Therefore, they are captured in the inclusive price vector. Costs to the government or to industry for constructing facilities are also relevant and useful. Other, nonuser impacts will probably have to be developed in each particular case. The demand forecasting models may not be the place to gather the basic information for evaluation. For many variables, however, it will be the basic source.

Another major source of performance measures can be developed from the output of both the land use models and the model of the urban economy. Clearly, these, particularly the economic measures, will be very important outputs for use in evaluation. They are the overall measures that are most "macro" in outlook and must be considered to reflect the desirable overview from the standpoint of the overall economy (particularly for equitable economies).

PROPOSALS FOR IMPROVING UTP PROCESS

The suggestions of the previous section were largely design oriented. That is, they dealt with how an urban travel demand forecasting model system might be structured. This section will deal more with how such a system should be used, particularly in the interim period before such a system might be fully implemented.

My specific suggestions are be policy oriented, use the currently available parts of such a system to explore short-run consequences, attempt to integrate models more closely with the decision-making process, integrate supporting performance measures into the system, attempt to develop understanding of the degree of control that is possible in the real-world process, and use the model system in a time-staged planning process.

1. Be policy oriented.

Too often as model designers, academicians, and theorists, we are caught up in the model-design issues and not the real-world policy issues. Because it is, after all, the policy issues we are attempting to answer with the models we are designing, I suggest that we do our best to understand them and structure our models so that they can be addressed. A great deal of the criticism of the current set of UTP models centers on exactly this point. Let us not make the same mistake again.

2. Use available parts to explore short-run consequences.

Because a large portion of the demand model methodology already exists, at least in pilot form, I suggest that what is needed next are proposals for specific model designs and then identification of test sites, data collection, specification, calibration, programming, and testing of the prototype models that emerge. I feel that it would be a good idea to support 2 or 3 competitive designs with arrangements for comparison and evaluation. The model systems formulated at this time will necessarily be short run; that is, they will not embody operational activity-system models. I would suggest that pilot versions of activity-system models be undertaken simultaneously, but probably as a separate effort.

The important thing about the demand forecasting prototype models is that they will be short run. They should not be used for 1990 planning. They should instead be used to explore 2- to 4-year operational policy; i.e., What will happen immediately after the opening of the new expressway? They could also be useful in the analysis of transit, bus, or expressway-bus planning. To the extent possible the outcomes should be monitored carefully (19). Large differences between predicted and observed data will indicate either structural problems in the models or a need for recalibration by using the new data.

3. Attempt to integrate models with the decision-making process.

This point follows directly from the previous one. Elected decision-makers are extremely responsive to the political process. If our models are to be useful to them, they must predict the short-run outcomes. The system I have described would do just that. It should be possible to interface more closely with mayors, city councils, governors, and public works directors. An additional point is that demand models calibrated on individual rather than aggregate zone data would be much more general than our present models and would not require recalibration from use to use or city to city. Therefore, they should be less expensive to use and also less ponderous. Huge staffs will not be required. Instead, we will be able to work much more closely with public officials and respond more quickly to their questions or suggestions. Admittedly, in any given application, there are still data on the supply aspects of a given system to collect, code, and debug; and if equilibrium computations are required, we still may have lots of computing to do. The operational problems of performing analysis will not become simple overnight.

4. Integrate supporting performance measures into the system.

To be policy-oriented, short-run responsive, and "plugged into" the decision-making process, the system must have a carefully designed set of performance measures integrated into it during the formulation stages. Both physical and valued consequences should be available in hierarchical form. Aggregations and summaries should be available as well. In my estimation, this is a key factor in the utility of the final system. Although the implementation of this suggestion does not require a high degree of analytical skill, careful conceptual design is required. That is not a trivial job.

5. Attempt to develop understanding of the process.

Once the full system is available, the next step is to use it to develop a fuller understanding of the urban process and the degree of control that can be exerted over it. This will require an extensive effort with the possibility of false starts, failures, lack of understanding, and frustration at every step. This process has already begun. We can help push it along with integrative programs and financial support.

At this point, it is not clear what can be controlled. We may not want to control the process even if this turns out to be possible. More probable, we are not going to have the political or institutional framework needed to handle this control. If, for example, we found that land use could be controlled, what person or council would we trust to exercise the control? This appears to me to have been the reason highway planners have traditionally fought the notion that the construction of highway facilities was responsible for influencing traffic demand. They really had to believe they were building to match "needs." Anyway, it is institutionally convenient to believe that the part of the process for which you are responsible is not creating waves. The most likely happening, I believe, is that we will find that it takes a considerable amount of coordinated policy to achieve a highly predictable level of control of land use. These controls will almost surely involve elements of zoning, housing policy, tax policy, environmental controls, utilities control, and use policies in addition to coordinated transportation policy. A device that could represent the future direction of development is large-scale planned unit development by a consortium of private and government entities that would plan and develop large tracts on a modular basis. Another, and I believe more probable direction, is the continued growth of urban areas by innumerable small developments.

6. Use the model system in a time-staged planning process.

From my point of view, the most important thing to learn about implementation is that it must be done project by project over time. This is in almost direct contradiction to the traditional view of planning, which tends to focus on the ultimate system as it could someday be. It may be this dichotomy that leads to the frequent failure of planning. To be successful we must, I believe, organize the implementation of our projects one by one over time. If our predictive models are to be useful, they must be able to show us what happens as each project is either implemented, dropped, or delayed. The combinatorial possibilities of this are too many to conceive, but in practice we will be able to explore all the combinations we will need to analyze as long as we focus on possible alternatives to be tried on the relatively short run and make long-term runs to see their ultimate impact on socioeconomic activity and discounted present value of the benefits.

Each time-staged set of projects becomes a plan to analyze in the system model. As the years go by, the runs start a year later and run a year longer. The construction budget projected for each year into the future interacts with project costs to set an upper limit on the set of projects that can be implemented. Dropping a project out of the plan makes it possible to introduce new projects or advance other projects scheduled for later.

The modeling process that I am referring to produces time series as output (Fig. 5). The time series produced are the performance measures that I indicated previously. One such measure might be the total system inclusive price discussed earlier. Because this is one measure of total costs to the public of using the system, it would be interesting to compare the discounted present value of this figure to the discounted present value that represents the cost of constructing it.

This is not the only, or perhaps even the most relevant, output of such a model system. The discounted present value of any variable of interest can be presented. For example, the number of person-hours of noise higher than 30 perceived decibels might be shown visually by zone or the revenues presented by mode. The possibilities are endless. Design and implementation of the system will, however, depend in large part on the variables we have to predict.

Finally, it is useful to indicate how such a model system is calibrated (Fig. 6). Of course, the individual components will have been calibrated independently. The portion that remains to be calibrated might be viewed as the time constraints of the overall dynamic system. The lags and leads of the various time series must be adjusted so they will correspond to those found in the real world. Therefore, I conclude that the appropriate method of verifying these constants is to attempt to use the models to replicate history. As adjustments are made to the constants, one may view this as using up degrees of freedom. The constraints obtained in one metropolitan area may not be exactly the same as those in another. Comparisons between areas may then constitute a sort of cross-sectional analysis.

Figure 5. Some time series inputs and outputs.

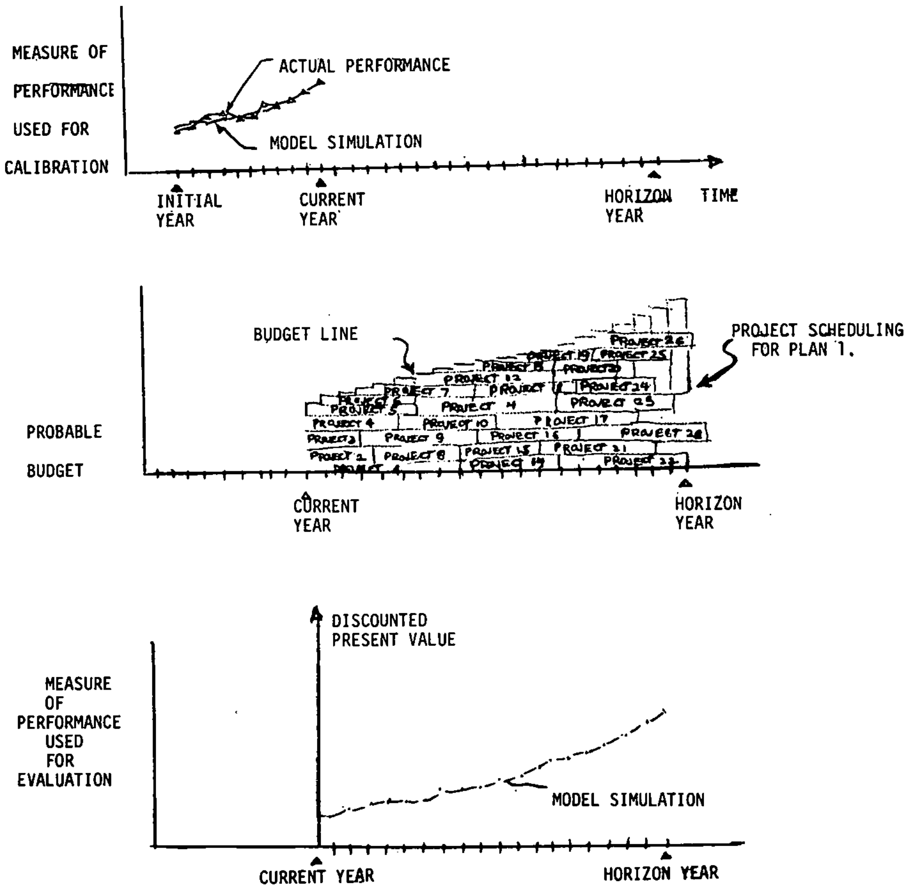
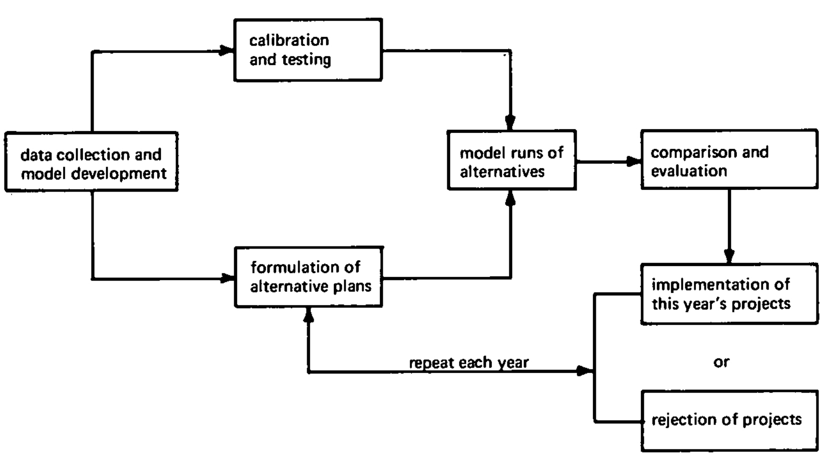


Figure 6. Model calibration and use for specific urban area.



SUMMARY AND CONCLUSIONS

The process I have described here is neither simple to develop nor simple to use. In fact, long-range forecasting is not simple to do. However, I do not believe that extreme accuracy is needed. What is needed is some indication of the range of values as well as the direction and magnitude of how the world will begin to change in response to the changes we are contemplating. We can use the models we now know about to forecast short-run outcomes of changes, and these should be of great benefit until we can get the other longer range activity-shift models developed and calibrated. After they are integrated into the system, it will take some time to develop the understanding of what the urban growth process is, what its controls are, and how we can manipulate the system to produce a favorable result.

The effort required to accomplish this will be major. The funds required will not be inconsequential, but let me hasten to add that, in light of the funds we will use during the next few years to build systems that are uneconomical, inefficient, and poorly planned, the funds will be trivial in the extreme. Furthermore, it is about time that we as human beings learned how our combined decisions are causing our cities to grow in ways that we do not want them to. We need the understanding that the development of this series of models implies. It is time we began in earnest.

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Workshop 3

DEMAND FORECASTING FOR NEW OPTIONS AND TECHNOLOGY

OBJECTIVES

Identify, review, and evaluate current and proposed travel demand forecasting techniques and procedures for use in assessing new options and technology in urban transportation.

Recommend new and improved forecasting procedures that are responsive to requirements of using travel forecasts in assessing the options and technology.

Develop a recommended program of research that is responsive to the identified requirements.

OPTIONS

New options and technology include all innovative actions or projects, without regard to time required for implementation. The characteristics that distinguish these options from those of Workshops 1 and 2 are uncertainties in describing the new options and a lack of experience in observing traveler response to implementation of the new systems. In short, new options are those that are not yet in widespread use. Examples of hardware options are those that are flexible with respect to time, i.e., line-haul systems (such as moving sidewalks and conveyor belts, horizontal elevators, multiactivity pallet systems, and personal rapid transit systems); flexible with respect to space, i.e., distribution systems (such as charter bus service, group-riding in taxis, and demand-responsive transit); improved but not completely flexible (such as jitneys); and flexible with respect to time and space (such as public automobile systems, dual-mode systems, automatic highways, and communications). Examples of nonhardware options are free transit, flexible pricing policies, restructuring land use patterns, changing energy prices, and changing values with respect to polluting.

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Report

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The first section of this report of the discussions of Workshop 3 identifies options and major issues facing planners of new transportation systems. In the next 2 sections are given the information needs for planning and implementation of new systems. Conclusions and recommendations for research and implementation programs are given in the last section.

ISSUES AND OPTIONS

Workshop 3 accepted the example options and acknowledged that they include institutional as well as technological alternatives and that the time frame of implementation may be the same as that for options considered by Workshops 1 and 2.

In general, the issues discussed by Workshops 1 and 2 are also applicable to new options. This summary will be confined to those of special concern or unique to Workshop 3. It should be recognized at the outset that demand, as applied to new systems, means different things to each of the actors of interest: ridership to the planner, profitability to the operator, market to the manufacturer, and impacts (social, economic, or trade) to the government policy-maker.

An important set of issues pertains to supply-related uncertainties (cost, performance, unanticipated impacts). There was optimism regarding the use of parametric approaches for rough screening and in exploring sensitivity to demand-related costs, but there was considerable concern about availability of maintenance cost data in the absence of operating systems.

It was generally agreed that information needed for modeling is not readily available. Origin-destination survey data are of little value, and demonstrations, although potentially useful, have not been designed or monitored with the data needs of model builders in mind. Can a modeling-testing program be structured so that the modeler specifies the demonstration? How should demonstrations be designed? What data should be collected and when? Is an iterative process of model-demonstration refinement feasible?

New systems require special consideration with regard to forecasting latent demand, estimating the effect of interaction with other modes, and comprehending transient effects (learning curves and "brand loyalty"). A major issue is concerned with transferability. To what extent can important new-system attributes be identified that are capable of being simulated on existing systems or by low-cost demonstrations?

Workshop 3 expressed a need for simple, responsive models, capable of interactive operation and structured to provide output in a form usable by policy-makers. The ability to operate in an iterative manner with experiments is desirable, and parametric capabilities are necessary. The use of models in sensitivity analysis was discussed, and questions of precision and cost were raised.

IMPACTS AND PREDICTIONS

Workshop 3 generally recognized that the process of urban transportation planning is no longer limited simply to the satisfaction of transportation needs. A large number of additional criteria have been and are being established by actors other than simply users of the transportation system in question. This trend impacts directly on the demand forecasting requirements, particularly those associated with implementation of new systems or with major departures from the standard operation of existing systems. To systematically identify and consider each of these actors, we considered 3 levels of interest groups (local, state, and national) as well as the manufacturing industry and then identified each of the impacted parties within those categories. The resulting list, which is given in Table 1, identifies many actors not generally considered decision-makers in the context of urban planning but who are in fact groups whose questions must now be answered. For each group, we identified more specifically the type of information required and a type of prediction or measurement that would assist in meeting that informational need.

Several general observations are in order regarding this list. First, the simple question of ridership, or link volumes, appears infrequently. It is understood that all transportation serves this need but that this is not sufficient. Of much greater interest are those predictions resulting from a disaggregated look at travel behavior: What specific user or nonuser groups are benefited or impacted? What specific land use changes result? How is the travel time for specific trips affected? How many jobs are created?

A casual inspection of this list suggests that few of the needs can be met by existing transportation planning tools. After more careful consideration, however, Workshop 3 concluded that many of the data and in fact many of the necessary tools are on hand if used judiciously and with appropriate minor modification. These observations are reflected in the conclusions and recommendations that follow.

CONCLUSIONS

1. Demand as applied to new systems includes dimensions not usually considered a part of the demand forecasting problem. There is a need not only to forecast ridership and local impacts but to consider and to attempt to quantify the extent to which a new system may find national acceptance. Such information is of obvious value to potential manufacturers for market forecasting purposes, but perhaps more important it is valuable to government policy-makers concerned with issues such as energy consumption, natural resource conservation, and capital funding planning.

2. There is a need for greatly improved information transfer from local users of new systems to higher level planning agencies and in turn for dissemination of such information to other potential users.

3. Existing disaggregate and behavioral methods of demand forecasting should be capable of producing useful results for new systems if an attempt is made to identify those attributes shared by existing and new systems and to use known responses to these attributes for calibration of models of new systems.

Table 1. Information needs and prediction characteristics.

Group	Information Needs	Prediction Characteristics (indicators)
Local		
Politicians	Financial considerations	Annual capital cost extimates, operating cost estimates, revenue (ridership), funding sources, funding ability
	Goal satisfaction (evaluation)	Transportation needs; community impacts including interest groups, economic viability, and environmental impacts; effective use of existing facilities; land use implications
	Other government interface	Relation to regional (or higher) plans, budgets, and the like
	Risk-confidence	Cost of "failure"; criterion of success or failure; ease of experimentation including financial, institutional, and technological flexibility and adaptability; lead time, staging, or other implementation problems
	Institutional factors	Labor union charter, legislation for new institutions, other transportation institutions or charters
	Awareness-differentiation of system availability	Attributes, taxonomy
Operators	Competitive impacts	Impact on competition, dependence on competition
	Operational requirements	Manpower, vehicle, and management needs; marketing information system; implication of new technology skill levels
	Financial considerations	Operating costs, risk with respect to reliability
	Institutional constraints	Labor input, productivity, regulatory constraints
Consumer[a]		Travel time, cost, convenience, comfort, safety, reliability, public image, perception
Resident[b]		Environmental intrusion, aesthetics, noise, nonuser safety, costs (taxes)
Developer	Land use implications	Land use changes, new large activity centers that can "design in" a new technology, land use controls
	Profit maximization	Increasing or decreasing property value
State		
Department of Transportation	Resource allocation	Geographical allocation of transportation, investment dollars, modal allocation
	Transferability	Use in other cities
Other	Financial requirements	Revenue alternatives
	Economic impacts	Employment
	Goals and priorities	Alternatives
Federal		
Department of Transportation	Funding requirements	National funding demand—capital intensive or noncapital intensive; system roles
	Transferability	Use in other cities and states, national potential benefit
	Development and implementation strategies	Research and development decisions, staging, and methodology; design of prototype development and demonstration projects, including site selection
	Technology assessment	Program decisions
	Distribution of funds	
Other	Resource requirements	Energy, raw materials, land
	Economic impacts	Employment, international trade, secondary effects
	National goals and priorities	Relationships and modification
Manufacturing	Profitability	Market forecasts, capital cost, staging alternatives, funding sources
	Risk assessment	Development funding, demonstrations

[a]Two types, including one who actually uses new system and one who uses competition that performs better or worse because of new system.
[b]One who is impacted by nontransportation characteristics of system.

4. A long-range program of fundamental research in travel behavior is necessary in order that emerging issues of response to alternatives to travel, land use interaction with transportation, and constrained supply situations can be properly dealt with.

RECOMMENDATIONS

1. Even though new systems present special problems of demand forecasting, there are 2 areas in which current methodology and practices can be applied: (a) use of existing simple models, calibrated with data from existing systems, to forecast a demand for new options on a small scale and (b) development of a system for immediate acquisition of appropriate data from existing and proposed demonstration projects.

2. Several projects can be implemented within 3 years: generation and dissemination of information regarding new system characteristics and applications; a program that addresses the unique requirement of demand forecasting for new systems to pro-

vide, on the national level, the economic, service, and resource implications of extensive implementation of new systems; a short-range applied research project aimed at the determination of attributes of existing and new systems and an experimental determination of user and nonuser perceptions of these attributes; and establishment of a product laboratory to assist in the implementation of this perceptual research.

3. Longer range and continuing basic research projects are also needed on travel behavior.

4. A large centralized time-sharing computer facility should be established to provide local planners with access not only to data files but also to a comprehensive software environment permitting the convenient building of models for specific purposes from an inventory of generalized models.

5. A system should be established for disseminating in a uniform way planning information to users at all levels.

Resource Paper

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At the Urban Mass Transportation Administration (UMTA), forecasting demand for new transportation options and technologies is a frequent subject of conversation. The proposed innovative (and speculative) modes of urban transport range from automated bicycle paths to regional dual-mode systems, from public automobile systems using a quarter of a million vehicles to automated 4-passenger personal rapid transit (PRT) maintaining ¼-sec headways, and from slender 60-ft boats to fat 500-ft blimps. Non-capital-intensive proposals include automated information systems for transit passengers, road pricing for automobile drivers, automobile-free zones for pedestrians, dial-a-ride service for the handicapped, and transportation-sensitive land use zoning for developers. Among seriously considered capital improvements are improved buses operating on guideways composed of exclusive structures and tunnels and 12- to 20-passenger automated people-movers of a near-infinite variety of shapes, propulsion, suspension, and command and control.

Unfortunately, the fact that we discuss new options and technologies does not mean that we know exactly how to forecast demand for them. In fact, our treatment of the subject varies from day to day. At times we take a very global or federal view, examining the worldwide and national economic and environmental implications of new technologies. At other times we try to address the topic as, say, the Ford Motor Company would, so that UMTA can decide on the proper planting of research and development seed money as a catalyst for industry. Or we approach the problem as a local transportation planner or transit operator might. And sometimes we examine potential demand from the selfish and definitive point of view of the user.

The myriad supply-side variations multiplied by many different evaluation criteria result in a baroque view of the demand-estimation problem. One becomes humble and loathe to make general statements on how to forecast demand for any new method of moving people. Either the subject must be restricted to specific generic technologies, or the statements must be general and vague. This paper chooses both options. It relates primarily to technologies requiring significant risk capital and having large urban areas as their hosts, and it vaguely describes research directions that will lead to a better methodology for forecasting demand for such systems to lessen the risk of their costly replacement.

Although the discussion is esoteric, it is nonmathematical; there are no formulas. Most of the problem statement speaks to uncertainty on the supply side and to the methodological shortcomings from common demand forecasting techniques. The unexplicated assumption is that the traditional urban transportation planning (UTP) model chain is woefully unsuited to multimodal transportation planning. Suggested modifications are restricted to the technical components of the UTP process. Neither the problems nor the solutions described are always unique to new systems. Furthermore, computer models receive principal emphasis.

The overriding thesis is that, for the state of the art of demand estimation to improve significantly, 3 conditions are necessary: Information sources must be exploited, and a rich and readily accessible data base must be available for experimentation; a ubiquitous and powerful computer environment—both hardware and software—must support this experimentation as well as planning in general; and the transportation planning art and its models must be more streamlined and sophisticated (i.e., much quicker but no dirtier). Although these 3 conditions alone are not sufficient, without them demand modeling research and development will continue to be prohibitively expensive and its results of restricted use to transportation planning.

NEED TO ESTIMATE DEMAND

In general, there are 2 distinct reasons why demand forecasts are necessary evils: cost-benefit analysis and engineering design. No system evaluation or engineering design can be complete without demand estimates. The performance of all urban transportation system components depends heavily on demand levels. Thus, to make good, careful guesses of a new system's expected performance and viability, we must estimate how many people will use it and how much they will pay for the service. Costs and benefits are subjective concepts. The passenger's chief concerns are travel time, cost, comfort, convenience, reliability, safety, accessibility, and mobility. The operator thinks mainly of capital and net operating costs. Industry eyes market potential, and the government considers the nation's economic and social welfare. All these concerns relate to patronage.

A transportation planner needs good patronage estimates to feed his reiterative design process that configures the system. To measure performance and improve design, he is particularly concerned with vehicle and passenger flows and densities on each element of the network. He requires demand forecasts with both spatial and temporal dimensions. At different points in his planning process he requires information ranging from highly aggregate, 24-hour regional corridor volume estimates down to the number of people queuing up in the aisle of a subway station during the peak quarter-hour.

At UMTA, the concern over demand estimation cuts across all interest groups. The administration is charged with improving urban transportation at minimum cost—improvement as seen by the user and community and costs as seen by the operator and industry. Although it is generally agreed that new technology can help solve the transportation crisis, the great omnipotent giant—American Industrial Know-How—marches only toward profit. Thus, UMTA encourages and funds research that industry would otherwise consider too detrimental to near-term earnings. UMTA needs to know the expected utility of proposed transportation hardware before it can support a related research and development program. Utility implies demand. Thus, with every decision to research and develop (or not to research and develop) system X, UMTA tacitly makes a demand forecast.

FORECASTING FOR NEW SYSTEMS

Problem

Demand forecasting for new systems is more difficult than for contemporary systems, because we have no directly related experience to draw from. That well-intended quasi-tautologous statement is both misleading and useless. System "newness" is typically characterized by innovative hardware or by conventional hardware performing an unaccustomed function. In the former case uniqueness is visible in the system's information command and control system, guideway, vehicle, or terminal. The latter case is exemplified by a helicopter squadron serving suburban commuters. Forecasting difficulty, on the other hand, results from complex intermodal, economic, and societal characteristics of a system's host environment. It would, for example, be much easier to forecast demand for a PRT in a new town than for a bus line paralleling an existing rail line in one of our great cities.

In fact, in a negative respect, high cost and high risk make demand estimation slightly easier for new systems. Cruder estimates can be used. High cost can often be used to reject the system's selection out of hand. The "breakeven" patronage level would be much beyond the realm of possibility. High risk implies that expected benefit must be extremely high, and such order-of-magnitude levels can be tested with "quick-and-dirty" forecasting techniques.

What makes forecasting for new systems tricky business is the uncertainty of the supply side. Costs, performance, and unanticipated impacts are all problematic.

Supply-Related Uncertainties

Cost

The most general and frustrating uncertainty connected with new systems is their cost. The uncertainty here is infinitely greater than with conventional systems. A system's cost is probably the single most crucial factor determining its feasibility. Furthermore, operating costs must be (partially) matched by fare-box revenue, and fares impact on the demand that provides revenues. Thus, an expected operating cost must be estimated quite precisely before a realistic subsidy estimate can be inferred.

For example, the capital and operating costs of PRT have been agonizingly difficult to pin down. Capital costs of all UMTA-sponsored development efforts have overshot their manufacturers' original estimates. Being largely a product function of reliability and fleet size, operating costs are particularly difficult. There are almost no good data available to estimate reliability, and large fleet sizes and a variable reliability give catastrophic upper limits to expected maintenance costs, which could imply downtime and repair costs for automated vehicles that might exceed the cost of human drivers!

Performance

Expected performance is another crucial random variable suffering from uncertainty. Although reliability and safety are critical performance parameters, experimental data on these factors are usually too sparse to be trustworthy. Again, the most costly, sophisticated, and automated systems have the greatest uncertainty and, thus, a very high risk.

Unanticipated Impacts

The weaving of a new technology into existing urban fabric can cause unforeseen impacts of enormous magnitude. Placement of new systems must be planned with greater care and attention to detail. Techniques used for contemporary systems are inadequate. They suffer from taking history for granted. New systems bring new problems, ranging from citizen rejection to social catastrophes.

Public reaction is a crucial unknown. If the public stops freeway construction, will it be equally adamant against extensive guideways? Will labor unions raise a fuss and put an "engineer" in each PRT? Will vandals make a shambles of a driverless vehicle? Will passengers be or feel safe? These questions must be answered before demand estimates are meaningful.

Fortunately, the unexpected negative impacts of new technology are becoming more of a concern these days. No one would have guessed 50 years ago that the automobile would be killing 50,000 Americans a year, using 25 percent of the nation's energy, and poisoning all of the cities' air. If anybody had, a march on Detroit would have stopped production of the Model T.

Information Sources

As input to a new system's modeling or planning effort, there are too few dependable information sources. Unfortunately, most of the popular literature and much of the manufacturers' technical reporting on new systems do not realistically address the problems of risk and uncertainty. Such problems are often completely ignored or glossed over with some reverential reference to a limitless capability of technology. For example, an ex-aerospace engineer now in urban transportation personally assured me that "the command and control problems of automatically driving 75,000 vehicles around 500 miles of guideway at 60 mph and a ¼-sec headway posed much less of a problem than the electronic control present in a single F-111 aircraft!"

To reduce risk and uncertainty, the modeler of demand for new systems must seek information from attitude and behavior surveys, product laboratory experiments, prototype development activities, and urban demonstrations.

Attitude and Behavior Surveys

Valuable and relatively inexpensive attitude and behavior surveys are essential research tools, but they can only describe a frame of mind. In the case of new systems, this frame of mind necessarily comprises ignorance. What is the best technique to conjure up in a subject's mind the right image of system X? It is critical that a new system's potential level of service be accurately understood and properly juxtaposed against its competition's.

Product Laboratories

Product laboratories can be excellent data-gathering facilities. Simulators, mockups, movies, and computer-driven video displays can provide a subject with a realistic impression of system characteristics without a prototype having to be built. They serve excellently as a means of judging human factors for design purposes. It is possible, for example, to show the user a computer-generated movie of his trip to work in 1980 in system X and in his automobile. Output from traffic assignment simulations should be "dequantified" to give him a front-seat picture of the estimated traffic.

Prototype Development

Prototype systems such as those exhibited at TRANSPO 72 and UMTA's test track at Pueblo, Colorado, provide excellent data on physical characteristics and development cost. Reliability experiments and safety tests are run there. They also serve as laboratories in which a somewhat realistic user environment can be simulated. Controlled experiments with selected passengers reveal their acceptance of the hardware. Like product laboratories, prototypes are very useful, but they do not assist demand forecasting in the manner required by the transportation planner. These experiments primarily benefit the manufacturer. They tell him whether items such as noise levels, sway, leg room, and color are acceptable. These judgments are necessary to uncover objectionable design features and to reduce risk and uncertainty, but they usually provide little insight on how likely a person is to leave his car at home. That decision, of course, depends little on color, sway, or the like. It depends mainly on the system's competitiveness with respect to time, cost, and convenience. These are site-dependent factors and must be estimated through simulation or demonstration.

Demonstrations

By far the richest source of information on a new system is its construction and operation in the user environment for which it was designed. It is currently felt that there is no substitute for such a demonstration to obtain satisfactorily accurate estimates of safety, reliability, public acceptance, and construction and operating costs. A "successful" demonstration will certify its safety and qualify the system for UMTA capital grant funds. An urban demonstration like the Morgantown PRT project uncovers emplacement difficulties (political, physical, and fiscal) and can serve as fertile ground for behavior and attitude surveys. On the other hand, the scale of the experiment is typically too small to draw hard and fast conclusions with respect to demand. Someone once described demonstrations as building half a bridge. The research challenge, then, is to devise experiments to ascertain from half a bridge in city A the demand for a whole bridge in city B. An urban demonstration does, however, surface negative reactions. Do people feel unsafe on the system? Do vandals deface or destroy it? Is it unreliable? Are its environmental impacts intolerable? Affirmative answers to these questions, however, are used in system redesign rather than demand estimation.

Special Demand Considerations

Although all the problems of forecasting for contemporary options are present during the planning for new systems, additional concern should be given to the problems of modal interaction and latent demand.

Modal Interaction

Every large-scale deployment of a new system will (at least initially) be a retrofit. It will constitute yet another subsystem in the multimodal mosaic that typifies urban transportation systems. Its dependence on or competition with other subsystems is seldom properly considered. For example, a dual-mode system will increase automobile ownership and trip length. What will be the impact on the street and parking subsystems?

Latent Demand

The high risk associated with a new system requires a commensurately higher benefit to justify its selection. If this benefit entails a large reduction of travel time, we would expect a much greater amount of induced travel than that caused by a contemporary system with a lesser direct impact. If the new system satisfies a large portion of existing travel demand at significantly less cost, then there can be a significant increase in total travel. For example, the Interstate System saved a great deal of travel time for many trips. The dual effects were to free some household money (time) for rebudgeting while at the same time enhancing the relative attractiveness of products entailing highway travel. The result, of course, is increased demand not only on the Interstate System but on local roads as well.

Modeling Considerations

Successful (useful) models have 3 important traits. First, they are driven by simple, understandable assumptions. Second, they are optimal within the constraints of the specified budget for their development and application. Third, they perform as advertised. Usually these traits result from the model's restricting its attention to a specific problem. Thus, there will never be a panacean transportation demand model. The various characteristics of transportation design problems and the variation of budget and data base preclude the feasibility of a single "universal" model. Demand models for untried systems are the most difficult to build. They need special treatment, particularly in the model formulation and calibration stages. Better tools are needed for the modeler, so that he may effectively use the scientific method to develop cost-effective models.

Formulation

In structuring models to forecast demand, the modeler works within tighter constraints for new systems than for contemporary systems. The formulation of mode-specific models is difficult enough, but the new modes require "abstract" models that describe a system only in functional terms—no mode-specific parameters are allowed. The typical abstract, time-cost models have not performed very well in practice, and their failure is probably due to poor model formulation as well as bad data. We are not yet able to price time and convenience properly. Even the simplest case, the automobile mode, is poorly handled. For example, transportation planners do not associate different impedance rates with different driving conditions. Although we know that bus riders value waiting time higher than riding time, no one uses the fact that time spent in an automobile in stop-and-go traffic is more highly priced than smooth, uncongested driving time.

The usual treatment of cost in most demand models is inadequate for new system forecasts. These models typically accept point estimates of cost and output point estimates of demand. For new systems, the high level of uncertainty associated with capital and operating costs suggests a parametric approach. The model should accept ranges of assumed costs and translate these into demand curves that are a function of costs, fares, and the like. Such a parametric study graphically translates the cost uncertainties into the corresponding demand variability and also performs a useful sensitivity analysis.

A further weakness in typical demand models is the use of improper predictor variables. The most common example is the misuse of automobile ownership as an independent variable in modal-choice models. A modal choice in its own right, automobile ownership is affected by transportation system variables, both highway and transit. If new systems are going to drastically change the coverage and travel times of public transit, then it is conceivable in the long term that automobile ownership levels will be lower than those expected had the transit system remained at its past, low service level.

Calibration

The above problems are all part of one serious general problem. Demand models have been traditionally evaluated on how well they calibrate instead of how well they forecast. The result of this error has been models that use hundreds of different parameters associated with "independent" variables that are often more difficult to forecast than travel demand itself. The typical iterative calibration process often destroys a structurally valid model by tinkering with its parameters to a point where present-day bias is systematically ingrained in the model and, thus, invalidates its forecasts. Certainly, in the past 15 years, enough travel data have been brought together that we may now use time series data instead of cross-sectional data to evaluate proposed models.

Development Costs

The final demand-estimation problem to be discussed here is a practical one: the high development costs of the models. Usually, this money is ineffectively spent. Typical modeling efforts put too little effort into the important areas of model formulation and evaluation. They spend most of their dollars in data collection and software development. A great duplication of effort results. The cost of demand modeling is much higher than it should be, and the models are not so good as they could be.

After modeler inexperience, the principal cause of most costly "failures" in demand modeling is the formulation of models for which available data are inadequate. Such models have utility from a research point of view, but leave the transportation planner holding the bag. By and large, most successful efforts have been ad hoc in nature and have data limitations constraining model formulation. The best model is built for the data (budget) at hand. The modeler is usually charged with providing a forecast from a given data base. He fails if he uses his ad hoc assignment to seek the best of all possible models independent of data base and then complains that his model's uselessness is the fault of the data.

Improved Modeling Tools

The reason the millions of dollars spent on demand modeling have yielded so few useful general results is the ad hoc nature of the efforts. For reasons mentioned, the models have limited utility. This is not to imply that the efforts were useless. Quite the contrary, in most cases they provided useful numbers to the planning activity for which the model was developed. What is needed is the development of modular, generalized tools that will assist these ad hoc efforts. If we can significantly reduce development costs, more effort can be spent on model formulation and evaluation, and better forecasts can be developed.

The goal of UMTA's new-systems requirements analysis program is to provide some of these tools. In addition to demand forecasting tutorials, UMTA intends to provide a software "breadboard" into which almost any urban transportation demand model can be plugged at minimal cost. The package will include generalized network analysis modules that extract user-specified level-of-service measures from a multimodal network description. Powerful statistical, mathematical programming, and traffic assignment modules will be available to aid in the calibration and evaluation stages. A module accepting any user-written multimodal demand formulation will manipulate the vector and matrix data sets describing activity measures and transportation system characteristics in the manner required by the formulation. Graphics and data-editing modules will facilitate data analysis and "massaging." With such a system, the demand modeler will be better equipped to find good, inexpensive, ad hoc solutions for the planner and to advance the state of the art through research and experimentation.

RESEARCH AND DEVELOPMENT TOPICS

This section gives 5 sample research and development problems and objectives that would lead to an improved ability to model demand for new systems. One recommendation that overshadows and embraces the others is for a large and powerful time-shared computer with a nationwide telecommunications network to be made available to the entire planning community. It would be used both for research and for plan development. It would host a rich variety of general, transportation planning software. It would store for ready access all local land use, travel, and network data and be as convenient to use as a telephone.

Planning and Modeling Computer Laboratory

As mentioned above, 2 impediments to effective demand modeling are the data problem and software development. Researchers dilute their financial and cerebral resources in chasing down and shaping up a useful data base. This is particularly frustrating when there exists a plethora of urban transportation data that have been bought and paid for. The data exist, but they are not accessible because of their multitudinous locations and formats.

One simple act that could greatly relieve this frustration and many others is for UMTA to install a large time-sharing computer that would be available nationally for use by authorized planning agencies and researchers through local terminals. This computer would have resident a large and powerful modular battery of transportation algorithms, statistical and mathematical packages, data management tools, and survey and computer graphics software. Any agency using it would have available a rich and uniform data base, including improved origin-destination surveys, that would be immediately accessible to the entire planning community—federal, state, and local. Such a facility could make modeling easier, cheaper, and more effective. The fruits of successful modeling efforts would be more easily disseminated. Software built for that computer could be available to everyone, almost immediately.

With such a system, a national transportation needs study could become streamlined and routine. Also, the system would readily support the inference of national demand for new transportation systems. Local agencies selected on the basis of the representative nature of their study areas could be asked to construct a plan that assumed a certain new transportation technology to be generally available. These plans would be constructed on the central computer and would provide data points on which a national extrapolation could be obtained automatically.

UMTA capital grants analysts would have at their fingertips data relating to the technical study supporting a grant request. UMTA could also execute post facto analyses of each technical study on which a capital grant request is based. For example, after Metro is working, research would be undertaken to evaluate the demand forecasts. Although the original modeler might not be around to hear the results, other modelers will benefit substantially from such an analysis. Only in this way can we guarantee continued improvement of our efforts. Transportation researchers, including modelers of demand for new technologies and options, could gain access to results of thousands of surveys and network designs with which they could test their hypotheses.

New Origin-Destination Survey Methodology

The traditional origin-destination survey is an infamous exercise in money wasting. It must be replaced with a more cost-effective tool. It is tragic that a public agency can spend millions of dollars surveying travel behavior in an urban area and have none of those data available for analysis before 2 years have passed. A typical scenario is the following: After 3 months of interviewing, a truckload of interviews is entered into an archaic data processing chain. Months of keypunching and verifying move into months of edit checking. Zone numbers are related to addresses. More checking follows more fixing. A year later a factoring process begins and is followed by other accuracy checks and general wholesale handwringing on why census numbers and survey numbers do not match, and on and on.

Finally, once the data are available, they are relatively uninformative to demand modelers. The standard origin-destination survey usually asks the wrong people the wrong questions. It uses primitive sample selection techniques—uniform sample rates independent of the variance of the data sampled. As a result the modeler is overinformed on homogeneous zones and is left in the dark in the heterogeneous zones. The same, unrevealing questions are asked of everyone even though some households have more complex decision mechanisms at work or use totally different components of the transportation system. Questions must be redesigned and varied to elicit behavioral and attitudinal information. Was the traveler aware of his alternatives? Why did he decide against them? What would it take to change his decisions? What trips did he not take? What is the distribution of his household budget?

If modern attitude survey and sampling techniques were coupled with the use of time-shared computers and modern data-entry hardware, some useful data would be available 1 week after the first interview, and all data would be usable within 2 weeks of the last interview. The whole keypunching, editing, and factoring effort could go on simultaneously with the interviewing. And the resulting data would be more informative.

Automatic Network Abstraction

An important factor that has shaped the character of travel demand forecasting models has been the large size of the regional transportation networks. Networks with more than 4,000 nodes are becoming the rule, and there are many large regional and statewide systems with 10,000 to 15,000 nodes. With networks of this size, the data processing problem transcends the modeling problem. Simplistic techniques are used to keep computer costs at a reasonable level. The result is a sad paradox. The networks are at once too detailed and too coarse. They are too big for sophisticated models and too small to yield numbers related to ground truth. It is this writer's opinion that for analytical purposes these large networks are both inadequate and unnecessary.

Designing Through a Window

In this design process the regional transportation planner typically restricts his focus to a small section of a large network or to a small abstract version of an entire regional network. In the former case, he windows in on a particular subarea (e.g., CBD or corridor) and experiments with alternate link configurations until he is satisfied with performance within the window. In this process, he invariably discovers that, as currently coded, the network within the window is too crudely described to ascertain the causes or problems or to specify realistic, ground-related solutions. On the other hand, nearly all of the network outside of the window has more detail than he needs. He is interested only in the traffic flow through his window of interest. The appropriate volume of traffic will flow through the window if some network detail is maintained near the window, but, because most trips are short, detail can decrease as the distance from the window increases.

Correctly coded, a network yielding reliable results within the window would probably require 800 nodes and could accurately represent an entire detailed network of more than 20,000 nodes. A network as small as 800 nodes is amenable to sophisticated algorithms in lieu of the crude traffic assignment models now used. More important, it can be processed fast enough for a time-shared computer to give real-time response. The planner could modify, add, and delete links in the window and request and receive, in effect, the results of a regional traffic assignment in seconds.

The rub is that, as soon as the planner has finished with one window, he moves on to another, and the 800-node network used for the first window is exactly the wrong one for the second. The solution here is to have the computer perform the appropriate network abstraction automatically, in real time. As the planner moves his window across the region, the computer can "abstract" the large, 20,000-node, detailed network into the 800 nodes for the specific window to be analyzed. An arbitrarily fine level of link detail could be maintained inside the window, and the link aggregation would gradually increase with the distance from the window. Design changes within the window can therefore be made and recorded in as great a detail as desired, but in future analyses that detail will be invoked only when relevant.

This technique allows the network data base to be as detailed and as large as necessary. The planner could, for example, use a census dime-file as a point of departure for analyzing present conditions and planning for the future. For the first time, the regional transportation planner's network description could be a realistic portrayal of what is on the ground. The network can be multimodal. Transit links could include vehicle frequencies, fares, and park-and-ride stations. Highway links could include parking facilities. With an 800-node abstraction of such a network, analytic and algorithmic potentials are immense. The results of using the tailored 800-node network could be both faster and more accurate than the traditional approach using the 20,000-node network.

An automatic, dynamic network abstraction technique is a necessary component of a responsive, on-line, interactive transportation planning design tool. The argument is that 800 nodes are always enough—if they are the right 800 nodes.

Sketch Planning

An important additional use of the network abstraction tool would be the creation of a region-wide abstraction. That is to say, the entire network is squeezed into the window. The detailed network would be aggregated to a uniform level of detail, requiring fewer than 800 nodes. The planner could then do transportation "sketch planning." In this mode, he would be designing with abstract links to ascertain required corridor capacities and first-order level-of-service measures for strategic planning purposes. The ability to abstract existing networks gives him the further ability to compare alternatives with the present net in a direct manner and also would provide him with an appropriate point of departure for the construction of future alternatives. The same capabilities would provide him the ability to aggregate a detailed future design for purposes of comparison and the input to processing routines requiring a small network.

With this size of network and at this level of detail, there probably is a solvable network equilibrium problem—solvable for 2 reasons. First, the network is small enough for a powerful (slow) algorithm to be cost effective. Second, the results would be meaningful. At the detailed ground-truth level, equilibrium in any simplistic mathematical sense is nonsense. Vehicular traffic, like molecular flow, behaves predictably only above a certain level of aggregation. The greater the aggregation is, the greater the likelihood is for a single, steady-state equilibrium solution. The remaining problem is to relate the solution flows on aggregate links to those on detailed links. Research should provide a reasonable means of estimating reasonable detailed link speeds, if not precise volumes.

Disaggregate Models and Monte Carlo Techniques

It has been known since before the first origin-destination survey that most urban travel demand is essentially household based. To forecast it most reasonably is therefore to establish relations of household members, their household characteristics, and the transportation system and, thence, to predict their travel behavior. These household models replicate observed behavior better than traditional aggregate models. They can directly address the distribution of a household's resources among its people and goods. Furthermore, they require less calibration effort than the aggregate statistical models in common use. To date, however, these disaggregate models have not been in wide use. One reason is that the best disaggregate models do not readily yield a total demand forecast in the form that aggregate models typically output. Another is that they require input data in a slightly different form.

Disaggregate models can readily provide not only more accurate but more useful and usable data than their predecessors. For example, a disaggregate household model could be used to perform an origin-destination survey for 1990. Using frequency distributions of the socioeconomic characteristics of each zone, a Monte Carlo technique could generate the "independent" variables of a random household. The model would then fill in the travel behavior data. Computer-built households would be sampled until variability reached an acceptable level. The computer would then factor the 1990 survey on the basis of the observed sampling rates for the many socioeconomic categories implied by the probability distributions. The result of the run would be a data base that could be aggregated and analyzed in many more ways than a simple set of trip tables or link volumes. Realistic scenarios of life in the 1990s could be called up and displayed. To the same degree that a present-day origin-destination survey can describe travel behavior of the present, the computer's sample could be used to describe expected future behavior. To reflect uncertainty, replicated simulations would provide forecasts in the form of probability distributions.

Relatively precise estimates of heretofore difficult variables such as walk time and automobile availability could be inferred easily with such a technique. A rigid analysis zone system is no longer required. There could be as many sets of zones as required to readily describe the study area—income zones, density zones, redevelopment zones. The computer can determine which zones are applicable to a sampled household. Indeed, the concept of the traffic analysis zone as we use it today would be meaningless.

In lieu of reiterating the lengthy detailed Monte Carlo simulation to ascertain appropriate equilibrated times on links, one could use output from an aggregate demand model applied at the regional abstract network level described above. Abstract link volumes could be related to the detailed links composing them to get a reasonable first cut at link speeds, transit vehicle frequencies, and line routings. If the accuracy of the coarse estimate could be assumed adequate (perhaps through iteration), an abstraction of the Monte Carlo simulation network could be compared to the coarse traffic assignment for additional "screenline" factors. Thus, the detailed simulation does not concern itself with detailed equilibrium—that never occurs anyway. It is used to obtain a finer grained demand estimate, ascertain loads on actual facilities, and provide richer data for evaluation.

Demonstration Planning Studies

Much of our ignorance concerning demand for new systems is propagated by the fact that the country's most experienced and knowledgeable professional transportation planners seldom seriously consider innovative transportation modes. This is probably as it should be. Most of these experts are designing real systems for real cities. They avoid high-risk solutions; their clients do not want them. The city's budget and common sense make planning for anything but a proven technology an academic or foolhardy exercise. Couple this with the fact that most problems of a new technology are unknown until a planner actually attempts to design its emplacement in a real city, and one understands why the loudest proponents of new technologies have the least knowledge of the transportation problem, why misinformation and overly optimistic claims are the rule, and why the manufacturers' literature constitutes a shaky base for demand estimation.

How can we get the right people considering new systems? I propose demonstration planning grants. We need these research planning grants as much as hardware demonstration grants. They would fund all or part of a full-fledged technical study that would pretend system X were available. These paper studies would often be dead ends, and none would lead to a traditional capital grant request; but they would be very useful in examining the potential for a new system. These studies would be much more numerous than actual demonstrations. They would act as a sieve to preclude useless, overrisky hardware experiments and would highlight the knowledge gaps to be filled with a promising demonstration.

In addition to being academic, these planning simulations would differ from the usual technical studies in the way they describe new systems. Instead of using estimated cost figures, as in the case of contemporary systems, they would parameterize capital and operating costs. As a study output, each would provide estimates of maximum costs for which the system could be considered viable. These estimates would furnish industry with research and development objectives. Performance characteristics such as maximum headway, minimum average speed, and vehicle and guideway sizes could be handled similarly. Thus, these efforts are more supply-side oriented and "backward seeking" than are typical technical studies.

SUMMARY AND CONCLUSIONS

This paper has argued that ignorance and ineptitude present in most urban travel demand forecasting are greatly accentuated in our attempts to predict the acceptance of new transportation technologies and options. Although the discussion has been restricted to capital-intensive alternatives, the same arguments apply to improvements that have lower emplacement costs. Our ignorance can be reduced by the systematic design and exploitation of attitude and behavior surveys, product laboratories, prototype developments, and urban demonstrations. Our ineptitude can be lessened through access to a national time-shared computer laboratory containing a comprehensive data base and software library.

This ubiquitous laboratory could enable the modeler to exercise the scientific method effectively in his research and development efforts. Its resident, streamlined network algorithms and data management modules would reduce the cost of model development and application and increase the quality of the output by an order of magnitude. Furthermore, the laboratory could host numerous planning activities, including demonstration planning studies, that involve early and serious deliberations on new systems. Such studies would provide test beds for new models, help industry gather useful data on requirements, and greatly increase our knowledge of the expected problems and impacts of new transportation modes.

The above are but a few suggestions offered with the dual hopes of accelerating the slow-motion black art of transportation planning and of raising our understanding of new systems above that of hopeful manufacturers and uninformed dilettantes.

Workshop 4

SOCIAL, ECONOMIC, AND ENVIRONMENTAL IMPACTS OF TRANSPORTATION SYSTEMS

OBJECTIVES

Identify, review, and evaluate the important relations between the amounts and distribution of travel and the social, economic, and environmental impacts of transportation facilities and systems.

Recommend improvements in the linkages between travel demand forecasting procedures and procedures for estimating the social, economic, and environmental impacts of transportation facilities and systems.

Recommend improved procedures for impact forecasting.

Develop recommended program of research that will improve impact forecasting.

IMPACTS

Social, economic, and environmental impacts include consequences of the transportation options considered by Workshops 1, 2, and 3. Examples are changes in direct costs of transportation options, travel costs, transportation system performance measures, and neighborhood street safety; effects on air quality, noise, vibration, aesthetics, water quality and availability, spatial arrangement of activities, existing transportation operations, and tax base; disruption of community during construction and destruction of public facilities; relocation of families, businesses, and institutions; impedance or improvement of social linkages; and expansion of laborsheds and market areas.

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Report

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Sections 1 and 2 of this report were prepared by subcommittees of Workshop 3 but were reviewed and agreed to by all workshop members. The requirements given in section 3 were agreed to by workshop members and presented during the conference but were prepared in final form by the chairman after the conference. Section 4 summarizes the research projects proposed by Workshop 4. It was prepared by the chairman and was not reviewed or approved by workshop members.

ISSUES

Rapidly changing societal priorities establish a need for the transportation planning process to consider a wider range of concerns. These changes also require flexibility in the specification of impacts to be forecast. Specifically needed are a wider range of travel system performance measures; capability to predict impacts of transportation decisions on land use and urban structure and on social groups and economic interests; and recognition that environmental impacts and mechanisms for the control of impacts can, in turn, bring about changes in travel demand patterns over time.

Although the impact-related issues that follow have relevance to the structuring of urban environments in general, the focus here is on those aspects related to the urban transportation planning process. Many of these issues are complex, interacting, and in some cases competing. Thus, a "new" planning process is required that addresses these issues in a systematic, organized manner, rather than in a series of unrelated responses to particular controversies.

Comprehensiveness

Measures of transportation system performance needed for use in program and project evaluation are (a) accessibility to opportunities, particularly for the aged, the young, the handicapped, and the unemployed; and (b) accessibility of unique trip generators such as airports, universities, major nodes of concentrated employment, and convention centers.

Any particular category of social, economic, or environmental impact may have to be modeled by using different functional forms and different variables in order to allow different scales of analysis. For example, the evaluation of the air pollution consequences of a regional transportation network is quite different from the evaluation of the air pollution consequences of a particular link or interchange.

Current models assume that the major objective is to forecast demand for travel based on predicted levels of population and economic activity. An alternative is a goal-seeking or normative model that derives flows from equalization of accessibility to opportunities, for example. The principal concern in the development of goal-seeking models should be on the performance impacts of the transportation system as objectives, rather than on the second-order consequences as constraints.

We need the capability to disaggregate along at least 3 dimensions: (a) by particular socioeconomic and interest groups and by trip destination; (b) by time of day in order to measure impacts at critical time periods, such as peak-hour measurements of accessibility to work and nighttime hour measurements of noise impacts in residential areas; and (c) by vehicle types because different vehicle types have different impacts on the environment and because there are different control strategies for the impacts of various kinds of vehicles. In addition, there is a need to develop a capability to shift from one level of aggregation to another during the analysis and planning processes and a consistency should be built into the modeling process that allows such flexibility in disaggregation.

Both positive and negative impacts of the "null" alternative should be considered in the evaluation of the impacts of all available alternatives.

It is important to consider the time flow of impacts during the life of the programs and facilities. For example, when air pollution is considered, the time-dependent growth in travel should be considered in terms of interaction with the time-dependent streams of changes in exhaust control technology.

Basic research should be continued in human behavior and in the physical relations between transportation technology and environment. Although the required research will have to extend over a long time period, concern for answers to immediate problems should not eclipse the ultimate need for greater understanding of basic processes.

Timeliness

Simplified techniques are needed to produce rapid response with minimal resource commitments. Such techniques can at least point to directions of change or define ranges of impacts. The estimates may be more useful than detailed answers that arrive too late.

Credibility and Reliability

The assumptions that underlie the reduction of complex data sets to presentations of performance and impact measures must be made explicit to the user of the information. In addition, estimates of the reliability of the measures, and their sensitivity to assumptions, should be provided to decision-makers, citizen groups, and other users.

Performance and impact measures should be presented in such a way that the characteristics of the performance of the alternatives can be easily communicated to citizen groups and politicians. Charts, tables, and graphs are more useful than piles of computer printouts

IMPACTS

The social, economic, and environmental impacts listed below were identified by Workshop 4 as being those that the transportation planning community is being pressed to address.

1. Mobility and accessibility
   a. Mobility of special groups such as the aged, handicapped, young, poor, and unemployed
   b. Mobility of the population as a whole and by subgroups in terms of modal mix to destinations, level of services to destinations, travel cost and time, comfort and convenience, numbers of opportunities, and emergency response capability
   c. Accessibility of special generators such as concentrated job locations, commercial sales facilities, airports and other terminals, hospitals, schools, service centers, and recreation centers
   d. Geographic location possibilities of population groups, modal alternatives, and destination locations

2. Environmental impact
   a. Air pollution in terms of spatial considerations (regional, subregional, or local), dispersion and fallout, pollution components and form, proximate versus ultimate source, mode and submode, age and maintenance levels of vehicles, level of service, level of technology of emission control and new energy sources, effect on users and nonusers, toxic effects, and time of occurrence and duration
   b. Noise in terms of spatial considerations (regional or subregional facility), impact on adjacent land use, mode, users versus nonusers, health effects, and time of day
   c. Natural environment in terms of accessibility to natural areas and effects on natural systems
   d. Management of solid, fluid, particulate, and radioactive wastes

3. Energy and other resources
   a. Use of gas, electric, oil, coal, and nuclear energy relative to reserves
   b. Use of nonenergy resources such as land for transportation purposes

4. Aesthetics
   a. Obtrusive structures for light and visibility
   b. Provision of desirable land uses such as parks and playgrounds
   c. Provision of open space
   d. Removal of eye sores

5. Community effects
   a. Development opportunities for factories and businesses, commercial facilities, parks and recreation facilities, housing, and social linkages
   b. Community disruption such as housing and business displaced, community services separated from users, breaking of intracommunity social linkages, and separation of ethnic and cultural groups
   c. Increased accessibility to different activities and to different parts of the urban area
   d. Institutional effects including tax base and community organization

6. Safety and security
   a. Safety with respect to mode, facility mix within mode, facility age, specific accident prevention and care facilities, class of injury, and total injuries and injury rates
   b. Security by mode, incident type, and time of day

7. Transportation performance and economic efficiency
   a. Travel time and costs, system performance, and economic efficiency with respect to level of investment, modal mix, system components, system users and user groups, user time budgets, and psychological effects
   b. System-facility costs, benefits, and performance within modes with regard to system-facility mix, new investment mix, individual new investments, existing versus new facilities, investment versus no investment versus disinvestment, urban versus suburban investments, investments benefiting different population groups, service coordination (transit), urban-interurban connections, and efficient operation and management of systems
   c. Costs and benefits among modes with regard to automobile-transit trade-offs, urban-interurban trade-offs and interconnections, passenger-freight and freight-freight interconnections, and utility-transportation corridor interconnections

8. Urban structure
   a. Effect of transportation systems on land use in terms of distribution, mix, intensity, development patterns, and development rate
   b. Urban structure, economic efficiency, and performance with respect to CBD-urban sprawl, new towns in town or out of town, land use, urban size, modal mix and density, nonvehicular travel, urban development and redevelopment patterns, nonpassenger travel modes, use of urban land for transportation, level and distribution of travel demand, and nontransportation economy and intrastructure costs

Other transportation investment options that have social, environmental, and economic implications and that relate to (specialized modal) problems are freight terminal location distribution, integrated downtown passenger terminals, satellite airports and airport access, additional airports and their location, and distribution and location of general aviation airports.

REQUIREMENTS

For the 8 identified areas of social, economic, and environmental impacts, Workshop 4 agreed on the following requirements for travel demand forecasting.

1. Mobility and Accessibility

Major modeling efforts will be necessarily directed toward forecasting travel demand for population subgroups and special generators for special trip purposes. Prime requirements are in the areas of data and understanding of travel behavior.

2. Environmental Impact

The UTP package can be used to simulate regional air pollution and noise but less sophisticated tools can probably be just as effective at the regional level for lesser cost. Simulation of air pollution and noise gradients from local sources can probably best be based on link volumes. The actual modeling, however, will be not demand modeling, but activity modeling. The relation between travel demand forecasting and assessing impacts on the natural environment other than air and noise appears to be tenuous.

3. Energy and Other Resources

Basic necessary research in the area of energy use and reserves probably lies largely outside the field of travel demand forecasting, except in terms of using gross aggregates of regional and other travel.

4. Aesthetics

The relation between aesthetics and travel demand forecasting appears to be tenuous. The closest relation is in areas such as estimating the impact of banning automobiles for aesthetic reasons. Aesthetics is primarily a question related to design and community acceptance.

5. Community Effects

A use and a need exist for demand analysis in the area of community effects, particularly as it relates to imposed constraints. There is a need for micromodeling of community travel demand either within or independent of the regional UTP process (or both).

6. Safety and Security

There is a long history of incorporation of safety measures in the existing UTP process. This type of inclusion will remain important. More such measures are necessary, particularly in subregional analysis and in planning safety systems.

7. Transportation System Performance and Efficiency

Measures of performance and efficiency have historically been an integral part of the UTP process. Such measures need to be incorporated in all new models.

8. Urban Structure

One of the most important questions that travel demand forecasting must address is urban structure. Land use modeling needs to be incorporated into the existing UTP process and also to become a basic element of many UTP extensions. It is crucial to much modeling independent of the UTP process.

RESEARCH NEEDS

The general view that became stronger during the conference is that the existing UTP process is extremely important both in its original context of regional systems planning and in many of the new and broadened concerns that planners are now being asked to address. For example, it appears that the necessary measurements of air pollution levels are a logical and reasonable output of existing model packages with at most slight modification. Similarly, it appears that, regardless of the changing emphases from long- to short-run concerns, the need for overall systems simulation and planning will remain. Extensions of the existing package will certainly take place, but its basic form will remain durable and useful.

At the same time, however, a completely new set of models must be developed that are directed not toward total regional highway and transit systems planning but toward subregional, project, and other demand questions, mostly in the short-range and medium time frame. Because these subregional, short-range concerns cover a great variety of planning problems and questions, a correspondingly great number of models will need to be developed. It appears likely that in their development similar underlying themes of theory and structure will occur. Data requirements in each of the problem areas will frequently be different because the problems are different. Similarly, the actual models will differ from problem area to problem area.

In the context of subregional and problem analysis, it appears that some of the recent efforts to make regional network models more and more detailed are to a degree misdirected. The existing regional data—and any conceivable regional data—are simply not fine enough for networks with many thousands of nodes. Even if we could have sufficient detailed data, we could hardly understand or assimilate the model output (even if we could afford it). Even adequate "windowing" devices appear to have extremely great problems of data and outside network relations. Almost by definition regional modeling must be coarse modeling, and there appears to be little benefit to trying to make it otherwise.

Subregional and minor link problems themselves can easily and appropriately be addressed at suitable degrees of disaggregation. There is no need in most of the subregional questions to consider the region as a whole, and a complete regional simulation is unnecessary. Here, though, even the most basic models do not exist. They need to be developed.

The direction of certain criticism has been toward the development of various types of disaggregate models. The criticism has been made that disaggregated models have overly small relevance to the regional UTP package and, thus, have little reason for development. According to this argument, the only use for disaggregate models is to "tune" the UTP package and possibly to make it more realistic and responsive to policy concerns. Indeed, this is a major fruitful application for disaggregate techniques and results. Probably of more importance, though, is the use of disaggregate models outside of the regional context. It is in the context of subregional and project problems that disaggregate models have their most direct application. In these contexts the models are suited to the problems and they can be used easily and cheaply, if we bother to develop them.

A final conclusion has to do with the need for basic understanding of the travel phenomenon and of the interrelations between human and urban systems. In the past we have expended considerable energy in the analysis of basic theoretical relations among alternative model structures. It appears that this type of endeavor can probably be made far more relevant and productive if it is accompanied with a great deal of investigation of the underlying determinants of the travel phenomenon and of the actual relations between human and urban systems. The results of such combined theoretical and empirical analysis should have powerful impacts on the transportation planning process at all levels of generality and in all time frames.

Resource Paper

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How may the relations that exist between the amounts and distribution of travel and the social, economic, and environmental impacts of transportation facilities and systems be identified and evaluated?

How may the linkages that exist in current practice between travel demand forecasting and procedures for estimating the social, economic, and environmental impacts of transportation systems and facilities be strengthened and improved?

What specific changes can be recommended for the objectives and procedures of travel demand forecasting that would serve to improve the results of impact forecasting and analysis in transportation planning?

What research can be recommended that would serve to improve the results of impact forecasting and analysis in transportation planning?

Answers to these questions are of critical importance because an increasing proportion—perhaps a majority—of transportation decisions are being made in the political arena, and the critical factors in these decisions revolve around issues that are related to transportation-system impact rather than around issues that relate to the balance between the demand and supply of transportation service itself. On the other hand, advances in transportation demand modeling have centered on refinements in our understanding of the demand-supply relations. Unless the questions are satisfactorily answered, we risk widening the gap between the concerns of the professional-technical transportation planning hierarchy and the decision issues that are of most importance to our communities and, thus, to the future of transportation systems and their planning. Clearly, this gap is already sufficiently wide as to make many of our technical abilities irrelevant in the current processes of decision-making with regard to transportation systems and projects (1). Although it is not likely that we can satisfactorily answer these questions during one conference, we can help to chart the directions that will be followed during the next decade in mobilizing the transportation research and planning communities toward the objective of seeking their answers. Answers to these questions are of critical importance if the transportation planning community is to recoup some of its losses in public confidence during the past decade and if it is to produce plans that meet public expectations and hence pass the important test of validity that comes with implementation.

The first part of this paper presents a conceptual framework for classifying and identifying the impacts of transportation systems and facilities and for identifying impacts that can be addressed through demand modeling. We can make this framework a useful vehicle for answering the above questions by using it to analyze some specific issues and options for more effective integration of demand modeling and the analysis of impacts of transportation systems. Within this framework, later portions of the paper present specific opportunities for the establishment of linkages between impact analysis and demand modeling. Finally, the framework is used to arrive at recommendations for a series of research tasks aimed at operationalizing the linkages between demand analysis and concern for the environmental, social, and economic impacts of transportation systems.

CONCEPTUAL FRAMEWORK FOR THE STUDY OF TRANSPORTATION IMPACTS

A discussion of the relations between the impacts of transportation systems and projects and the knowledge about those systems and projects should begin by returning to some basic concepts introduced by Thomas and Schofer a few years ago. Using their terminology, we can describe a transportation project as a change in an existing system. The change consists of the addition of inputs into that system and produces certain outputs. Inputs are the things drawn from the environment in order to modify the existing transportation system, and they might be "in the form of material resources, such as raw materials, money, and labor, as well as nonmaterial things such as information, ideas, or skills" (2, p. 10).

Thomas and Schofer point out that the transportation planner is concerned with changing the uses of such inputs in order to affect changes in the outputs of the transportation system, and they divide these outputs into 2 categories that will prove useful in the structuring of transportation-system impacts. First, there is a class of outputs that may be called performance outputs. The performance outputs of a transportation system are those results of system changes that are directly related to the objectives of the system or the purposes for which it was built. Changes in travel times from one point to another and changes in travel volumes on particular links are good examples of performance outputs, for they represent the extent to which the planner succeeds in meeting the objectives that have been set for transportation-system performance.

A second class of outputs is termed concomitant outputs; they consist of the "material and nonmaterial things flowing out of the system and into its environment which are not direct contributions to the attainment of the objectives of the system. Concomitant outputs may be generated by the operation of the system or even the simple existence of the system" (2, p. 10). Examples of the concomitant outputs include the liberation of hydrocarbons into the atomosphere, the consumption of space for transportation rights-of-way, and the noise produced by the vehicles that are part of the system. Clearly, these are outputs of major transportation projects, although we certainly do not produce the systems with the intent of generating such by-products. They occur because we are constrained by existing technology; if it were possible to produce high-quality transportation service through the provision of performance outputs without concomitant outputs, planners would choose to do so. Currently, many concomitant outputs of transportation systems are treated as externalities in that the transportation-system planner does not control them and the user is not always called on to pay the costs that the concomitants impose on nonusers or to modify his behavior in order to control their production.

One last borrowed term from Thomas and Schofer is the consequences that flow from the inputs, from the performance outputs, and from the concomitant outputs of transportation-system investments. These consequences are the results of the interaction between the inputs or outputs of the system and the environment within which the system is built. Clearly, the consequences of transportation-system inputs, performance outputs, and concomitant outputs are of great concern in the study of impacts (2, p. 11). For example, one consequence of the input of land might be a reduction in the tax collections of a municipality through which a transportation facility has been built because this land has been transferred from private to public ownership. Another consequence, this time the result of performance outputs, might be the increased use of a particular public park that was previously relatively inaccessible to the population of an urban area but to which travel times were significantly reduced by the opening of a new facility. Finally, an example of a consequence of a concomitant output might be an increase in the number of cases of emphysema that occur in a community because of increased exposure to the concomitant output of hydrocarbons in the air as a result of the construction of a freeway through the community. Clearly, these consequences depend on both transportation-system characteristics and the environment of that system. Thus, the changes in tax revenues depend on the preexisting tax base as well as the amount of land consumed for the construction of the facility; the changes in travel to the public park depend on the locational relations between the population and the park as well as the changes in the travel times; and the changes in the incidence of emphysema will depend on population density, preexisting health conditions, and presence of other sources of pollution as well as the presence of the new freeway.

Transportation-system impacts may be viewed in terms of a spiral of changes that take place in communities as a result of investments in changes in the transportation system serving them. In the analysis of these changes, the terms introduced by Thomas and Schofer provide a convenient way of labeling the different types of effects to which system changes give rise. I will, therefore, now turn more directly to considerations of transportation-system impact and will call on the terminology already introduced in order to build a framework for distinguishing among types of impacts and for relating each type to the concerns of transportation demand forecasting.

The most immediate and direct effects of transportation-system investments might be termed first-order impacts. These are the most measurable and probably the most predictable changes produced by investments in the network, and they include what have previously been characterized as changes in inputs, performance outputs, and concomitant outputs. First-order impacts, therefore, include the changes in the systems consumption of inputs, such as space and capital; changes in the production of performance outputs, such as point-to-point travel times and travel volumes on particular links in the network; and changes in the production of concomitant outputs, including shifts in the production of airborne pollutants and noise and the creation of linear "barriers" to movement at the local level.

When these first-order impacts are viewed in concert with the environments within which they take place, they give rise to second-order impacts. These include the important effects that Thomas and Schofer have labeled as consequences of transportation investments. Thus, in response to the first-order effects of travel time and traffic volume changes, urban activity patterns change and travel habits are adjusted to take advantage of the performance outputs of the transportation system. Similarly, the changes in concomitant outputs might give rise to second-order impacts such as increases in incidence of respiratory disease or decreases in property values if homes are exposed to high levels of noise or to visual impacts of transportation facilities.

The second-order impacts of changes in transportation systems may give rise to further repercussions that are entirely within the physical and institutional environments of those systems and that result from but do not directly involve the performance or concomitant outputs of the system or its inputs. Thus, a third-order impact might be a change in the levels of citizen organization within a community through the creation of antifreeway action groups or through letter-writing campaigns. Such a third-order impact might be a change of response resulting from a second-order impact that occurred as an intended or concomitant result of first-order impacts. Table 1 gives the relation between transportation system inputs and outputs and the 3 orders of impact. Table 2 gives examples of how this framework might be used to categorize particular transportation impacts at each of the 3 proposed levels.

Such a division of transportation-system impacts into 3 levels is valuable in studying the relations between these impacts and the concerns and capabilities of demand modeling. The numbers given in Table 3 indicate the relative strength of interrelations that exist between impact analysis and travel demand modeling and are defined as follows:

Linkages Between Demand Models and Impact Analysis	Relative Strength
Current focus of travel demand forecasting	1
Areas of potential linkage in short-to-intermediate time span	2
Areas of potential linkage in intermediate-to-long time span	3
Areas of little direct linkage, but from which important insights on the role and context of models can be drawn	4

The lower numbers indicate linkages that already exist or that could be developed within a relatively short time span at relatively low expenditures in research and development. Higher numbers indicate weaker linkages between the demand models and impact analysis and higher required levels of study to achieve useful ties. I hope to be able to demonstrate that demand modeling can now be directly applied to the analysis of some first-order impacts, and indeed the analysis of these impacts is the explicit intent of demand modeling. In the short term, it might prove possible and it certainly would be desirable to expand the concerns of demand modeling, through relatively specific research and development efforts, to the consideration and analysis of additional first-order impacts and perhaps some critical second-order impacts. I will contend that it will be more difficult and that it will take longer to employ demand models in the consideration of a wide range of second-order impacts and that this difficulty is a function of the institutional arrangements within which transportation planning is carried out as well as a function of the technical capabilities of modeling. Finally, I will assert that the third-order impacts are probably not effectively addressed by demand models, but that these effects help to define the role of demand models and the political climates within which they are employed. The implications of this division of impacts is not that first-order impacts are more important than those of second or third order; often the third-order impacts do directly affect decision-making. Rather, the value of the distinction is intended to relate more to the role of demand models in dealing with these impacts.

ISSUES AND OPTIONS FOR CONSIDERING IMPACTS IN DEMAND MODELING

Linkages Between Travel Demand Models and First-Order Impacts

First-order impacts include the most direct and measurable changes that take place among the inputs to and the performance and concomitant outputs from the transportation system as a result of physical or programmatic changes in that system. Transportation demand models have generally been applied to the forecasting of some of the first-order impacts that would occur under alternative system modifications. These forecasts, in turn, are used in the process of evaluating the alternative system changes.

Currently, the first-order impacts that have received the most attention in demand modeling include those that are related to the performance outputs of the transportation system. The traditional sequence of land use, trip generation, trip distribution, modal split, and traffic assignment, later efforts to produce direct and multimodal assignments, and recently developed procedures for the direct estimation of link volumes and for microassignment of traffic to detailed representations of neighborhood level networks, all produce estimates of performance characteristics of transportation networks such as modal and link volumes, aggregate estimates of point-to-point travel times, and information about typical trip lengths within the study area of different purposes. By applying these techniques to a reasonable number of alternative networks, the planner has attempted to generate information on the comparative performance of these networks for use in benefit-cost analysis or within other frameworks for comparative evaluation. The value and appropriateness of such demand modeling efforts should not be understated, for, in spite of the many flaws that we can all identify, these efforts represent the most systematic and detailed studies of any public service system that have taken place to date.

Existing modeling techniques are strongest in estimating the performance of future transportation networks at the regional or system-wide level, and this reflects the past emphasis on system-wide evaluations of alternative networks by the major regional transportation studies that developed existing model sets. Current models are weaker, however, in estimating some of the concomitant impacts of transportation systems at the regional level and are still weaker in producing estimates of both performance and concomitant outputs at the disaggregate level of individual links or neighborhoods. Current emphasis in evaluation is shifting toward the consideration of more localized effects and toward the establishment of more explicit linkages between the performance and concomitant effects of transportation investments at the localized level. As I have indicated earlier, I believe that the most immediate potential for expanding the capabilities of travel demand analysis is at the level of first-order impacts. Some of the most important possibilities for research and development in demand modeling involve a greater emphasis on performance measurement at the localized level as well as the consideration of first-order impacts of the concomitants of transportation investments at both regional and local levels.

Measuring Differential Accessibility Levels

Although travel demand models are already principally oriented toward the forecasting of performance outputs, there are several ways in which these models might be employed, even in the very short run, to provide additional system-performance information that would be of great value to planners. Generally, the models use information on socioeconomic characteristics of individuals, often aggregated to the travel-zone level, in the estimation of travel volumes. The outputs of the modeling sequence, however, are rarely presented in such a manner that system-performance differentials that exist among various subpopulations are made obvious. Because the gaps that exist in accessibility among major population components are becoming as important in transportation decision-making as the aggregate measures of system performance, this addition to the analysis of transportation-system performance can be a significant aid to planning.

Wickstrom has proposed that existing transportation models can be used to estimate the number of employment, shopping, or recreational opportunities that are available to spatially identified population groups within particular travel times (3). Carrying this concept further, we can use origin-destination survey data on employment of individuals and on the locations of employment opportunities to determine whether the transportation system is providing levels of accessibility between blue-collar workers and blue-collar jobs equal or inferior to the accessibility it is providing between professional workers and professional job locations. Initial indications from data that I am currently analyzing for Los Angeles are that population groups differ significantly in terms of the accessibility that the system provides to jobs for which they qualify and that these differences appear when the population is stratified spatially and also by income and by occupation category (4). The addition of some simple indexes of accessibility to current demand models and the aggregation of subpopulations according to socioeconomic characteristics rather than spatial location of residence are enabling us to use existing assignment models in the estimation of differential levels of system performance for these different population groups.

Similar comparisons can be made among trips made for a variety of purposes and between populations in which automobile ownership is high and populations that depend more heavily on the transit modes. For example, using very simple additions to packaged UTP model sets, we have estimated that, from one census tract in Los Angeles, residents who own automobiles may reach 1,678 physicians' offices, hospitals, and medical-group-practice offices within 30 min of their homes at off-peak hours. From the same tract, only 37 such health-care opportunities may be reached within 30 min of transit travel time. It is significant that this comparison was made for a zone in which car ownership is relatively low.

This type of analysis might be a step toward more explicitly recognizing travel needs of important subpopulations rather than focusing, as analysts have tended to do, on models that do not differentiate explicitly among different groups of travelers, modes, and trip purposes. Because the modifications needed in demand models to perform such comparisons are minimal and because the value of such information is potentially quite large in setting priorities for network improvement in terms of relative impacts, it is an area that is ripe for short-term research support and operational application.

What is really significant about such measures of system performance is that they represent a change in perspective for the planner and analyst. In the past, analysts have tended to judge system performance in terms of characteristics of trips that are actually made or that are forecast for some date in the future. With only simple modifications, the capability can also be developed to analyze performance of current and proposed networks in terms of opportunities to make trips by specific population groups. This is most significant for the analysis of social impacts of system performance because observed low levels of travel among the poor and the elderly might be derived from a failure of transportation systems to provide them with opportunities to travel rather than from innate tendencies of such citizens to travel less frequently.

Need for Greater Disaggregation in Demand Modeling

Emphasis on greater disaggregation in travel demand analysis has been growing for several years, and the above arguments do not exhaust the important reasons for pursuing this concept as a basic approach to the improvement of demand modeling. For example, under the rubric of "behavioral" models, researchers have modeled trip generation and modal split at the level of individual household or traveler rather than follow the traditional approach that uses the travel-analysis zone as the unit of analysis. It has been found that statistical relations that describe travel and mode choice at such disaggregate levels may differ considerably from zonal models. In part, this reflects the fact that total variance in travel includes within-zone variance as well as between-zone variance. The aggregate models operate only on between-zone variances, and we tend to assume that relations fitted to zonal averages between, say, income and daily trip-making are characteristic relations valid also at lower levels of aggregation. This is not necessarily so, however, for some recent studies have shown that within-zone variation about zonal means may be much greater than variation among the means for different zones (5). It would seem, therefore, that continued and further analysis of travel, disaggregated by personal characteristics and trip purposes, is important for more complete and valid representation of first-order impacts of transportation-system performance.

Linking Demand Models to First-Order Air Quality and Noise Impacts

Opportunities also exist for the establishment of direct linkages between travel demand models and the study of the concomitant outputs of transportation systems when these are considered at the first level of impact analysis. Thus, with the expenditure of some significant research energies, it should be possible to establish techniques to produce system-wide estimates of the production of environmental contaminants of transportation systems and perhaps to give more direct attention to the noise outputs of transportation links through more integrated modeling efforts. These linkages are important both at the level of regional transportation-system evaluation and at a more localized level as well.

In many metropolitan areas, levels of pollutants in the environment are derived primarily from the exhausts of motor vehicles. In Los Angeles, for example, it has been estimated that more than 90 percent of the CO, HC, and NO_x concentrations in the urban environment orginate in the transportation system. Efforts to improve the quality of the air in urban areas have been focused in the area of technological devices, such as the retrofit of older vehicles with pollution-control devices, and of research and development efforts aimed at producing cleaner fuels and a catalytic muffler. In the short term it is likely that technological solutions promise greater payoff than approaches that depend on the changing of travel patterns or the reorganization of land uses and population densities. There are, however, some contributions that might be made by the planner, using travel demand models as a tool in the analysis of alternatives (6).

One way of examining the effect of urban development and transportation systems on air pollution levels is with the aid of a simple "box" model as shown in Figure 1 (7). The urbanized area is the bottom of the box where the emissions due to automobile operation occur. Removal of pollutants from the box is for the most part accomplished by horizontal air motion and eddy flux out of the top of the box. The dimension h refers to the height of the mixing layer and the dimension D refers to the area's diameter. The long-term spatial average concentration of a pollutant can be approximated by the expression shown in Eq. 1 (8, 9).

$$\bar{c} = \frac{QD}{hw} \tag{1}$$

where Q is the pollutant emission (per unit time) per unit area and w is the average wind speed. This equation suggests that there are 3 basic aspects of the urban air pollution problem: (a) emissions (per unit time) per unit area, which is related to population levels, travel patterns, and technology; (b) city size or area, which is related to population levels and population density; and (c) pollutant dilution (hw factor), which is related to meteorological conditions.

Recent research has shown that Q is dependent on the total mileage driven within the region per unit time and on the average emissions per mile of driving. Although the emission per mile of driving is dependent on technological characteristics to a great extent, it also has been shown to bear a systematic and generally inverse relation to mean network speeds (7). Clearly, travel demand models can thus be used to estimate the inputs to such a box model because they provide estimates of network speeds and daily mileage of travel. Although such box models are simple and highly aggregated, if used in conjunction with land use and travel demand models they could be used to estimate some of the regional environmental effects of land use/travel network alternatives. For example, a coupling of land use, travel, and box models of this sort could compare estimates of the pollution consequences of high-density transit-dependent alternatives for a region with lower density development patterns that would perhaps increase total vehicle-miles of travel but lower the density of travel. Of course, the travel demand models applied in such an evaluation context would also produce information on other aspects of transportation-system performance to be included in the comprehensive evaluation of such alternatives.

Although the inclusion of environmental concomitants in modeling the first-order impacts of alternative transportation systems at the regional level would be an improvement over current demand modeling and one that would be valuable in providing a more comprehensive network evaluation capability, there are good reasons for researching the possibilities for providing disaggregate measures of environmental impacts as well. Many of the air, water, noise, and visual impacts of transportation facilities have their greatest effects on the population most closely located to the facilities themselves. For example, certain components of air pollution and noise levels generated by transportation facilities depend heavily on link volumes and the design characteristics of the facilities, such as grade, presence or absence of barriers, and density of development in the vicinity of the facility. Noise levels, for example, are also dependent on acceleration and speeds of traffic and the proportion of the vehicle stream that consists of heavy trucks (10). Although not yet operational, several researchers are working toward models that use information on traffic volumes and speeds and information from land use models on development characteristics of an area to derive necessary design characteristics of particular transportation links. The designs would result in the facility meeting some predetermined noise level standards (11). For example, given travel volumes, link speed, and composition of the vehicle stream, it might be estimated that a depressed facility might be needed to meet a standard of a particular noise intensity at a particular distance from the freeway in an area of single-family homes. This type of modeling is a logical extension of noise-impact research already performed and could provide additional information to the planner for estimating the cost-benefit relations for alternative systems. Similar opportunities exist for the analysis of other environmental concomitants of transportation facilities.

Potential for Goal-Seeking Planning Models Within Environmental Constraints

For the past 100 years American economic and political history has largely reflected an orientation toward growth. In almost every dimension of public policy-making at the national and regional levels, it has been assumed that there would be a continuing high level of population growth and economic and physical expansion in human activities. In every sector of public policy-making, emphasis has been on the accommodation of growth, and rarely were alternatives of limited or controlled growth ever considered.

Urban and regional land use and transportation planning have not been exceptions to the general rule of growth orientation. The modeling processes associated with land use and transportation planning have essentially treated forecasts of growth in population and economic activity as exogenous to planning and management. These forecasts have been taken to be the starting points for a planning process that basically consists of the application of mathematical methods to the evaluation of alternative means for the accommodation of projected growth within an acceptable range of system performance.

Recently, however, concern for environmental quality and the perception that zero-population growth might become a reality have lead to a shift in thinking. It is now becoming more common for public policy-makers to consider limited-growth alternatives, especially in program areas where the first-order environmental impacts of continued high rates of growth are seen as leading to environmental degradation. Regional land use and transportation planning is one sector in which limited-growth alternatives are now viewed as desirable in order to impose less of a burden on natural resources such as surface and ground water, open space, and air quality. Because data collection, analysis, and modeling methods used in urban planning have been based on assumptions of accommodation to growth, these current technical components of planning may require modification in order to be applied to the analysis of alternatives that include strategies for limited growth.

I believe that many of the functional relations captured by land use and transportation models are valid and that the manner in which such models are employed might be modified to incorporate environmental quality objectives in the planning process from the very beginning. This kind of a planning process, shown in Figure 2, would build on existing modeling capabilities, but would not employ the models simply to accommodate all forecast growth in population, economic activity, and travel. For example, current knowledge about vehicular emissions and federal air quality standards might be combined with knowledge about a region's meteorological conditions to produce estimates of the maximum amount of travel that could be permitted in the region if air quality were kept within the recommended levels. Next, existing models that relate travel to levels of economic activity could be used, with some necessary but tractable modifications, to derive tolerable levels of economic activity. Models that relate population and economic activity and that are currently in wide use could, in turn, be employed for the region to estimate total population growth limits that would be consistent with the levels of travel allowed by the air quality standards. Notice that, while retaining the functional relations among population, economic activity, and travel of the current models, the proposed approach reverses the role of predicted and predictor variables. In effect, it amounts conceptually to running some of the models backward; instead of proceeding from forecast growth to environmental impacts, the process being proposed begins with environmental standards and environmental "holding capacity" and derives a desirable upper limit on travel and, in turn, on economic activity and population.

One step toward dealing more effectively with first-order environmental impacts in such a "backward-seeking" or goal-directed manner is the development of network generation or design models as part of the demand-model package. Such models have been proposed and formulated in rudimentary form for the purpose of searching among the huge number of possible transportation-network alternatives for those that have the greatest potential for further elaboration and more detailed evaluation. These models may employ optimization techniques as a search method, using such system inputs as cost in the role of the objective function and possibly using information on high-valued resources as constraints. They provide a starting point for the selection of transportation-network designs that satisfy a set of constraints related to such first-order environmental impacts as air quality within the planning region. Network design models and the potential that they have for parametric analysis will also help to shed greater light on the sensitivity of the process of selection among alternative networks to variations in the valuation of the required inputs, such as land. Although such models already exist and are in the process of being refined (12, 13), more research is required to make them operational in actual planning situations and to link them more effectively with variables not incorporated in the more traditional forms of travel demand models.

Repro-Modeling: A Short-Range Option

If effective linkages are to be achieved between transportation demand models and impact-estimation models such as those for air quality and noise, careful attention will have to be given to the data requirements and computational burdens that are imposed by such modeling efforts.

The box model introduced earlier was extremely simplistic; many pollution-dispersion models in use today are a great deal more complex, especially those that incorporate representations of the changes in air quality that take place because of photochemical reactions. Indeed, such air quality models may be more complex and more demanding of data than is the entire transportation planning model sequence. It is difficult to imagine, therefore, a combination of the 2 sets of models for routine use by operating planning agencies. The resulting product would simply be too unwieldy and too expensive to operate. Simplified modeling structures are required, and their development should be given high priority.

One way to achieve simplified models that can link travel and impact forecasting in the relatively short run is through the application of repro-modeling (14). Repro-modeling is the use of the existing complex environmental and travel models as sources

Figure 1. Box model for examining air-pollution levels.

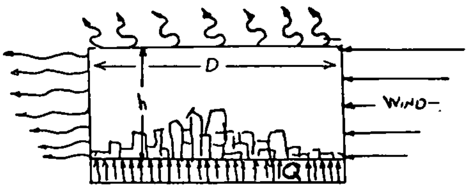

Figure 2. Proposed planning process based on environmental quality standards.

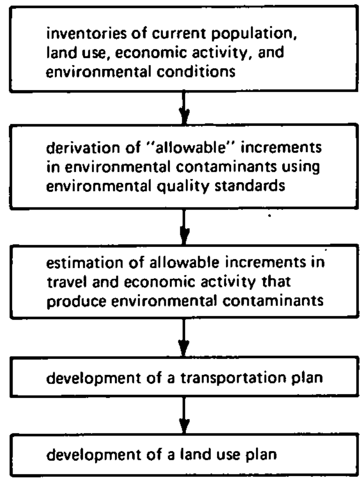

Table 1. Relation of successive orders of impacts and inputs and outputs of transportation system.

Impacts	Transportation System Inputs / Performance Outputs / Concomitant Outputs
First order	Measured as direct changes in inputs or outputs, principally within the transportation system
Second order	Social, economic, and environmental consequences, measured in terms of interrelations between system and environment
Third order	Structural and institutional changes occurring principally in the environment of the transportation system, a few steps removed from the inputs and outputs themselves

Table 2. Examples of impacts resulting from transportation system inputs and outputs.

Impacts	Transportation System Inputs	Performance Outputs	Concomitant Outputs
First order	X acres of land taken in community A for freeway right-of-way	Travel time between community B and public park in community C decreases by 50 percent	Ambient air quality in valley D falls because of 20 percent increase in automobile exhaust emissions
Second order	Property taxes increase by Y percent in community A	Utilization of public park C increases by 25 percent	Respiratory illnesses in valley D increase by 10 percent per year
Third order	Industry in community A decides to expand elsewhere	Citizens in community C organize to exclude nonresidents from using the park	Population of valley D organizes to prevent additional road building in valley

Table 3. Current and potential linkages between travel demand modeling and impact analysis.

Impacts	Transportation System Inputs	Performance Outputs	Concomitant Outputs
First order	2	1	2
Second order	3	3	3
Third order	4	4	4

of data for the construction of simpler operational models that replicate the input-output relations of the more complex modeling set. For example, a complex pollution-dispersion model might be used as a "black box" to generate relations among vehicle speeds, traffic volumes, and various pollutants produced by the internal combustion engine. Next, piece-wise linear relations might be fitted through regression analysis to the most significant input-output relations represented by the complex model set; the complex models could be used to generate the data for the regression runs. For transportation-network planning, the simplified repro-model could be used in place of the complex model, sacrificing detail and theoretical precision for operational models that are computationally feasible. Such reduced models could be developed within a couple of years and appended to the current packaged model sets as a first step toward systematic environmental evaluation of transportation-network alternatives.

Linkages Between Travel Demand Models and Second-Order Impacts

In the previous section, attention was given to current and potential linkages between demand models and the basic measures of system input, performance, and concomitant output. It was shown that, although demand models are already quite directly concerned with the analysis of first-order impacts, there is great potential for broadening the range of first-order impacts that can be considered by using demand models and by using linkages between demand models and other predictive and analytical techniques.

In addition to these first-order impacts, the inputs and outputs of transportation systems interact with the environment of those systems and produce second-order effects that have become increasingly more important to transportation planners and to regional planners. Examples of the second-order impacts include (a) the social reorganization of communities due to the space consumed and social interaction patterns disrupted by the input of land for transportation facilities; (b) the reorganization of land uses in response to changes in physical accessibility due to new facilities; and (c) changes in community health or aesthetics due to such concomitant outputs as pollutants or visual impacts.

It is these second-order impacts that have formed the basis for the body of literature that exists under the heading of "impact studies" and that deal with issues such as changes in land values after freeway construction and suburbanization of residence and industry as a function of transportation network investments. Such impact studies are yielding an increasing level of understanding of the relations between transportation systems and the remainder of the urban environment, but there are several factors that make it difficult to immediately adapt this understanding to modifications in travel demand modeling. First, because the second-order impacts follow (both functionally and temporally) the first-order impacts, which were the subject of the previous section, many of the potential linkages that were described in that section will first have to be established in order to facilitate further efforts at incorporating higher order impacts. Second, additional knowledge of portions of the environment beyond the transportation system will be required in order to establish interrelations with demand models. Third, the institutional arrangements within which transportation planning is carried out tend to limit the planner's capability to deal effectively with the second-order impacts, and this reduces his motivation for establishing direct linkages between them and demand models. Because of these impediments to the immediate joining of second-order impact considerations with demand modeling, I conclude that direct linkages are probably at least a decade away, but that a great deal of learning will result from transportation modeling and research that will be carried on during that period and from knowledge that will be drawn from other fields and applied to transportation systems and their consequences.

The spiral of second-order impacts that result from changes in transportation-system performance is extremely complex and interesting. After 20 years of study, the transportation planner is well aware of the land use changes that take place in the vicinity of freeway access points or rapid transit stations, and documentation exists from dozens of impact studies that have been performed and are now under way. We would like to include such information much more directly in demand modeling, but the task will prove more complex than might appear at first glance.

Recent writings on the concept of "equilibrium" models have emphasized the joint determination of activity patterns and transportation, and the implementation of such models would be a step in the direction of merging second-order performance impacts with demand models (15, 16). In fact, the extent to which these impacts have in the past departed from the land use forecasts on which travel demand models were based is partly an indication of the extent to which the demand models have failed to deal with actual equilibrium conditions. To a certain extent, this shortcoming can be traced to inabilities to produce accurate projections at low levels of aggregation. Thus, our travel models might be based on forecast growth of 10 percent during 20 years in a fairly large subarea, and transportation facilities might be planned and built to accommodate this projected growth. Even if the projected growth level of 10 percent were achieved, impact studies might reveal that the growth took place quite unevenly within the sector, perhaps the vast preponderance in a small proportion of the area that is directly adjacent to the new facility and not much elsewhere. Thus, the models might have achieved a valid prediction of equilibrium at the large scale, but might demonstrate large errors at the level of individual travel zones. This portion of the problem can be addressed by systematic research within the transportation community.

In addition, however, many of the shifts in development that take place in urban areas depend on many factors that go far beyond considerations of accessibility. For example, some forecasts of economic activity for Los Angeles in the 1970s were performed during the 1960s and showed an increasing growth and dominance of the aerospace industries in the region. Of course, that growth has not come about. More precise forecasting models, which are based on more adequately defined notions of equilibrium between transportation and development, could not have resulted in more accurate forecasts of travel demand if the basic estimate of economic activity was grossly in error. Although travel demand models based on equilibrium concepts are theoretically and conceptually superior to the older "sequential-independent" models, they will not necessarily result in more effective travel forecasts or more effective consideration of developmental impacts. Research is required to clarify these issues, for we know relatively little about the sensitivity of alternative systems of demand models to inputs (such as economic-activity estimates) and relatively little about the joint influence of aggregation levels and accuracy of input data. Increased understanding of these phenomena will be required to deal more effectively with such impacts within the processes of travel demand modeling.

As new research results in a greater understanding of the ways in which equilibrium between economic-activity patterns and travel is jointly determined, it would seem possible to merge the concepts underlying equilibrium arguments and the process of building network-generation or design models. For example, we might envision using equilibrium concepts and such environmental constraints as air quality standards to reverse the order that we currently use in forecasting population, economic activity, and travel. We might ultimately begin with a series of constraints representing reasonable environmental standards and use something like the simple box model in order to derive from these constraints an allowable volume of travel in the region. Next, the equilibrium concept might be employed to work backward from this total volume of travel to estimates of "permissible" levels of development in the region and then to allowable economic-activity and population levels that would be in balance with regional travel volumes and environmental constraints. Except at the grossest level, this type of effort would be quite difficult within current understandings of the relations of travel, economic activity, and environmental holding capacity, but the capability to engage in such modeling efforts should be the subject of research during the next decade.

Of course, the extreme fragmentation that exists within most planning regions among agencies that have control over land use and those that have regional transportation planning responsibilities also influences the extent to which the planner can adequately deal with the second-order impacts. Indeed, in many regions transportation planning itself is fragmented by mode and administratively separated from those responsible for implementation. Thus, potential for joint control of spatial patterns of activities and transportation network performance is small in the intermediate future, and this might lessen the motivation for joint consideration of impacts and demand models. We should not let administrative fragmentation and concern for the current limitations on implementing models that deal jointly with movement, land use, and environment deter us from the development of such models. In many other areas (e.g., critical path scheduling, program budgeting) administrative practice and organization have followed the development of new analytical techniques. The development of new modeling capabilities could also contribute to the ultimate reorganization of planning practice to permit a more unified approach.

The second-order impacts of the inputs and concomitant outputs of transportation systems are subjects of a great deal of important and promising research that is already under way and should be continued. For example, in dealing with the social disruption caused by the consumption of space and the barrier effects of transportation facilities, Burkhardt has proposed a neighborhood social interaction index (17) and has shown that the social cohesiveness of communities is generally correlated with several demographic variables that are normally reported in census data and origin-destination survey data. As with the physical environment impacts, the potential exists for merging such social impact indexes into the transportation modeling process. One promising avenue of attack might be the incorporation of such community indexes within network generation and search models that have been referred to earlier. In addition to physical and cost considerations, constraint sets that influence such design procedures might be expanded to include the specification of socially cohesive spatial units in an attempt to minimize the undesirable community disruption caused by facilities. In similar ways, it might be possible to identify areas of high potential impact, such as where illness occurs because of automotive air pollution, based on data such as preexisting ambient air quality, proportion of elderly persons in the population, and local wind conditions, but relatively little is currently known about the relations among these variables beyond observed correlations. For this reason, although a great deal can be learned during the next decade about these relations, the potential for their direct inclusion in demand modeling is small during the short-term future, but greater in the longer term.

Demand-Model Considerations Related to Third-Order Impacts

Third-order impacts have been referred to earlier as relatively long-term social and institutional reorganizations that might result within communities from the inputs and from the performance and concomitant outputs that are related to transportation-system investments. In response to first- and second-order impacts, we are beginning to learn a great deal more about how community leadership changes, how facility location and corporate marketing patterns change, and even how individuals' perceptions of their environment and of the quality of its management change. Although increasing knowledge of these phenomena is of interest to transportation planners and the influences of transportation systems may be among the most important in decision-making in the coming decade, it is not likely that this knowledge can ever yield mathematical statements that can be directly incorporated into demand models.

Techniques, such as sociological field work, and extensive case studies are beginning to yield fairly reliable and systematic information on the effects of transportation on community power structures, leadership, and the processes of information and influence in decision-making. This information, however, is often of such generality that it cannot constitute the specific inputs and outputs of demand models. After all, demand models do still deal with fairly well-defined concepts of system performance, and the concepts of system performance that are relevant at the level of third-order impacts are much less specific and less subject to measurement or operational definition.

There are some important conclusions about the role of demand modeling in decision-making and about the political-administrative environment within which modeling takes place to be reached from a greater understanding of third-order effects. For example, case studies of transportation planning in the Boston region have shown that a third-order impact of transportation planning activities there, given the particular characteristics of that environment, was to raise transportation planning concerns to the level of major statewide political concern and to the status of major election issues (1). Within this context, the use of the projections produced by demand modelers seemed quite irrelevant, and the planner's technocratic adherence to the narrow measures of performance defined by his models clearly placed him at a disadvantage in arguing his case in the political arena. Such studies, then, have emphasized the importance of broadening demand-modeling concerns to include the systematic consideration of inputs and concomitant outputs as well as the traditional performance outputs in analyses and projections and to include, as far as possible, second-order impacts as well as immediately measurable first-order effects.

We may conclude, therefore, that research on the relation of demand modeling to the planning process and to political decision-making is relevant to the modeling community because it helps to define, although sometimes in very painful ways, what performance requirements should be set for the models and what kinds of information the models can and cannot provide in decision situations.

Relation of Demand Models to Decision-Making Frameworks and Rules

It is important to emphasize that demand models are not an end in themselves, but rather they are tools that are used in the production of information that is then employed in the evaluation of alternative network proposals. It is important, therefore, to relate the demand models themselves to the techniques or methods of evaluation that will be employed in the comparison of alternative transportation systems in the future. Although our evaluation framework should strongly influence the nature of demand models by specifying the types of information that those models are called on to produce, it is also true that the flexibility and effectiveness of demand models will strongly influence our approach to evaluation.

Historically, the evaluation of alternative transportation systems has been based largely on engineering-economic principles. This was reflected in the evaluation criteria of the Chicago Area Transportation Study, which in the early 1960s evaluated alternative networks by seeking the one that provided "least total transportation cost" per vehicle-mile (18). A similar rationale led to extensive use of benefit-cost comparisons in many regional transportation studies. In part, the need to produce monetary estimates of the impacts of transportation systems in order to use such evaluation frameworks may have limited the range of system performance and impact measures that have been incorporated into demand modeling. More recently, however, many planners have argued for newer evaluation frameworks that are more flexible than the foregoing decision rules. Thus, subjective-scoring and linear-weighting techniques (19), the "goals-achievement" matrix (20), and other systematic, though subjective, evaluation approaches have been proposed. The cost-effectiveness framework for evaluation has been used to emphasize the capability for reaching rational decisions while including some criteria for which dollar values may be derived plus other criteria that are difficult to translate into dollar terms (2, Chs. 8 and 10). These alternative evaluation frameworks should be of great interest to those principally concerned with demand models because of the close linkage between demand modeling and system evaluation. Enough is now known about the alternative evaluation approaches that research and experimentation could be carried out with the goal of determining their relative utility in current transportation-system applications.

Earlier, it was suggested that additional impact measures should appropriately be incorporated into the processes of demand modeling and that some dimensions for the broadening of the variable set included in demand modeling are within the current state of the art. We might ask whether these new variables (e.g., the differential accessibility to opportunities provided to different population groups) would more easily be incorporated into system evaluation under one decision framework or another. Can dollar values appropriately be placed on a wider range of impacts for use within the benefit-cost framework, or would the consideration of new variables best be achieved with more subjectively based evaluation techniques? Do the alternative evaluation approaches result in similar or widely different sensitivity to input variables, and can the requirements of these techniques be used in the specification of needed levels of accuracy and aggregation in demand models? In addition, we might turn the process around and prescribe changes in evaluation methods based on the range of variables, levels of aggregation, and precision of estimates that can be produced by an expanded set of demand models. I believe that each of these questions can be addressed through research and experimentation that are currently feasible and that would yield a relatively high payoff to transportation planners.

A particular area of current interest is the use of interactive computer techniques for the efficient combination of the analytical capabilities of computerized network models and the subjective judgment of the analyst or planner. Several partial models have been developed that have potential for expansion and wider application in the evaluation of network alternatives. One of the serious problems that currently exist is the large amount of computer core required for the software associated with the interactive evaluation system itself and the large demands that complex sets of travel demand models also place on most computer installations. For example, the INTUVAL system developed at UCLA (21) is capable of rating as many as 10 alternative alignments for a particular route on as many as 10 dimensions of evaluation, but it uses so much of the computer's capacity and requires so much computer time to operate that only a single and exceedingly simple representation of travel demand may be employed. Even with limited computer capabilities it is possible to use such interactive methods in fairly broad screenings of alternatives in much the manner that network generation and search models are proposed to be used. Interactive capabilities also cause us to raise questions about how much fine-grained detail is really required for network evaluation and whether a more effective evaluation tool might be one that allows the comparison of many alternatives according to a large number of dimensions, but perhaps with much less precision than current demand models. This argument is especially attractive to those who feel that the precision of current demand models is far greater than their accuracy.

RECOMMENDED RESEARCH DIRECTIONS

In previous sections mention was made of a number of possible research directions that, if followed, might result in modifications to the demand-modeling process and make that process more capable of producing realistic estimates of the social, economic, and environmental impacts of transportation facilities. In this section I make these recommendations more explicit by listing several research directions that can be pursued in short and intermediate time frames. This listing represents only a starting point because it consists of my personal priorities and expectations. The short-term proposals are for 1 to 3 years, and the longer term proposals are for 3 to 10 years.

Short-Term Proposals

1. Transportation demand modeling should be supplemented by estimates of the extent to which new network configurations would influence the accessibility to opportunities (jobs, services, recreation) of specific population groups (poor, aged, carless). This can be accomplished in the short run by simply measuring the changes in distributions of trip opportunities by time and cost as a result of alternative network configura-

tions. The provision of opportunities through new linkages between population subgroups and potential trip ends should be recognized as a transportation planning objective that goes beyond the matching of supply to manifest demand.

2. Demand models should be extended so that estimates of link volumes and speeds can be supplemented by existing knowledge of noise attenuation to produce estimates of noise exposure at any point within the corridor. Highly precise estimates are probably not required for transportation planning purposes.

3. Efforts should be made to link regional air quality estimates to transportation-network characteristics. For macro- or regional-level and for system-level transportation planning, estimates of sufficient precision can be produced within a short time horizon by employing repro-modeling on existing air pollution concentration and dispersion models.

Longer Term Proposals

1. More definitive study should be conducted relating transportation-system parameters to air quality at the local as well as regional scale. Although a great deal is being learned about air quality, and the transportation system is the major source of contaminants in most regions, transportation modeling and air pollution modeling have remained functionally independent. Specific research efforts are required to link these so that transportation-system planning can be carried out within environmental-quality objectives. Recent research in network-generation models constitutes a useful starting point for the ultimate development of models that search among alternative transportation-activity patterns for those that meet environmental as well as cost constraints.

2. Research should continue on the development of disaggregated models of travel at the levels of individuals and households. Such models have potential for enabling the transportation planner to make more effective estimates of social impacts of transportation projects by enabling him to trace out the behavioral outcomes of transportation-network changes. Basic behavioral research is still needed on the processes by which individuals decide between transportation alternatives as travelers and how they relate to transportation facilities as components of the total urban environment. Attitudinal studies of the past decade have yielded some useful results, but basic theoretical frameworks are still absent. This absence limits our ability to incorporate the findings into demand modeling or impact modeling in a predictive rather than analytical manner.

3. There has already been a great deal of research on the second-order impacts of transportation investments. Impact studies are continuing and contribute increases in understanding of the relations between transportation and economic-activity patterns, land values, and timing of development. A major research effort is now warranted to collect and collate the results of scores of impact studies already completed and under way and to generalize from the various efforts. The richness of empirical data from numerous before-and-after studies should be employed in a new round of theory building. The ultimate payoff will be in the construction of models that more effectively represent the dynamic interdependencies between transportation networks and urban development trajectories.

4. Research is required on new decision-making frameworks that would enable the planner to evaluate alternative network proposals in multidimensional decision spaces. Benefit-cost and subjective-weighting schemes limit our abilities to effectively distinguish between alternative networks and to incorporate our knowledge of social and environmental impacts with the transportation-performance consequences of choices among alternatives.

5. Efforts should continue to develop computer-graphics and other interactive settings for the quick screening of alternative transportation-network proposals in terms of their social, economic, and environmental consequences and to allow implementation of new decision-making frameworks.

6. Additional research is required on the relations between the political processes

in transportation decision-making and the technical and analytical processes involved in demand modeling as well as impact modeling. At times, it appears that the results of the technical analyses carry too little weight in the making of political decisions, but the reverse may also be true. Research by social scientists on the nature of the decision-making process and the role of the technical processes could help establish more realistic performance specifications for demand modeling and impact analysis.

CONCLUSIONS

Urban planners and modelers in general have a natural tendency to propose, at the drop of a hat, that any currently identified shortcomings in their models can be eliminated within one decade if they are only given enough encouragement, cooperation, and money. I have avoided making assertions of this type with respect to the potential for making travel demand models more consistent with our current perceptions of needed improvements related to the treatment of the social, economic, and environmental impacts of transportation. I have tried hard to be realistic and have not suggested that all of the complexities associated with impact issues can be or should be addressed through demand modeling. I am optimistic, however, that significant improvements in demand modeling can be made in the years to come and that those improvements will make them more responsive to impact considerations. In areas where the models themselves probably will not be responsive, I have suggested that we can still learn a great deal by considering alternative evaluation frameworks within which demand models can be used and by considering new institutional arrangements within which modeling and other parts of the planning process might take place.

In summary, it appears that the most immediate impact issues that might be addressed through demand models relate to the measurement and prediction of network performance provided to particular subpopulations defined by socioeconomic, demographic, and spatial characteristics. There is evidence that the gaps in service provided to different groups are significant and that relatively little modification in current modeling practice could help us to plan more effectively toward the elimination of gross inequalities. It also seems that steps could be taken to deal more effectively with the interrelations between network and link characteristics and immediate concomitants of transportation service such as air pollution and noise at both regional and neighborhood levels. In the somewhat longer term, it would appear that demand models could more effectively be linked with measures of intrusion into established social and behavior patterns at the community level. In addition, attempts should be made to develop operational network-generation and screening models to supplement demand models in the development of strategies for avoiding extreme negative impacts on communities or the taking of properties of high social and symbolic value. I have also suggested that, although it is not likely that third-order impacts such as political struggles and community leadership changes could ever be incorporated into demand modeling, these issues should be studied for clues as to the appropriate focuses and roles that demand modelers should seek to meet with their efforts. In addition, it is important to match demand models with the new and emerging evaluation frameworks because system evaluation requirements will help to dictate the scope and form of the information sought from the models.

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Workshop 5

TRAVEL BEHAVIOR

OBJECTIVES

Identify the current extent of theoretical and empirical knowledge of travel behavior and the travel decision process.

Identify gaps in current knowledge and specify steps that may be taken to fill them.

Identify the means by which an improved understanding of travel behavior may be used in the formulation of improved travel demand forecasting models.

Develop a recommended program of research in travel behavior.

EXAMPLES

Travel behavior relates to descriptions and understanding of how and in response to what travelers behave. A considerable body of theoretical and empirical knowledge or belief on the subject already exists. For example, one economic theory of travel behavior considers most travel to be an intermediate good that must be consumed at some monetary and psychological cost to the traveler in order to derive equal or greater benefits in kind from activities indulged in at the trip destination. The response of travelers to travel cost and destination opportunity "choices" (considered as a package) will vary depending on the characteristics of the behavioral units. Definition of the attributes of the choices in terms of appropriate transportation system costs and destination opportunities and a definition of appropriate behavioral units are yet to be made. Empirical descriptions of travel behavior are, of course, extensive. Current inductive empirical understanding of travel behavior derives from a varied set of sources. The sources range, for example, from observations on some sequence of the travel decision process to holistic models calibrated with relatively complete data sets describing travel behavior as a set of simultaneous decisions.

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Report

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Workshop 5 identified 11 major topics for future research: information dissemination; definition, measurement, and treatment of attributes of transportation service; behavior response to low-capital options; activity patterns and destination choice; comparison of attitudinal and conventional forecasting techniques; travel decision-making process; behavior of special user groups; monitoring travel behavior; simultaneous estimation of service and demand; evaluation of alternative marketing strategies; and problems of aggregation and scale in travel analysis.

THEMES OF PROPOSED RESEARCH

Considerable emphasis was placed on the need to develop a more coherent understanding of travel behavior from a variety of specialized perspectives. Emphasis was placed particularly on developing a better understanding of the potential impact of low-capital options, i.e., options involving relatively small levels of capital expenditure and dealing mainly with incremental changes in the service, supply, pricing, or marketing characteristics of existing transportation systems. Typical examples are the behavioral response to car-pool schemes, priority transit schemes, parking and gasoline taxes, enhanced security provisions, improved vehicle design, alternative marketing strategies, short-range scheduling and service modifications, and marginal pricing changes.

In a parallel vein, emphasis was also placed on the need to address more specifically the behavior and requirements of special user groups, whose needs differ significantly from the norm and who are either ignored in current demand forecasting analyses or simply lumped together with the rest of the population. Particular stress was placed on those segments of the population whose behavior and use of existing systems are subject to identifiable constraints. In both instances, the emphasis is on the analysis of behavior at a highly disaggregate, specialized rather than a generic level, at least in the early stages of investigation.

There was considerable debate concerning the role that attitudinal analysis techniques may usefully play in the development of an improved understanding of travel behavior. The interest of the workshop members in this general topic is reflected primarily in 2 recommended research projects.

The first of these focuses on the need for a clearer identification of the salient attributes of transportation service including the methods to be used in characterizing and measuring them and the mechanisms whereby they may be incorporated in either attitudinal or conventional model structures. Particular concern was expressed in this regard with respect to the definition of system-specific and system-common attributes, the stability and transitivity of user perceptions and attitudes toward alternative attributes, and the problems of extrapolating attitudes concerning existing systems to the analysis of new systems.

The second focuses on a comparison of the efficacy of attitudinal versus conventional techniques when applied to a single (or several) common test cases. Emphasis was placed in this latter case on a careful, comparative analysis of the viability of attitudinal versus conventional techniques, on an analysis of their relative cost and utility, and on an identification of those areas where each may be most appropriately applied in an operational context.

The message in this case is simple: There is a well-developed body of analytical techniques derived mainly from the fields of market and consumer research that appear to be highly appropriate to certain forms of travel behavior research. To date, its use has been explored only to a limited degree. It appears worthy of much closer examination.

One of the most common pleas of the behavioral analyst is for more and better data. At the present time we are virtually ignoring one important source of such information, and that is the successive changes that are continually being implemented in transportation systems throughout the country. The problem is partly that we simply lack the appropriate mechanisms for collecting such data and partly that the necessary financial support is usually not forthcoming. It was proposed, therefore, that a systematic program be developed for monitoring the impact of both long- and short-run behavior of selected changes in transportation service, based on a sample of case studies of existing systems. The interest here was to capture information on operational changes in existing transportation services rather than to set up a set of explicit demonstration experiments. Particular emphasis was placed on the types of low-capital options discussed above.

Finally, it was argued that existing information on the travel decision process is extremely fragmentary, partly because of the diffuse and uncorrelated nature of much existing research. To overcome the problem and to provide an effective, concentrated nucleus of research that might then serve as an effective foundation for the development of improved, more responsive demand forecasting models, Workshop 5 recommended that a comprehensive program of basic research be undertaken in the mechanisms underlying the travel decision-making process. This program should focus particularly on issues such as

1. Examination of the basic structure of the travel-decision process and its relation to the established activity patterns and identification of characteristics of varying decision units;
2. Development of a coherent, compatible set of behavioral data bases to serve as input to a variety of subsequent forms of analysis;
3. Identification of the sensitivity of travel decision-making to varying service parameters and other "controllable" factors under situations of at least quasi-experimental control;
4. Examination of the interrelations between long- and short-run travel investment decisions and between long- and short-run behavior;
5. Analysis of the interrelations between destination choice and trip purpose on the one hand and route and mode choice and time of travel on the other; and
6. Consideration of potential short- and long-run substitution effects, involving the potential substitution of other forms of communication or interaction for current, physical movement.

The thrust of this recommendation is to guarantee (at least conceptually) that sufficient resources be made available in one time and one place to permit significant inroads to be made in the development of improved behavioral analyses.

The issues raised above flowed only from one of the several workshops at the conference . They serve, however, to illustrate rather well the combination of pragmatic and theoretical concerns that should desirably underlie any successful research program. Some of these former, pragmatic issues are pursued in the remainder of the paper.

APPLICATION OF TRAVEL ANALYSIS RESEARCH

The organization of this conference and the attendance are indicative of the importance attached to research in behavioral travel demand and evaluation of travel time. Yet, the absence of an appropriately funded and managed urban travel analysis research program in the United States suggests that the priority that the conference participants associate with research in this area is not shared by decision-makers who are in a position to implement such a program. In this context, it is perhaps useful to consider the justification for an urban travel analysis research program and the contribution that such a program could make to the achievement of national goals, as these are perceived by decision-makers.

During the past 10 years, the preponderance of the urban travel analysis research effort has been focused on regional planning analyses characterized by relatively coarse representations of the various urban transportation modes and relatively long forecast periods of 15 years and more. The focus of research activity on these types of problems is understandable in the context of the urban transportation planning process as it was evolved by the Federal Highway Administration.

National urban transportation policy for the 1970s is, however, clearly focused on the development of an effective urban public transportation program for American cities. This focus is based on the belief that the environmental, social, and economic benefits of such a program are such that the general community should contribute to its development and support. In other words, the rationale for developing an effective urban public transportation program stems from its contribution to the overall development of the community's objectives, not solely from a profit motive. Within this context, the issues of gross system patronage and revenues that are the principal focus of the regional type of analyses are of less interest, whereas other issues—particularly the marketing of public transportation to enhance its ability to penetrate the urban travel market as well as environmental concerns—become of paramount importance. Inasmuch as the focus of national interest has shifted from regional-scale analyses to issues associated with public transportation and the environment, there should be a corresponding refocusing of urban travel analysis research activities.

To identify the high-priority urban travel analysis research areas, one must appreciate the important elements of a public transportation marketing program. These include

1. Identification of target markets for public transportation (population segments that represent high potential sources of business;
2. Identification of the features and the stimuli most likely to influence the target markets; and
3. Assignment of priorities in the redesign of the public transportation service product.

Thus, the justification for conducting an urban travel analysis research program is based on the need to more effectively market public transportation. Unless we justify an urban travel analysis research program in this or similar terms, there is a strong danger that urban travel analysis research program proposals will be dismissed as being irrelevant to national goals and merely reflecting the desire of researchers to conduct research in an area that they enjoy. This perspective does provide, however, an opportunity for an even broader urban travel analysis research program than was provided by the requirements of system-level planning analyses. Many urban travel analysis research projects could be defined within this framework of marketing public transportation. Some of the projects that we feel are particularly important at this time include transit station and bus route choice, access mode choice to line-haul systems, automobile car-pooling and increased automobile occupancy, vehicle equipment and terminal design, the passenger's perception of personal security and its role in influencing system patronage, the importance of schedule reliability, and the importance of the image projected by transit operating personnel. All of these research projects should be designed to assess not only the impact of the given factor on the use of public transportation but also the normative issues of what the design of public transportation service should be.

IMPLEMENTATION OF RESEARCH RESULTS

Although the focus of this conference was on the identification of priorities for future research, it is equally important to assess the results of the important research that has already been accomplished to date and the degree to which these research results have been implemented in operational practice. Even if a research program were clearly related to national priorities, the program would not be sustained if the research results were not implemented into operational practice. Nearly 5 years after the work of Lisco and Stopher, behavioral, stochastic, disaggregate models are (with few exceptions) not being employed in operational planning studies and are largely discussed in research rather than operational planning contexts. Although there are certainly aspects of behavioral, stochastic, disaggregate models that do require further research, there is no question that they can be safely used in modal-split and automobile occupancy analyses. The major advantage of using these models include

1. The significant savings in the data required to calibrate models (we estimate that the volume of data required to calibrate a disaggregate model is an order of magnitude smaller than the amount of data required to calibrate an aggregate model);
2. The ability to simultaneously analyze competition among more than 2 modes (which allows for a model that simultaneously considers automobile occupancy and modal choice, defines several alternative transit modes, and allows for several access modes); and
3. The ability to develop meaningful modal choice relations even when the volume of travel by a given mode (e.g., public transportation or intercity rail) is quite small.

Thus, some of the research into behavioral, stochastic, disaggregate models has been completed and is available for implementation in operational planning projects, and there are distinct economic and technical justifications for using these techniques. Why then has the introduction of these techniques into operational planning practice been so limited, and what can be done in the future to encourage more rapid dissemination and implementation of research results? These are difficult issues, and they are not easily analyzed or resolved. Certainly 2 factors that contributed to the slowness with which these techniques have been implemented are (a) the unavailability of a well-documented and efficient computer system and (b) the general unavailability of well-qualified personnel.

If the urban travel analysis research program that has been synthesized in this conference is to have any opportunity to be funded at an appropriate level, it should clearly include major elements relating to the implementation of research results. Projects that we believe would contribute significantly to increasing the probability that these research results would be implemented include

1. A well-documented and efficient computer system for use in conjunction with behavioral, stochastic, disaggregate models (this computer system should include a calibration program, programs to assist in the preparation of a calibration data set, and

programs to effectively apply the calibrated models);

2. Training programs to develop qualified personnel (these should include short courses oriented to current practitioners as well as treatment within the graduate program of universities);

3. A program of demonstration planning projects specifically designed to field test the latest planning techniques—including new urban travel analysis approaches—within an operational planning environment and to demonstrate that these techniques can be effectively used to increase the quality of the transportation planning product; and

4. Effective techniques for applying behavioral, stochastic, disaggregate models (the advantages of using these models are to some extent being diluted because of the manner in which these models are being applied, and new approaches for applying these models are needed that will exploit their advantages during the alternatives evaluation phase of a planning effort).

INSTITUTIONAL CONSIDERATIONS

Implementation of a national urban travel analysis research program and use of advanced travel analysis techniques at the local level require institutional changes at both the federal and the local levels. To argue that the problem of implementing a research program would be solved if only the appropriate funding were available overlooks what may well be a most important aspect of the problem, namely, that the federal government is not currently well organized to manage an urban travel analysis research program.

The urban travel analysis research effort of the U.S. Department of Transportation is fragmented among various groups within the department (Federal Highway Administration, Urban Mass Transportation Administration, and Office of the Secretary) and the National Cooperative Highway Research Program. Further, many of the issues that should be addressed within such a program are of major concern to a number of agencies outside the department, particularly the Environmental Protection Agency and the Department of Housing and Urban Development. Although a significant amount of coordination with respect to urban travel research does take place among these groups, the organization of an effective urban travel analysis research program requires a more developed institutional structure.

Thus, we see a need within the federal structure for an institution that funds and manages a multimodal urban travel analysis research effort. This institution should clearly be designed to avoid even the suspicion of having a modal bias and, for this reason, should not be lodged in either the Federal Highway Administration or the Urban Mass Transportation Administration. Although multimodal research and policy studies related to urban travel analysis might be directly funded and managed by this new institution, this would not preclude the conduct of more mission-oriented urban travel analysis research efforts within the modal agencies. For example, the Urban Mass Transportation Administration might continue research projects specifically oriented to the problems of the transit industry such as the impact of the traveler's perceived security on his attitude toward public transit. For those projects continued within the operating administrations, this new institution would serve as a formal coordinating point rather than as the program manager. Given the very applied nature of an urban travel analysis research program, it would appear desirable that the institution be placed within an operating department—probably the Department of Transportation—and not lodged in a more research-oriented environment where the perspective of the application of the research may be lost.

A different type of institutional problem is currently evident at the local level. Inasmuch as anyone can call himself or herself a transportation planner, there is considerable variance in the quality of transportation planning activity throughout the country. One consequence of the relatively small amount of poor-quality work is to cast an aspersion on all work conducted in this area because of the analyses conducted by a relatively few. As other professions have matured, they have recognized the requirement to establish standards of practice regarding the methodology of their profession and how this methodology is applied in specific instances. Further, they have recognized the need to license or certify professionals in their areas of practice and to maintain the structure to enforce a high standard of practice with the ultimate sanction being withdrawal of certification. Lawyers, doctors, certified public accountants, architects, and structural engineers have recognized the need to establish a professional level of practice. It is interesting to note that the Operations Research Society of America has also begun to explore how it can establish a professional standard of practice for that profession. Given the difficulties associated with establishing a professional standard of practice for the transportation planning profession, perhaps the time has arrived when the first steps in this direction should be initiated.

Resource Paper on the Transportation Disadvantaged

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Increasing dependence on the automobile as a means of personal transportation, rapidly spreading urban centers, and declining intercity public transportation systems have resulted in decreased mobility for many people in urban environments. This problem first received national attention in the wake of the 1965 riots in Los Angeles and Watts when the connection between transportation and poverty was made explicit in the McCone report (1).

Several transportation demonstration projects were subsequently established by the Urban Mass Transportation Administration to bus ghetto residents to suburban jobs. Planned quickly, these demonstrations relied heavily on assumptions about travel demand and other related factors that had been useful in designing highways and CBD transit systems. Evaluation of 6 years of demonstration-project operations yielded some surprises and caused planners to question their initial planning assumptions. Some of the major differences are summarized here.

TRIP ORIGINS

Planners assumed initially that the disadvantaged were concentrated in small, residential "pockets," by and large in the inner city, and the early demonstration projects were designed accordingly. It is now clear that this assumption is not justified, even for ghetto residents. In Boston, for example, many riders of demonstration-project buses reported that they spent more than 15 minutes traveling from their homes to the bus stop (2). In Nassau and Suffolk counties on Long Island, planners observed that "low-income households [are] spread throughout the counties in very small concentrations. These concentrations are usually in remote areas that have inadequate or nonexistent bus service" (3). The assumption of concentrated origins breaks down entirely, of course, in low-density areas, where the origins of non-car-owning poor are very nearly as dispersed as those of car owners (4).

TRIP DESTINATION AND PURPOSE

The dispersed destinations of the disadvantaged have been recognized for some time at least as far as the journey to work is concerned. In response to the dramatic increase in suburban industrial jobs in recent years (5), the bus demonstration projects attempted to serve as many of these locations as possible within financial and time constraints. The poor with work experience were quick to respond to these transportation improvements. For example, in a 46-person ridership survey of the Roxbury-Route 128 Express in Boston, 80 percent of the riders had some vocational training and their skill levels were generally high (2).

However, planners failed to recognize that the people whose mobility they were trying to increase were frequently not qualified for the jobs available. In Watts, for example, an employment drive referred only 15 percent of the 9,400 applicants to jobs and actually placed less than 6 percent (6). Planners subsequently recognized that the jobs that are available to the "hard-core" unemployed commonly involve long hours, weekend or evening shifts, no opportunities for advancement, poor pay, and other undesirable conditions. Low wages are such an important factor in deterring the poor from employment that Nassau-Suffolk planners concluded that "low-income persons cannot afford to accept jobs that pay a minimum wage.... After paying union dues, wage deductions, and transportation costs, their net pay is not enough to live on (3).

The dispersion of trip destinations among the poor for purposes other than work has also not been widely recognized. A surprisingly high proportion of demonstration bus riders were destined for some place other than employment. Ridership surveys of bus systems that have served suburban commercial and recreational areas as well as industrial job sites indicate the importance the poor attach to nonwork trips. In Washington and Minneapolis-St. Paul, for example, the proportion of nonwork riders often approached 20 percent (7). The importance of nonwork trips is especially significant for the large percentage of nonworking poor—the elderly, the young, and the low-income housewives.

MODE CHOICE

Demonstration-project planners initially assumed little or no car availability among the poor although, in fact, many poor do have cars available for some portions of their trips.

Limited information available about car pooling suggests that it accounts for a large proportion of the automobile trips taken by the poor, particularly the work trip. On Long Island, for example, surveys showed that only 32 percent of the riders used the demonstration-project buses for the round trip. This indicates that the remainder, some 68 percent, had some other form of transportation available (8). It is likely that this was some form of car pooling or ride sharing.

Poor car owners, however, are distinct from middle-class car owners because of a number of problems associated with automobile use. First, their cars are often unreliable. Research with the Watts demonstration project suggests that perhaps as many as 20 percent of the vehicles used by the poor are not reliable enough for the journey to work because of mechanical failure or vandalism problems (slashed tires) in the owner's neighborhood (9): "A number of Watts residents reported that they had actually lost their jobs because their cars were continually breaking down."

The evaluation of these demonstration projects and subsequent research on the problems of urban mobility raised some questions but left others unanswered. Thus, the Federal Highway Administration initiated a research project, which was conducted by Abt Associates, to identify the urban transportation disadvantaged, assess their travel demands, and determine the impact of inadequate transportation on their employment status and quality of life.

DEFINITION OF TRANSPORTATION DISADVANTAGED

The assessment of the travel demand of transportation-disadvantaged groups required a definition of the transportation disadvantaged. Previous research and demonstration programs have defined the disadvantaged in terms of income and assumed that improvements in the transportation system would improve the mobility of poverty-level households—largely helping them to gain better access to badly needed employment and social service opportunities. Income obviously is related to travel demand, the best understood relation being that between income and automobile ownership. The effect of income on the ability of the traveler to participate in the activity at the trip's end is also important. In fact, were the transportation system perfect and were there no other constraints on mobility, trip generation could probably be explained entirely by income.

But the transportation system is not perfect, and factors other than income constrain mobility. In fact, it is these other factors and their relation to the transportation system—not income—that the transportation planner has some influence over. Thus, to identify which system improvements increase the mobility of the disadvantaged and to evaluate their effectiveness, the planner must define disadvantaged in terms of travel behavior. An individual (or group) is transportation disadvantaged, then, if he takes significantly fewer trips, for any purpose, or has significantly longer travel times than would be expected for his income.

RESEARCH METHODOLOGY

The research began with a review of the literature that identified the characteristics that have been used to define transportation-disadvantaged groups; these included income, age, automobile ownership, automobile reliability, race, family size, and residential location. Because the literature generally focuses on only a few of these descriptors at once, a more systematic approach was taken to identify new groups.

Guttman scale analysis was chosen for this purpose. This scaling technique tests whether a given population can be ranked on a single dimension by the presence or absence of several characteristics thought to be related to that dimension, in this case, transportation disadvantage. Trip frequency and trip time were chosen as the criteria for ordering individual travelers on this scale, and 15 descriptors from the literature and a large data base for metropolitan Washington were used to construct them. Although no single scale including all of the descriptors turned out to be completely satisfactory, several descriptors repeatedly appeared together, in the same order, in most of the scales. These were

1. Number of cars (0, 1, or more);
2. Year of best car (older than 1965, 1965, or newer);
3. Trip time from home to work (less than 30 minutes, 30 minutes, or more);
4. Age (under 65, 65, or older);
5. Trip time for social-recreational purposes (less than 15 minutes, 15 minutes, or more);
6. Number of children under 5 (fewer than 2, 2, or more); and
7. Income (less than $4,000, $4,000, or more).

An analysis of the trip frequencies of persons in households having these characteristics, as well as those identified by the literature, was undertaken by using the data base from the Nationwide Personal Transportation Survey of 1969-70. Four income groups were defined, and descriptors were ranked (within each income category) according to the number of nonwork trips associated with each. Three traits—not owning a car, being elderly, and being nonwhite—appeared in the transportation-disadvantaged groupings consistently across all income categories. The inclusion of race as a descriptor of the transportation disadvantaged contradicts the results of the Guttman scale analysis but was consistent with the literature. Also appearing as transportation disadvantaged were persons in large households having only 1 car and persons in both large and small households having 1 old car—1965 or earlier.

These 3 approaches—the literature review, Guttman scale analysis, and analysis of the data from the Nationwide Personal Transportation Survey—identified 5 groups of transportation disadvantaged for further study: members of carless households, members of car-deficient households, elderly, nonwhites, and owners of old cars.

A detailed analysis of the travel behavior of these 5 groups was made by using data from the household interviews of the Nationwide Personal Transportation Survey and data from surveys taken in 3 types of urban areas: Washington, D.C., central core (10); San Antonio, Texas, sprawl (11); and Greensboro, North Carolina, growth center (12). Households were classified by income, which was held constant in comparisons of the travel behavior of groups defined as advantaged and disadvantaged. This control made it possible to examine the effects on the transportation disadvantaged of characteristics other than income—characteristics that would otherwise be "swamped" by evidence of the well-known and powerful relation between trip generation and income. The 4 income levels are given below. Findings about the travel behavior of each of these 5 groups are summarized in the following sections:

Level	Dollars
Poverty	Under 4,000
Low	4,000 to 6,000
Middle	6,000 to 10,000
High	Over 10,000

MEMBERS OF CARLESS HOUSEHOLDS

Data from the Nationwide Personal Transportation Survey indicate that approximately 15 percent of all SMSA residents live in households with no automobiles available. Based on a total SMSA population of 139 million, as determined by the census of 1970, this would suggest a carless population of approximately 21 million persons. About 80 percent or 16.8 million of those carless persons live in the central city, and the remaining 20 percent live in outlying suburban areas.

Taken as a whole, members of carless households throughout the nation seem to take about 1 trip less per person per day than do people with the same income with 1 car. The difference in the total number of trips generated is much greater between 0- and 1-car households than between 1- and 2-car households. The difference is largely in the number of nonwork trips taken (Table 1). In the poverty and low-income categories, ownership of a car increases shopping trips more than trips for any other purpose. However, in the middle- and high-income groups, a car seems to have greater influence on social-recreational trip generation.

The mode choices of carless household members give some indication of how members of this disadvantaged group have accommodated themselves to their carlessness. Table 2 gives the percentage of all trips taken by automobile-driver, automobile-passenger, and public transportation modes for members of large and small households in the poverty, low-income, and middle-income groups. The accommodations vary according to the income of the traveler. Members of poverty households depend extensively on public transportation, especially when the household is large, but also borrow cars and share rides when possible. As incomes rise, there is more and more ride sharing, less use of public transportation, and continued car borrowing. At the middle-income level, the strongest tendency of the carless is to share a ride with someone else, and the use of both public transportation and borrowed cars decreases.

In sum, carlessness is associated with reduced participation in some essential but many potential rewarding activities and with inconvenience when these activities are pursued. The extent of ride sharing and car borrowing suggests that efforts to increase the mobility of the carless might focus attention on these accommodations and improve their convenience and reliability.

MEMBERS OF CAR-DEFICIENT HOUSEHOLDS

The Nationwide Personal Transportation Survey indicates that about 23 percent of the SMSA population or some 32 million persons live in households that are car deficient; that is, they have 4 or more members and only 1 car. Forty percent or 12.8 million of these persons live inside the central city, and the remaining 19.2 million live in the suburbs.

Data given in Table 3 do not show a consistent pattern of constrained travel by members of car-deficient households. However, persons in households that are car deficient and have adequate car availability take approximately 0.10 fewer trips daily than persons in households with adequate car availability.

Mode-choice data for car-deficient households indicate that the car is used intensively for all trip purposes. If the car is not available for the trip, different solutions emerge, depending on the income of the household. Data given in Table 4 show that, in general, about 40 percent of all work, shopping, and social-recreational trips are taken as automobile-driver trips, and the remainder of the trips are divided among automobile-passenger, public transportation, and other modes (generally taxi). With few exceptions, only a small percentage of all trips are by public transportation. However, public transportation is used as much as ride sharing or car pooling in the poverty and low-income groups, but the preferred mode is clearly the automobile in the middle- and high-income groups.

THE ELDERLY

The census of population for 1970 reports that there are 12.8 million persons in SMSAs who are 65 years of age or older. Fifty-three percent of them live inside the central city, and 47 percent live in outlying areas. The data given in Table 5 indicate that the decrease in trip generation by the elderly is split evenly between work and nonwork trip purposes. On the average, the elderly take 0.9 fewer nonwork trips per person per day than the nonelderly. In lower income groups, the elderly take only slightly fewer trips for social-recreational, shopping, and personal business purposes; in the higher income categories, these differences are very large.

The mode-choice data given in Table 6 show that the elderly in all income groups take most of their trips by automobile, although they use this mode slightly less than the nonelderly. In the higher income groups, some of the automobile trips by the elderly are diverted to other, unspecified vehicular modes. In general, the elderly are more likely than the nonelderly to be automobile passengers (as opposed to drivers) except that in the low-income group the elderly drive almost as much as the nonelderly. There is somewhat less use of public transportation among the elderly—probably attributable to the physical difficulties associated with this mode. Taxis, on the other hand, are used more extensively, but in higher rather than lower income groups—contrary to findings for other transportation-disadvantaged groups.

The mode choices of the elderly who do travel shed some light on where improvements might be made. The lessened use of public transportation and greater use of taxis, especially among higher income elderly, suggests that removal of physical barriers in transit could make this lower cost mode more accessible to the elderly. In addition, steps might be taken to reduce taxi fares for the elderly—perhaps through institutionalized group riding.

NONWHITES

Data from the 1970 census indicate that there are approximately 18.8 million nonwhites living in SMSAs. Seventy-seven percent of these groups live in central cities, and the remaining 23 percent live in outlying suburban areas.

Data on trip frequency for work and nonwork purposes for whites and nonwhites (Table 7) indicate that trips by nonwhites for nonwork purposes are constrained the

Table 1. Average number of trips per person per day by trip purpose and household income and car ownership.

Purpose	Poverty			Low Income			Middle Income			High Income		
	0 Car	1 Car	2+ Cars	0 Car	1 Car	2+ Cars	0 Car	1 Car	2+ Cars	0 Car	1 Car	2+ Cars
Work	0.19	0.39	0.20	0.38	0.45	0.47	0.41	0.55	0.59	0.53	0.55	0.60
Shopping	0.11	0.46	0.20	0.07	0.37	0.31	0.09	0.43	0.49	0.19	0.41	0.46
Social-recreational	0.27	0.55	0.94	0.22	0.48	0.58	0.19	0.79	0.73	0	0.74	0.76
Personal business	0.12	0.24	0.17	0.13	0.34	0.45	0.14	0.41	0.46	0.07	0.34	0.45
Other	0.78	0.62	0.76	0.72	0.70	0.85	0.89	0.61	0.63	0.66	0.64	0.68
All nonwork trips	1.28	1.87	2.07	1.14	1.89	2.19	1.31	2.24	2.31	0.92	2.13	2.35
All trips	1.47	2.26	2.27	1.52	2.34	2.66	1.72	2.79	2.90	1.45	2.68	2.96

Note: Sample size was 5,302 persons.

Table 2. Percentage of trips of persons in carless households with 1 member employed by trip purpose and mode and household size and income.

Household Size	Purpose	Poverty				Low Income				Middle Income			
		Auto Driver	Auto Pass.	Public Transit	Other	Auto Driver	Auto Pass.	Public Transit	Other	Auto Driver	Auto Pass.	Public Transit	Other
Small (1 to 3)	All trips	14	25	28	33	13	31	19	37	3	40	18	39
	Work	16	24	49	11	14	45	28	13	13	31	44	12
	Shopping	44	0	56	0	29	57	14	0	0	50	50	0
	Social-recreational	0	65	35	0	8	46	38	8	0	89	11	0
Large (4+)	All trips	0	17	39	44	2	29	19	50	17	0	8	75
	Work	0	20	80	0	0	21	71	8	0	0	100	0
	Shopping	0	0	0	100	33	0	67	0	100	0	0	0
	Social-recreational	0	0	100	0	0	85	15	0	100	0	0	0

Note: Sample size was 258 persons.

Table 3. Average number of trips per person per day by trip purpose and household size, income, and car ownership.

Purpose	Poverty		Low Income		Middle Income		High Income	
	4+ Members 1 Car	4- Members* 2 Cars	4+ Members 1 Car	4- Members 2 Cars	4+ Members 1 Car	4- Members 2 Cars	4+ Members 1 Car	4- Members 2 Cars
Work	0.45		0.32	0.77	0.42	0.75	0.44	0.80
Shopping	0.34		0.32	0.63	0.36	0.42	0.34	0.34
Social-recreational	0.63		0.25	0.85	0.65	0.67	0.62	0.71
Personal business	0.18		0.38	0.32	0.33	0.40	0.24	0.49
Other	0.95		0.65	0.62	0.65	0.42	0.73	0.47
All nonwork trips	2.10		1.60	2.42	1.99	1.91	1.93	2.01
All trips	2.55		1.93	3.19	2.41	2.66	2.37	2.81

Note: Sample size was 2,066 persons.

*Too few households to provide reliable data.

Table 4. Percentage of trips of persons in households with 4+ members and 1 car by trip purpose and mode and household income.

Purpose	Poverty				Low Income				Middle Income				High Income			
	Auto Driver	Auto Pass.	Public Transit	Other	Auto Driver	Auto Pass.	Public Transit	Other	Auto Driver	Auto Pass.	Public Transit	Other	Auto Driver	Auto Pass.	Public Transit	Other
All trips	39	54	7	0	60	29	11	0	49	49	2	0	48	45	7	0
Work	67	26	0	7	62	24	14	0	62	31	7	0	53	28	19	0
Shopping	34	66	0	0	39	33	28	0	41	57	2	0	54	42	4	0
Social-recreational	39	61	0	0	54	46	0	0	44	56	0	0	38	61	1	0

Note: Sample size was 1,444 persons.

Table 5. Average number of trips per person per day by trip purpose, household income, and age.

Purpose	Poverty		Low Income		Middle Income		High Income	
	>65	<65	>65	<65	>65	<65	<65	>65
Work	0.11	0.38	0.19	0.48	0.39	0.56	0.37	0.59
Shopping	0.29	0.24	0.27	0.28	0.24	0.42	0.27	0.44
Social-recreational	0.38	0.46	0.41	0.42	0.49	0.72	0.29	0.74
Personal business	0.10	0.22	0.24	0.31	0.24	0.41	0.20	0.41
Other	0.62	0.77	0.52	0.76	1.07	0.63	0.69	0.67
All nonwork trips	1.39	1.69	1.44	1.77	2.04	2.18	1.45	2.26
All trips	1.50	2.07	1.63	2.25	2.43	2.74	1.82	2.85

Note: Sample size was 5,187 persons.

most. Nonwhites throughout the nation take from 0.4 to 0.9 fewer nonwork trips per person per day than do whites; the greatest difference is in the highest income group and the smallest in the poverty group. With respect to trip purpose, nonwhites appear to be most disadvantaged in pursuing social-recreational activities but are also disadvantaged in the frequency with which they shop (in higher income groups) or conduct personal business (in lower income groups).

Nationwide data on mode choice among nonwhites show less use of the automobile (especially as automobile drivers) and greater dependence on public transportation (Table 8). The data indicate further that this may be attributable to lower rates of car ownership, and programs to facilitate car ownership by minority group members could improve mobility.

Members of poverty-level minority groups also depend more on taxis. According to the nationwide survey, 6 percent of their trips are by that mode. The flexibility and low-investment cost of taxi travel give it great potential for improving the mobility of poor nonwhites.

OWNERS OF OLD CARS

The Nationwide Personal Transportation Survey in 1969 and 1970 indicates that at that time approximately 27 percent of the SMSA population had only 1 car, which was a 1965 model or older, that is, about 4 years old. Forty-seven percent of the owners of old cars or 17.2 million persons live in the central city, and 53 percent or 19.8 million live in the suburbs.

Data given in Table 9 show that an owner of 1 old car takes an average of 0.2 fewer trips for all purposes than an owner of 1 new car. The problems of an old car seem to affect social-recreational trips most, but work trips are also constrained. Old-car owners rely more heavily on public transportation for the work trip (Table 10) and on other modes for work and other trips. One can infer that these differences result from the lessened reliability of older cars, and perhaps better automobile maintenance could alleviate these disadvantages.

RECOMMENDATIONS

For the long term, the members of carless and car-deficient households would best be served by federal investment in the development of new transportation systems that have characteristics similar to the private automobile. These systems will respond to the needs of people who do not have ready access to private transportation and who are not able or do not wish to assume the burdens of automobile ownership. However, because of the long lead times required for development and introduction of new systems, several interim measures should be taken to alleviate the inequalities in mobility.

The U.S. Department of Transportation should develop and disseminate guidelines for the organization and operation of car-pool information systems. The information should cover both work and nonwork trips and be distributed through such potential organizers as employers, state employment offices, shopping center managers, churches, charitable organizations, redevelopment and housing authorities, neighborhood action groups, and operators of recreational, health, and social service agencies. Opportunities for federal subsidy—direct or indirect—to car poolers should be identified and developed.

Federal action should be taken to make driver training and licensing programs more widely available, especially to people who do not own cars. Because this would encourage more car borrowing, it should be accompanied by efforts, perhaps toward requiring additional insurance coverage, to reduce the risk to an automobile owner of lending his car.

Data suggest that poverty household members who have no car available would make more use of public transit if it served their residences and trip destinations better. Interim efforts should be made to evaluate the accessibility of transit in poor neighborhoods and improve the level of service (subsidized as necessary) wherever possible.

Table 6. Percentage of trips by trip purpose, household income, and age.

Mode	Poverty		Low Income		Middle Income		High Income	
	>65	<65	>65	<65	>65	<65	<65	>65
Automobile driver	29	32	42	43	45	49	30	52
Automobile passenger	26	27	25	27	22	34	28	32
Public transit	6	11	6	6	1	3	1	3
Taxi	1	0	0	0	1	0	1	0
Other	38	30	27	24	31	14	40	13
All trips	100	100	100	100	100	100	100	100

Note: Sample size was 5,187 persons.

Table 7. Average number of trips per person per day by trip purpose, household income, and race.

Purpose	Poverty		Low Income		Middle Income		High Income	
	Nonwhite	White	Nonwhite	White	Nonwhite	White	Nonwhite	White
Work	0.28	0.26	0.39	0.45	0.55	0.55	0.52	0.58
Shopping	0.21	0.28	0.17	0.31	0.28	0.44	0.11	0.46
Social-recreational	0.22	0.51	0.20	0.49	0.32	0.77	0.46	0.76
Personal business	0.14	0.18	0.05	0.38	0.31	0.41	0.21	0.42
Other	0.74	0.70	0.78	0.72	0.75	0.63	0.67	0.67
All nonwork trips	1.31	1.67	1.19	1.90	1.66	2.25	1.45	2.31
All trips	1.59	1.93	1.58	2.35	2.21	2.80	1.97	2.89

Note: Sample size was 5,302 persons.

Table 8. Percentage of trips by trip mode, household income, and race.

Mode	Poverty		Low Income		Middle Income		High Income	
	Nonwhite	White	Nonwhite	White	Nonwhite	White	Nonwhite	White
Automobile driver	16	37	23	48	37	50	45	52
Automobile passenger	24	28	19	29	27	35	21	33
Public transit	17	7	18	3	9	2	10	3
Taxi	1	0	0	0	1	0	1	0
Other	42	28	40	20	26	13	23	12
All trips	100	100	100	100	100	100	100	100

Note: Sample size was 5,302 persons.

Table 9. Average number of trips of persons in households with 1 old or new car by trip purpose and mode.

Purpose	Automobile Driver		Automobile Passenger		Public Transit		Other		All Trips	
	Old Car	New Car	Old Car	New Car	Old Car	New Car	Old Car	New Car	Old Car	New Car
Work	0.31	0.41	0.09	0.11	0.05	0.04	0.01	0.01	0.46	0.57
Shopping	0.23	0.24	0.16	0.18	0.01	0.01	0	0.01	0.40	0.44
Social-recreational	0.32	0.35	0.30	0.39	0.01	0.01	0.01	0.02	0.64	0.77
Personal business	0.22	0.27	0.11	0.09	0	0	0	0.02	0.33	0.38
Other	0.11	0.14	0.12	0.13	0.01	0	0.40	0.35	0.64	0.62
All nonwork trips	0.88	1.00	0.69	0.79	0.03	0.02	0.41	0.40	2.01	2.21
All trips	1.19	1.41	0.78	0.90	0.08	0.06	0.42	0.41	2.47	2.78

Note: Sample size was 1,016 persons.

Table 10. Percentage of trips of persons in households with 1 old or new car by trip purpose and mode.

Purpose	Automobile Driver		Automobile Passenger		Public Transit		Other	
	Old Car	New Car	Old Car	New Car	Old Car	New Car	Old Car	New Car
Work	67	72	19	20	11	7	3	1
Shopping	58	56	40	41	2	2	0	1
Social-recreational	51	45	46	51	1	2	2	2
Personal business	65	69	32	24	2	1	1	6
Other	17	22	19	21	1	2	63	55
All trips	47	50	35	33	3	2	15	15

Note: Sample size was 1,016 persons.

Several other actions would also benefit particular transportation-disadvantaged groups. The extensive use of taxicabs by poor nonwhites suggests expanding the availability of this mode to provide additional demand-responsive service. Investigations should be undertaken on the possiblity of stimulating ownership of taxicabs by minority group members, especially by blacks in ghetto locations. Taxicab transportation could also be brought closer to the financial capabilities of elderly persons. Special fares for shared rides should be considered and tested by taxicab companies. The Federal Highway Administration should evaluate demonstration programs of this type where they are now in operation.

All of these recommendations would benefit owners of old cars. In addition, guidelines for the organization and operation of automobile repair courses should be developed and widely disseminated to potential organizers such as the YMCA and YWCA, local entrepreneurs, and the Small Business Administration.

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Resource Paper on Attitudinal Models

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What is an attitude? This is the first question that must be raised in the development of attitudinal models of travel behavior. It is an important question that has been ignored in the vast majority of the ever-increasing number of research projects that deal explicitly or implicitly with transportation attitudes. It is a question not merely of academic interest but at the very heart of the model-building process. Although this paper will make no attempt to crystallize an answer, it will attempt to place alternate attitude conceptualizations within the perspectives of urban passenger transportation planning and evaluation and to discuss the (2-way) linkages between these conceptualizations and the construct and testing of hypotheses of travel decision-making behavior.

Attitudes in the market research vein are thought of as mediating variables intervening between the consumers' psychological inputs and outputs (75). Yet, as discussed in detail by Fishbein (29), attitude conceptualizations have been the subjects of debates and controversies among psychologists and sociologists for more than half a century. The resultant absence of a clear conceptual consensus has forced even the most pragmatic of the marketing consumer analysts using "attitudinal" data to at least mention the existence of the alternate theories and in many cases to specify their particular measurements in the light of selected postulates. Moreover, the recent employment of a wide spectrum of multivariate statistical analysis methods to a multiplicity of both marketing and psychological data has brought about more concise specifications of hypotheses and conditional acceptances or rejections of them.

A brief excursion through the perceived mainstream of the psychological debate on the subject is thought to be relevant to the interpretation of the more analytically structured work exposed briefly in later sections of this paper. With brash disregard of the true genesis of the concepts, the initial definition to be presented is that of Thurstone (105): An attitude is "the amount of affect for or against a psychological object." Earlier Thurstone (104) had elaborated this unidimensional definition with the statement that attitude is "the sum total of a man's inclinations and feelings, prejudice or bias, preconceived notions, ideas, fears, threats, and convictions about any specified topic." (Opinion was in turn defined as the verbal expression of attitude.)

Although these definitions underlay Thurstone's landmark works on the establishment of probabilistic specifications for attitudes (and associated postulates concerning attitude frequency distributions that continue to serve as basic foundations for measurements), much of his terminology and many of his assumptions enjoyed no universal acceptance. Allport (3), after reviewing a large number of definitions of attitude, concluded that most investigators agreed that an attitude is a learned predisposition to respond to an object or class of objects in a consistently favorable or unfavorable manner. Allport's conceptualization was, like Thurstone's, a unidimensional one. However, the characterizing bipolarity corresponds strongly with some of the currently most widely used attitude scaling devices (e.g., semantic differential scales).

Doob (22) suggested that there is not necessarily a one-to-one correspondence between attitude and behavior; two persons may hold the same attitude, yet learn to react differently. More specifically, he linked attitude and behavior theories by specifying that attitude is a learned response; it may be evoked by any one of a variety of stimulus patterns; it is also a stimulus, which may evoke any of a number of learned responses; it cannot be directly observed (only its evoked responses); and it can only arbitrarily be distinguished from other types of responses. Chein (16), while applauding the usefulness of this relation between attitude theory and learning theory, attempted to clarify Doob's characterization of attitudes as being implicit by proposing that they be regarded as salient in the situation to which they become pertinent, otherwise unobservable except through effects.

Seminal work in the measurement of attitudes is that by Osgood and his associates (72, 73). They identified the projection onto the "evaluative" dimension of the total semantic space as "attitude" and developed an instrument to scale an individual's evaluation of an object. This instrument, known as the semantic differential, incorporates a subject's rating of an object on a 7-point, bipolar scale; the scale ends are identified by opposing pairs of descriptive words (e.g., good-bad, good looking-ugly, or safe-unsafe). This unidimensional technique allows measurement of attitudes in an operationally concise manner. Conceptually, this restriction to a single evaluative component underlies much of the more recent multidimensional work, if one were only allowed to ignore problems of terminology (i.e., whether the entire multidimensional space or just one or more dimensions are labeled as attitude).

Significant developments along the multidimensional lines were supplied by Rosenberg (85) and Rosenberg and Hovland (86). They perceived attitudes as "predispositions to respond in a particular way toward a specified class of objects" and isolated 3 dimensions of attitude: the affective component, the cognitive component, and the behavioral component. In a complementary fashion, Fishbein and Raven (30) developed a definition of "belief" analogous to Osgood's evaluative construct, and they employed a similar bipolar scaling technique to measure the degree to which a subject believed in the existence of a concept (i.e., rated from nonexistent to existent or improbable to probable). Katz (53) and Katz and Stotland (54) clarified the more functional approach to attitude by specifying that attitudes serve a series of human needs: ego defense, expression of value, utilitarian adjustment, and knowledge enhancement.

Fishbein (27, 28, 29) extended the multidimensional conceptualization to (what can be defined for purposes of this exposition) the fullest extent necessary to provide sound underpinnings for contemporary methodological and empirical work on attitudinal models of consumer decision-making behavior. Stating that increased precision and understanding can be gained by bringing definitions of attitude into closer harmony with the techniques by which attitudes are measured, Fishbein developed a theory in which both the evaluative component (attitude) and the cognitive component (belief) of an individual's perception toward an object are needed to explain behavior.

Variations of this theme are given by Palda (75), who formulates 3 components—attitudes, preferences, and images, and by Hansen (46), who proposes 2 sets of factors as intervening between the communications consumers receive and the choices they make. These factors are values, goals and motives by which alternatives are evaluated, and attitudes about the alternatives that relate them to the values. Finally, Rokeach (83) developed a comprehensive definition of attitude that seemed to encompass much of the preceding work on conceptualization; he declared that an attitude is relatively enduring, is an organization of belief, is organized around an object or situation, is a set of interrelated predispositions to respond, and leads to a preferential response. Well, that seems straightforward enough.

ATTITUDES AND TRANSPORTATION PLANNING

It has been effectively argued in a number of papers on travel demand [e.g., by Lansing et al. (58), Ackoff (2), Wallace (111), Sommers (98), and Hartgen and Tanner (48)] that the employment of attitudes as explanatory variables in models of transportation decision-making behavior enables the qualitative or non-engineering-metric attributes of travel alternatives to be taken into account. The basic postulate here is that differences between travel alternatives in terms of these qualitative attributes (such as styling and cleanliness of vehicles and security from threatening behavior of other individuals) as well as differences in terms of quantitative attributes (such as travel time and cost) are determinative in travel choice.

Indeed, intuitive judgment and scattered empirical evidence [e.g., as reported by Mahoney (63), Brunner et al. (13), Paine et al. (74), McMillan and Assael (66, 67), Sommers (98), Golob et al. (34), and Sherret (90)] argue for the general acceptance of this postulate. It is not an objective of this paper to review the many disucssions on the topic to be found in the professional literature. It is an objective, however, to present in summary the major issues involving transportation-planning and -evaluation impacts that are perceived as being dependent in large measure on the development of attitudinal models along lines such as those outlined in later sections of the paper.

First, there is the new-mode demand-estimation problem. It is felt that attitudes toward a wide spectrum of system attributes as determinative variables are one effective way of projecting usage of new modes that differ substantially in terms of design and performance from present modes. As discussed in the professional literature, these substantial differences make extrapolation from observed present behavior on the basis of quantitative performance measures exceedingly difficult. Application of attitudinal models to new-product development in general is discussed briefly in the following section of this paper, and Wallace (111) specifically covers the new-mode problem in light of marketing "product clinic" approaches for gathering the respondents' perceptions of proposed new modes.

Second, there is the issue of the estimation of the more complete transportation-demand curve, or surface, as opposed to estimation of only the demand component known as modal split. Attitudinal behavior models hold the promise of forecasting the elastic or latent components of urban passenger-travel demand for (and complex shifts in the timing and destinational characteristics of trips) and diversions from existing modes to new or modified transportation systems of specified design and anticipated performance. This lofty anticipation is motivated by the implicit nature of attitudes brought out in the conceptualization discussion; it would seem possible to explore a decision-maker's desires to travel as well as his revealed behavior given present alternatives. The development of such elastic demand models, however, suggests that the currently popular scope of travel demand models be expanded to include the destination and timing of trips as well as certain other factors. These subjects are discussed in a later section.

An associated issue involves the potential linking of travel demand models and the structure and growth of the urban environment. If it is indeed possible to identify and quantify latent demand dependent on changes in perceived accessibility or mobility, analogous efforts could be employed to project the demand for trips to and from conceived activity centers and residential areas. Of course, the reliability and validity of such projections are a function of the successful presentation of hypothetical new alternatives to individual travel decision-makers through the use of some sort of attitudinal survey instrument. It is also dependent on the ability of these decision-makers to accurately estimate their future behavior in an artificial circumstance and in the absence of inputs from a large number of variables that affect the decision process but cannot be anticipated or are of a random nature. Nevertheless, the author is basically optimistic about the possibilities.

A fourth issue is the need for the establishment of a meaningful feedback loop from demand analysis to systems design in the urban transportation planning process. It is axiomatic that it is important to know the impact on system demand (i.e., the level and distribution of projected usage among groups of individuals) of changes in the design of the system and its components. These changes may be in terms of readily quantifiable attributes such as speed and headway of a fixed-route-and-schedule public transportation system, in which case feedback could be accomplished through application of traditional, although disaggregated, demand models; or the changes may be in terms of qualitative attributes such as vehicle styling or comfort. In this latter case, attitudinal models may hold the answer to the designer's problem. This use of attitudes is analogous to applications in the marketing field of new-product design, and some of the published applications are referenced in the section in this paper on alternative model formulations.

The fifth issue raised in this brief presentation of attitudinal model impacts on transportation planning concerns the linkage between demand estimation and systems evaluation. A primary advantage of the proposed disaggregate behavioral models (discussed in the section on attitudes and existing model approaches) is that individual-based demand estimates provide the appropriate information on distribution of usage for the user-oriented evaluation of a system of specified design and anticipated performance. This is particularly the case for the utility-maximizing models. Suffice it to say that all anticipated attitudinal models (at the very least the models currently formulated in the market research field and discussed below) are of this disaggregate class and conform to these and other listed advantages. [Stopher and Lisco (101) discuss one such accounting of disaggregate model advantages.] The use of attitudinal models in this context also opens the possibility of employing peoples' perceived values of cost or benefit (i.e., their attitudes toward changes) in addition to objectively specified values, although this opens up a number of evaluation problems outside the scope of this discussion.

The last issue to be cited is the future establishment of a general demand model framework that can be applied in a large number of metropolitan environments through recalibration only, without requiring basic changes in form. This need, verbalized effectively by Weiner (114), could probably be satisfied by any one of a series of disaggregate models [e.g., those reported by Stopher and Lisco (101), Hoel and Demetsky (50), and Rassam et al. (81)], but is considered particularly within the structure of attitudinal models. Aggregation in attitudinal models, by definition, can be performed with respect to data-derived relatively homogeneous perception toward transportation alternatives and can be related to demographic and socioeconomic measures on individuals and households through the use of multivariate statistical methods such as regression, discriminant analysis, and canonical correlation. Basing the aggregation process on relative differences in model variables is thought superior to a priori stratification, all else (i.e., predictive power) being equal. Also, comprehensive attitudinal models are expected to explicitly incorporate variables such as an individual's previous exposure to various generic types of passenger transportation systems. These variables differentiate the respective population of metropolitan areas just as distributions of socioeconomic and demographic measures do. Again, these pronouncements are made under assumptions of certain forms of the attitudinal model; those forms are summarized in the following sections of this paper.

GENERAL THEORIES OF ATTITUDE AND BEHAVIOR

Specification of Attitude Toward an Object

A number of interrelated theoretical, cognitive, affective, and conative structures of attitude have been proposed by investigators in the fields of psychology and market research. Empirical tests of some hypotheses have been conducted, primarily with consumer data. No attempt is made to survey the breadth of this work nor to discriminate among it on the basis of subtle yet important differences in assumptions or functional forms. Rather, efforts in the area judged as being particularly relevant to the development of attitudinal travel-behavior models are explored to the degree deemed necessary for the purposes of this brief exposition.

The division of an overall attitude toward an object or situation into a number of similarly defined, separable components has characterized much of the specification work of recent vintage. This division fits nicely into the main body of the current and anticipated attitudinal travel-behavior modeling. As discussed in the following section of this paper, the division is particularly consistent with the fundamental basis on which many of the models are constructed, specifically the new approach to consumer theory postulated by Lancaster (57), who specifies the direct objects of utility as the properties of attributes of the consumer good, as opposed to the good itself.

A logical starting point is Rosenberg's cognitive summation theory of attitude. The hypothesis specified by Rosenberg (85) is

$$A_{ij} = \sum_{k=1}^{n} P_{ijk} V_{ik} \tag{1}$$

where

A_{ij} = affect aroused in individual i by object j;
P_{ijk} = perceived potency or perceived instrumentality of object j for achieving or blocking value k for individual i;
V_{ik} = rated value importance of the k th value to individual i; and
n = number of salient values.

Employing data on the ranking of value item statements and chi-square tests of association, Rosenberg reported the successful testing of the above hypotheses and also the successful testing of hypotheses relating overall affect to each of perceived instrumentality and value importance taken alone. However, as Howard and Sheth (51) point out, a number of procedural and methodological problems prevented Rosenberg from establishing convincing comparisons among the differences in explanatory power of his 3 hypotheses. Rosenberg chose to focus on the "affective" component of attitude, which was then described in terms of the postulated attitudinal cognitive structure. This approach [similar to that of Peak (76)] characterizes, with some modifications, much of the psychological and consumer theory work on attitude structures judged as being directly relevant to travel demand modeling.

Fishbein (26) and Anderson and Fishbein (6) presented a 2-component cognitive theory in which the variables were defined as follows:

$$A_{ij} = \sum_{k=1}^{n} B_{ijk} a_{ik} \tag{2}$$

where

A_{ij} = individual i's attitude toward object j;
B_{ijk} = strength of belief k held by individual i about object j;
a_{ik} = evaluative aspect of B_{ijk}; and
n = number of salient beliefs.

Fishbein and his associates noted that, although evaluative beliefs represent only one type of belief, they make up that particular subset of beliefs related to an individual's attitude toward an object. [Other beliefs listed by Fishbein (29) include beliefs about the object's component parts, the characteristics or qualities of the object, the object's relation to other objects or concepts, what should be done with respect to the object, and what the object should or should not be allowed to do.] For evaluative beliefs, the object is considered to be perceived as an instrument that can satisfy the evaluator's goals and objectives (i.e., block or aid the attainment of various valued states), and the attributes of the object are considered to be perceived as goal-satisfying properties.

This cognitive-summation theory of attitude organization and change was proposed as an alternative to the cognitive-consistency theories in which attitude is viewed as a weighted average of belief scores. Consistency theories were advanced by Osgood and his associates (72, 73) under the label of the congruity principle, by Heider (49) under the label of balance theory, and by Anderson (5). The evidence from comparative tests of the 2 approaches, as provided by Fishbein and Hunter (31) and Anderson and Fishbein (6), argues in favor of summation, primarily because of the discovered significant contribution to attitude of the set size, n.

Market researchers soon applied the cognitive-summation model, with few modifications, to consumer buying behavior (9, 45, 46). This work was consistent with the definition by Kotler (55) of a product as "a bundle of physical, service, and symbolic particulars expected to yield satisfactions or benefits to the buyer." Attitude was approached as a unidimensional expression of the degree of favorableness toward a product, and Sheth (91) observed that the general consensus in the field was that attitude is "an affect-type construct in which buyer's likes and dislikes of a brand or product class are abstracted." However, Sheth and his associates scrutinized the major assumptions built into the cognitive-summation models of Rosenberg, Fishbein, and others. Sheth (95) listed 4 questions concerning the model: Are 2 factors necessary for the calculation of attitude scores? Why employ a multiplicative combination of these 2 factors? Why aggregate over all salient beliefs (i.e., object attributes) to a single value? Should such summation be performed before or after factor multiplication?

With respect first to the aggregation issue, Sheth (91) introduced a multiple-regression approach for the explanation of attitude in terms of the n separate belief scores. Using semantic differential scale data obtained from a longitudinal consumer panel, he obtained (multiple) correlations between separate scores and overall attitudes toward a brand (as measured by a single rating score). Those correlations were significantly higher than (simple) correlations between single aggregated belief scores and the overall attitudes. There is at present little disagreement in the market research area concerning the superiority of the disaggregate model over the aggregate one, and additional evidence on improvements in explanatory power has been supplied by Sheth (92, 95) and Alpert (4).

A major advantage of the disaggregate model is that it enables the identification of the relative contributions of the beliefs or attributes of the object toward formation of the consumer's attitude, which is, of course, important information in promotional planning and new-product development. A wide variety of statistical estimation processes can be used to obtain this information from various survey data sources. Among such efforts are the regression approaches of Sheth (91, 92), Cohen and Houston (18) and Alpert (4); the discriminant analysis approach of Banks (8), Perry (77), and Cohen and Ahtola (17); and the canonical correlation work of Lutz and Howard (62) and Sheth (94).

A disaggregate approach of a slightly different nature is the ideal point model advanced by Lehmann (59):

$$A_{ij} = \sum_{k=1}^{n} V_{ik} \left| P_{ijk} - I_{ik} \right|^{r} \qquad (3)$$

where A_{ij}, V_{ik}, P_{ijk}, and n are defined as in Eq. 1, I_{ik} represents individual i's "ideal" point for attribute k, and r is an integer defining the distance metric. This model is strongly related to the psychometrician's ideal point multidimensional scaling research. Although success in predictive ability has been reported (59), some operational problems have been experienced, such as the respondent's revealed inability to conceptualize ideal point values (12). As one interesting variation to the above, Einhorn and Gonedes (25) tested a model in which the discrepancy between an object's value and the ideal point is an exponentially increasing function.

With respect to the issue of whether 2 factors are necessary for the determination of scores, i.e., whether both evaluative belief and importance are needed, there is contradictory evidence. Arguing for a single measurement per attribute, Howard and Sheth (51) reanalyzed the tables of Rosenberg (85) and tentatively concluded that his "value importance" terms actually suppressed the correlation between attitude and "perceived instrumentality" in the aggregate model. Moreover, Sheth and Talarzyk (96), Lutz and Howard (62), and Sheth (92) each uncovered additional information (determined through multiple regression, canonical correlation analysis, and multiple-set canonical analysis respectively) that the attribute (or value) importance measure, as reported by respondents through direct questioning using semantic differential scales, adds nothing to the explanation of overall attitude accomplished by the data from the semantic differential scales of beliefs (or perceived instrumentalities). On the other side of the coin, Hansen (46), in tests of a model describing the difference in attitudes between 2 alternatives, found that the value-importance terms contributed significantly to the variance explanation.

$$A_{i1} - A_{i2} = \sum_{k=1}^{n} V_{ik}(P_{i1k} - P_{i2k}) \qquad (4)$$

where the variables are defined as in Eq. 1.

The 1- or 2-factor issue remains open to debate today. Nevertheless, it is reasonably clear that the direct questioning approach to determining attribute importances has at most proved marginally valuable. It is hypothesized that these importances are best determined through covariance methods similar to those outlined above or through indirect survey techniques. The former approach would employ perceived instrumentality or evaluative belief measures as exogenous variables and measures of attitude or, more properly, behavior toward the object as endogenous variables; the link to behavior is the subject of the next section of this paper. The latter approach is a partial subject of the section on measurement and data collection.

Prediction of Behavior

The linkages among beliefs and value importances, overall attitude, behavioral intention, and behavior impinge on the areas of psychological inquiry concerned with cognitions, affects, and conations. A modest amount of theoretical work has been performed on these linkages and is of relevance to the development of travel demand models. Fishbein (28) did not substantially differentiate between affect and behavioral intention (i.e., an individual's intention to react in a certain way, given his attitude toward an object), although he introduced a concept of social normative beliefs to help account for institutional and social constraints. Dulany (23, 24), in his theory of propositional control, explicitly incorporated these constraints by specifying behavioral intention as a function of attitude, beliefs (weighted by their reinforcing values), and social and institutional pressures (weighted by their strengths). This approach is similar to the distinction drawn by Rokeach (83) between attitudes toward an object and attitudes toward a situation and, together with the related work of McGuire (65), forms a basis for much of the consumer theory work in the field.

Dulany made no distinction, however, between behavioral intention and behavior.

This was accomplished by Howard and Sheth (51) and Sheth (92). They specified actual behavior as a function of behavioral intention and nonpredictable (often random) situational factors, such as the availability of a brand or the sudden introduction of a new product. Multiple-regression tests performed by those researchers have confirmed the hypothesis that evaluative beliefs (and possibly value importances) are most strongly related to affect, then to behavioral intention, and least to behavior in the brand purchase context. Sheth (94) reinforced this stepwise explanatory chain concept by testing the strengths of critical combinatorial correlation links through canonical analysis of consumer panel data: Beliefs and some situational factors made up the predictor set; and affect (overall attitude rating), behavioral intention (intention to purchase), and behavior (reported actual purchase) made up the criterion set. Finally, Lutz and Howard (62), using multiple-set canonical analysis, established with similar data that both evaluative beliefs alone and beliefs weighted by importances were significantly more correlated to product preference measures than to actual buyer behavior.

Although these multivariate statistical studies serve to validate particular postulates concerning relations among cognition, affect, and conation, they all reveal a rather poor connectivity between attribute-level attitude and actual behavior in the consumer context. Those few travel-behavior models employing attribute data (and discussed in the section of this paper on existing transportation demand models) have secured behavioral explanations as good as those encountered in reviewing the market research literature, although these behavioral explanations were generated with the same data on which the models were calibrated and not on independent measurements.

The first general area that might be explored for the purpose of increasing the predictive validity of the cognitive-structure models is concerned with alternate measurement devices and data subjects. The first issue is the subject of the following section; examples of some possible new data subjects are information as to the degree of a subject's involvement with and preceived confidence in judging an object, proposed by Day (19) in his discussions of the stability dimension of attitude judgments, and attempted quantification of specific situational factors, along the lines initiated by Sheth (94). Another productive data source might be the "subjective" attribute data suggested by Dichter (21), Martineau (64), and Mindak (69). These attributes, which may well prove determinant in behavioral prediction, would vary across both objects and respondent socioeconomics and demographics; examples are prestigious-nonprestigious and for whites-for blacks.

Another general area to be considered for the purpose of increasing predictive power, particularly in a real forecasting situation with independent data, is the reduction in multicollinearity in the attribute data. One method for accomplishing this reduction is the application of factor analytic techniques to the raw attitude data, although this method introduces several major problems, not the least of which are factor interpretation and addition of a transformation in the design feedback loop of the demand system. A second method, employed by Sherret (90) in the travel demand application, is the econometric application of simultaneous equations to structure multicollinearity hypothesized as resulting from supply-side phenomena. This method is explored in detail in another paper by Wallace and Sherret (112).

Additional sources for predictive error are those listed by Wallace (111): the naiveté of the cognitive model (e.g., linearity assumptions); the omission of certain salient attributes or values; and the assumptions underlying aggregation across individuals possessing unique value systems and perceptions toward alternatives. This last source of error may be somewhat alleviated by the implementation of multivariate statistical optimal aggregation techniques such as various cluster analyses, Q-type of factor analysis, and discriminant analysis for the aggregation of individuals on the basis of their revealed preferences of perceptions. Such alleviation has as yet been accomplished in principle only, however, and aggregation remains a limiting factor in the entire utility theory class of individual-based travel demand and general-buyer behavior models.

Measurement

For reasons associated with brevity and intended emphasis on model structure, major issues related to the measurement of attitudes and other perceptual variables will be only briefly enumerated. The reader is referred to the many works in the professional literature identified in this section for more detailed treatments of the subjects.

Focusing first on the unidimensional scaling of direct attitudinal responses, we can readily see that the most widely used technique in market research is the semantic differential scale developed by Osgood and described in the attitude concept section of this paper. Other widely used techniques include the Thurstone scale (106), the Likert scale (60), the paired-comparisons scale (103), the successive-intervals scale (87), and the Guttman scale (43). The unidimensional nature of these techniques is emphasized by the fact that procedures used to determine scale consistency [e.g., those of Green (37)] employ unidimensionality as a criterion. Each of these devices is based on slightly different assumptions regarding the subject's ability to respond and the nature of the variable that is being measured, and each should be evaluated in the light of its applicability to various measurement phases of specific attitudinal demand models. Too often semantic differential scales have been applied in ignorance of these alternate techniques and without regard to their own genesis and intended scope of application.

The question as to how many response categories to use in a technique such as the semantic differential scale has been partially answered by Green and Rao (40) through a simulation model test employing geometric interpoint distance recovery criteria. Their work reaffirmed the 7-point scale previously defended by Miller (68) on the basic arguments involving the human capacity for processing information.

In another development related to this class of techniques, Day (20) has argued for adoption of a "constant sum" scale, which requires a respondent to distribute some portion of a fixed set of evaluation "points" to each attribute, as a solution to skewed distribution and lack of variance problems encountered in semantic differential data (52). The question of monadic (i.e., separate) versus paired ratings of alternatives has been investigated empirically by Greenberg (41), and his conclusions favor monadic ratings for most applications.

As an alternative to the unidimensional measurement of direct data, Abelson (1), Green and Carmone (39), Green (38), Day (20), and Greenberg (42), among others, have applied methods of multidimensional scaling from the psychophysical domain to attitude-similarity data in attempts to map the psychological space underlying attitude perception. These methods were originally developed by Richardson (82), Attneave (7), Torgerson (108), and Shepard (88, 89) and are based on a mathematical theorem of Young and Householder (115). Examples of recent methodological advances are given by Tucker and Messick (110) and Carroll and Chang (15). Computer programs to construct spaces in which the rank order of distances corresponds maximally with the nonmetric rankings of the respondents' pairwise similarity judgments are described by Young and Torgerson (116) and Kruskal (56).

These multidimensional scaling methods are not without some very profound difficulties, however, and two of these are the number and interpretation of dimensions (88, 89, 102) and the computer capacity and time required to run the programs with medium or large data sets. Other shortcomings with respect to the applications considered here have been the relative restriction of multidimensional scaling experience to similarities as opposed to preference data and the (associated) inability to develop a joint space in which measures of affect or conation or both are directly related to the cognitive components. Moreover, Green and Rao (40) have simulated an important application where traditional factor-analytic methods provide equally good results as multidimensional scaling. All comparative evidence is inconclusive, however, and it is felt that the future will bring a number of applications in which advanced multidimensional scaling will provide unique and penetrating analyses.

There are many direct-measurement techniques beyond those few popular ones discussed above, and the methods can be broadly classified in a number of ways. Fishburn (32) provided one such taxonomic scheme in his thorough methodological study of alternate additive utility theories and their measurement requirements, and Stevens (99) and then Torgerson (109) presented the famous ratio, interval, ordinal, and nominal scale classification. All of the direct-measurement devices are subject to semantic generalization, however, and that is the tendency for respondents to view 2 objects similarly without regard to obvious dissimilarities. This is particularly relevant in the transportation context, where 2 "public transit" systems, perhaps one radically new, might be viewed the same by certain individuals. As pointed out by Roman (84), this tendency must be identified and attacked through the structuring of questions about both the objects and the selected generic classes of objects [i.e., employment of both the "attitude-toward-situations" and the "attitude-toward-object" of Rokeach (83)].

Indirect survey measurement techniques will not be discussed in any detail; they are summarized by Myers and Alpert (70) and Alpert (4). In many cases, these devices have been developed in response to very real questions (21), such as, "Do respondents know the answer to direct perceptual questions?" The techniques range from third-person hypothetical questioning in which "most people" is substituted for "you" in attitudinal scales (44) to highly controversial motivational research methods. Campbell (14) discussed the assessment of social prejudices through the use of nonstructured or disguised (or both) techniques that may be relevant to the use of attitudinal models in perceived evaluations of transportation system costs and benefits.

ATTITUDE THEORY AND DEMAND FOR TRANSPORTATION: NATURE AND SCOPE OF RECOMMENDED ANALYSIS

The cognitive structures of affect and behavior discussed in the preceding section are consistent with the treatment of urban passenger transportation as an attribute-defined consumer good. This conceptualization is based on the new (general) consumer theory of Lancaster (57) and was initially adopted to the case of transportation by Quandt and Baumol (79) and their associates. As detailed in a number of sources in the professional literature, this conceptualization can be refined to treat transportation as an intermediate economic good. This is the approach taken by the economic utility theorists, who seemingly roam at will throughout the transportation research field. They have been known to attempt to describe the travel decision-making process as a tradeoff between the perceived benefits of making a trip to a particular destination at a particular time for the satisfaction of a purpose and the perceived generalized costs of making the trip by a particular mode along a particular route.

It is felt that this framework provides for the logical inclusion of attitude theory and, moreover, holds the potential of accomplishing the state-of-the-art advances outlined in the section of this paper on attitudes and transportation planning. The decision-makers' perceptions of the available travel alternatives, in terms of the destinations and scheduling of trips as well as the modes and routes, can be explicitly handled in these models. They must not be viewed as a panacea, however, because all the vexing problems described above, and more, must be tackled.

Theoretical specifications of the utility models are available [e.g., Niedercorn and Bechdolt (71) and Golob and Beckmann (34)], as are limited empirical test applications with nonattitudinal data [e.g., Pratt (78), Shunk and Bouchard (97), Hoel and Denetsky (50), and Golob et al. (36)]. Beckmann et al. (10) have extended the utility approach to the description of automobile-ownership decisions. Also, the probabilistic approaches to modal choice [e.g., Warner (113), Lisco (61), Quarmby (80), and Stopher (100)] are considered compatible with the attitude-utility framework because of the widely accepted statistical distribution properties of utility perception [e.g., Thurstone (105)].

The few pioneering demand studies that have employed attitudinal data in cognitive structures [e.g., Sommers (98), Hartgen and Tanner (47, 48), and Sherret (90)] have, taken together, established a base line from which to expand the efforts. Needed are studies that incorporate the attributes of the trip destination-purpose-schedule complex, that investigate the combinatorial properties of attribute cognitions across multiple modes and modal interfaces, and that test quantifications of the social and institutional factors impacting on travel behavior. In this latter area, Hartgen and Tanner (47) have attempted with some success to incorporate factors related to decision-making with the environment of the household [Sheth (93) has also addressed this topic].

It is hoped that the research briefly alluded to above and a wide range of small-scale attitudinal hypothesis formation and testing using a variety of data sets will be cumulative toward a comprehensive model. These data sets, which need not be of extensive sample sizes, might be generated through mail questionnaires, panel surveys, on-board ridership surveys, telephone interviews, in-depth group interviews, and the usual home interviews. [An example of the use of the former data collection method for the first-stage testing of one cognitive structure is given by Golob (33).] Moreover, it is hoped that these studies will take advantage of the potential before-and-after data associated with demonstrations of new transportation systems.

Recommendations by Beckmann et al. (11) for travel demand research are both complementary and reinforcing to those outlined above.

CONCLUSIONS

The theoretical formulation, empirical testing, and practical application in planning and evaluation of attitudinal models of urban passenger travel demand (with but a few exceptions) are in a primitive state, vis-à-vis the formulation, testing, and application in new-product development of analogous attitudinal models in the field of market research. Moreover, the use of the term attitude is not well understood by most transportation researchers, who nevertheless embark immediately on its measurement. Discussion of the possible reasons for this relative discrepancy is beyond the scope of this paper, but it is felt that this fact signals the presence of potentially productive research topics. Such research might be along the general directions indicated in the preceding recommendations, along the directions of the few existing attitudinal travel-demand models, or, more probably, along imaginative new directions outside the present limited insight into the subject.

The urban transportation context dictates that attitudinal travel demand models be of a more complex structure than the analogous models in consumer buyer theory. Such complexity, however, is strongly associated with a high level of expected returns from research efforts: The explicit handling of social and environmental attributes of transportation systems in attitudinal models may prove invaluable to systems evaluation that is interrelated with the complex of human activities and social and institutional concerns within the urban framework.

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Resource Paper on Product Attributes

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One of the most fundamental questions that arises in both advertising and product planning is what product attributes (i.e., characteristics) are most important in the consumer decision-making process. Advertising objectives are often set based on improving consumer perception of a product in terms of the specific product attributes deemed to be most important (1). In the product-planning area, decisions must always be made that require trade-offs in that a higher level of one attribute necessitates a lower (or higher) level of some other attribute because of engineering or financial considerations or both. These trade-off decisions require inputs regarding the relative importance consumers attach to the attributes in question (2).

To be of assistance in these decisions, the marketing analyst must first obtain measures on a set of attributes that describe the alternative products from a consumer-choice point of view. The analyst must then determine which product attributes appear to be most important to consumers in their choice among alternative products. However, although there is a great deal of literature that is relevant, there is no generally accepted methodology. A full review of this literature is not possible here, but Myers and Alpert (3) and others have provided a review of many of the various approaches that have been suggested. The purpose of this paper then is to develop and illustrate a new approach for obtaining measures on a set of attributes that describe alternative products from a consumer viewpoint and for estimating the relative importance consumers attach to each of the attributes in selecting among the alternative products.

The particular consumer product choice selected to illustrate the methodology suggested is the transportation mode (product) choice decision for the journey to work. In this paper, the choice involved is between automobile and rail transit. However, Wallace, in an earlier paper (4), has applied some of the same methodology for new-car-purchase decisions with encouraging results. The approach suggested here is, generally speaking, a combined application of measurement theory (scaling), consumer demand theory, analysis of variance, and econometrics.

ATTRIBUTE DEFINITION AND MEASUREMENT

Developing a description of alternative products in terms of attributes immediately raises the problem of definition and measurement. Quantitative attributes, that is, those with natural physical units of measurement familiar to the consumer, cause little difficulty. Examples are price (dollars) and gas mileage (miles/gallon) for automobiles or travel time (minutes) and fare (dollars) for modes of travel. But qualitative attributes having no natural physical unit of measurement familiar to the consumer do cause a problem. Examples are tartness and cleaning power for tooth paste and comfort, sex appeal, dependability, and noise for automobiles. Because in practice it is seldom (if ever) possible to fully describe alternative products solely in terms of quantitative attributes, some scaling technique is required. It will later be argued that, because this is so, for consistency it seems reasonable to obtain scale ratings on all attributes.

There is considerable literature on scaling procedures and their applications. There are the traditional metric methods such as the semantic differential and the Thurstone methods and the newer nonmetric scaling methods. Each has its strengths and weaknesses, a discussion of which is beyond the scope of this paper. Green and Tull (5) provide a thorough review of these methods. The approach taken here is the semantic differential, but other procedures could have been used. However, a recent study by Green and Rao (6) indicates that the traditional metric scaling techniques appear to perform as well as the newer nonmetric methods when it comes to returning a known product group configuration.

Product-attribute definition and measurement via the semantic differential requires, first, a choice as to the number of intervals; second, a selection of polar adjectives to define the end points of the scale; and, third, a choice between a monadic and paired-comparison research design. A 7-point scale has been recommended by Osgood (7). Although some have suggested fewer intervals, the Green and Rao (6) work also supports Osgood's recommendation—so selecting a 7-point scale appears reasonable.

Regarding the definition of polar adjectives, there appear to be 2 approaches. The first is to attempt to define the end points so that attribute-rating measurements will not be value loaded, that is, will depend solely on level of the attribute and not on respondent's utility function (8). But for qualitative attributes in particular, this does not appear to be possible because it is very difficult (if not impossible) to define end points that guarantee that most respondents do not provide ratings based on a mental comparison with other actual or ideal products. If we assume that this is the case, the only alternative is to force value-loaded judgments from respondents by appropriate selection of the polar adjectives. In this way, individual measurements become attribute-satisfaction ratings rather than attribute ratings because respondents are asked to provide a measure of their satisfaction with regard to a particular attribute of a specific product.

Models are often formulated in which attribute ratings and attribute-satisfaction ratings are used interchangeably. Myers and Alpert (3, p. 18) cite a regression model in which certain attributes such as color, overall appearance, and taste of a cocktail dip mix were rated on a 7-point scale with end points "liked very much" and "disliked very much" and other attributes such as strength of flavor and spiciness were rated on a 5-point scale from "much too strong (spicy)" to "much too weak (bland)." Buying intention was used as the dependent variable. Attribute-satisfaction ratings were obtained on the first set of attributes, whereas an apparent attempt was made to obtain attribute ratings on the latter set. A more obvious attempt would have been to label the end points "very weak" to "very strong" for flavor and "very spicy" to "very bland" for spiciness. However, even with these end points, some respondents will, in general provide ratings based on a mental comparison with another actual or ideal product in the same choice category, and other respondents may provide ratings that are not value loaded. This inconsistency among respondents leads to unreliable measurements and strongly suggests the use of end-point definitions that clearly request measures of satisfaction with a particular product attribute. This implies the use of end points such as "poor/excellent," "very unsatisfactory/very satisfactory" or "highly unsatisfactory/completely acceptable," as shown in Figure 1. Although this point is of critical importance, arguing it further is beyond the scope of this paper.

The fact that obtaining reliable measures regarding the level of qualitative attributes does not appear possible and that measuring attribute-satisfaction ratings is thereby necessary has very important ramifications for building models to estimate the importance of attributes. These difficulties arise because attribute-satisfaction ratings depend not only on the level of the attribute but also on the individual consumer's utility function (9). A potential solution to this problem was suggested by Wallace (2), and a questionnaire was designed to provide the data necessary to calibrate and validate the proposed consumer-choice model. The data obtained and method of collection are described in the next section.

As stated above, a choice must also be made between a paired-comparison and a monadic research design. Greenberg's study (10) provides numerous references regarding the strengths and weaknesses of the 2 approaches. One of the major arguments against the paired-comparison approach is that it tends to magnify what are actually minor differences in attribute satisfaction. This problem is particularly relevant when these data are to be used as input to a model designed to infer the importance of attributes from consumer product-choice decisions. Another strong argument in favor of the monadic design is that it provides data in the case of quantitative attributes to test alternative hypotheses regarding the mapping from attribute to attribute-satisfaction ratings. This fact will be made use of in a later section. Because of these points, a monadic design appears most reasonable. Of course, the monadic design must be used if an attribute has a different meaning or no meaning at all for the 2 products under consideration.

THE EXPERIMENT

As mentioned above, the product-choice decision process for which data were collected is the mode-choice decision for the journey to work. The following information was obtained by a 5-page, mailed questionnaire for the respondent's first and second mode choice: attribute-satisfaction ratings based on the semantic differential for 15 different attributes (Fig. 1), attribute values for 7 quantitative attributes (Table 1), and the usual demographic data. There was a total mailing of 10,000; approximately 1,000 were returned. The statistical results in this paper are for the subsample making the choice between automobile (driver or passenger) and rail transit. The total sample was 117 (60 choosing automobile, 57 choosing transit). A detailed discussion of the questionnaire and its design is in the literature (11).

DEMAND EQUATION FORMULATION AND ESTIMATION PROCEDURES

The first objective of this section is to develop the demand side of a model for estimating the importance of product attributes. Actually a family of demand-side equations is developed. The second objective is to suggest means by which these models can be calibrated. To facilitate later discussion of the empirical results, we will describe the model in terms of the mode-choice decision. To generalize, traveler is replaced by consumer and mode by product.

The model will be confined to explaining the modal-choice behavior of individuals who actually do have a choice between alternatives (i.e., are not captive to any one mode) and to considering the modal choice as a binary decision between the 2 "best" alternatives available. The latter assumption is based simply on the hypothesis that the typical traveler is unlikely to have many more than 2 feasible alternatives and in

Figure 1.

Below is a list of phrases some people use to describe their trip to work. For each phrase, rate your overall HOME TO WORK trip by placing a check mark ☑ in the box along the scale at that point which best describes your SATISFACTION with that aspect of the overall trip. If a phrase does not apply, check the box marked "Not Applicable" (N.A.)

		COMFORT IN VEHICLE *(See Footnote)			N.A.
1.	EXCELLENT	7 6 5 4 3 2 1	POOR		0
		DEPENDABILITY OF ON-TIME ARRIVAL			N.A.
2.	EXCELLENT	☐☐☐☐☐☐☐	POOR		☐
		PROTECTION FROM WEATHER WHILE WAITING			N.A.
3.	EXCELLENT	☐☐☐☐☐☐☐	POOR		☐
		FREQUENCY OF VEHICLE DEPARTURE TIMES			N.A.
4.	EXCELLENT	☐☐☐☐☐☐☐	POOR		☐
		PLEASANTNESS OF TRIP			N.A.
5.	EXCELLENT	☐☐☐☐☐☐☐	POOR		☐
		ATTRACTIVENESS OF VEHICLE *(See Footnote)			N.A.
6.	EXCELLENT	☐☐☐☐☐☐☐	POOR		☐
		NOISE IN VEHICLE *(See Footnote)			N.A.
7.	COMPLETELY ACCEPTABLE	☐☐☐☐☐☐☐	HIGHLY UNSATISFACTORY		☐
		CHANCE OF ACCIDENTS			N.A.
8.	COMPLETELY ACCEPTABLE	☐☐☐☐☐☐☐	HIGHLY UNSATISFACTORY		☐
		EXPOSURE TO UNDESIRABLE BEHAVIOR OF OTHERS			N.A.
9.	COMPLETELY ACCEPTABLE	☐☐☐☐☐☐☐	HIGHLY UNSATISFACTORY		☐
		TRAFFIC			N.A.
10.	COMPLETELY ACCEPTABLE	☐☐☐☐☐☐☐	HIGHLY UNSATISFACTORY		☐
		BODILY CROWDING			N.A.
11.	COMPLETELY ACCEPTABLE	☐☐☐☐☐☐☐	HIGHLY UNSATISFACTORY		☐
		OUT OF POCKET COST OF TRIP			N.A.
12.	COMPLETELY ACCEPTABLE	☐☐☐☐☐☐☐	HIGHLY UNSATISFACTORY		☐
		TOTAL TIME SPENT RIDING			N.A.
13.	COMPLETELY ACCEPTABLE	☐☐☐☐☐☐☐	HIGHLY UNSATISFACTORY		☐
		TOTAL TIME SPENT WALKING			N.A.
14.	COMPLETELY ACCEPTABLE	☐☐☐☐☐☐☐	HIGHLY UNSATISFACTORY		☐
		TOTAL TIME SPENT WAITING			N.A.
15.	COMPLETELY ACCEPTABLE	☐☐☐☐☐☐☐	HIGHLY UNSATISFACTORY		☐

*(Consider vehicle used for LONGEST TIME during trip)

Table 1. Descriptions of quantitative attributes.

Attribute Number	Attribute Description	Units	Abbreviation
4	Frequency of vehicle departure times	Minutes	Frequency
13	Total time spent riding	Minutes	Riding time
14	Total time spent walking	Minutes	Walking time
15	Total time spent waiting	Minutes	Waiting time
16	Distance traveled	Miles (coded)	Distance
17	Daily parking cost	Cents	Parking cost
18	One-way fare	Cents	Fare

any case in the end is not likely to make a decision between more than 2; that is, he is likely to reduce a choice between 3 or more to the "best" 2 and choose between these. This process of reducing the number of alternatives as the time of actual choice nears is discussed by Nicosia (12) and others.

For a representative individual traveler from the population and for modes j = 1, 2 and attributes i = 1, 2, ..., m, the following notation is established:

- y = probability that mode 1 is preferred to mode 2;
- X_i^j = value or level of attribute i on mode j;
- X^j = m-element vector of attribute value $[X_i^j]$ for mode j;
- $Q_i^j = Q_i(X_i^j)$ = attribute-satisfaction rating for attribute value X_i^j;
- Q^j = m-element vector of attribute-satisfaction ratings $[Q_i^j]$;
- $Q_i = Q_i(X_i^1) - Q_i(X_i^2) = Q_i^1 - Q_i^2$ = relative attribute-satisfaction rating for attribute i for modes 1 and 2;
- Q = m-element vector of relative attribute-satisfaction ratings Q_i;
- $U_i(X_i^j)$ = utility associated with attribute value X_i^j; and
- $U(X^j)$ = total utility associated with mode j.

We next assumed the probability that an individual chooses mode 1, that is, prefers mode 1 to mode 2, is a function f of the difference in the total utilities to him of the 2 modes.

$$y = f[U(X^1) - U(X^2)] \tag{1}$$

The probability p that he prefers mode 2 to mode 1 is then given by

$$p = 1 - y \tag{2}$$

indicating that a choice is made to travel by either mode 1 or mode 2. Generalizing to the choice between many modes is nontrivial.

We also assume the total utility of a mode is derived from the utilities of the attributes of the mode in the additive form

$$U(X^j) = \sum_{i=1}^{m} U_i(X_i^j) \tag{3}$$

for j = 1, 2. The assumption of additive utilities, i.e., the assumption that the utility of the whole is equal to the sum of the utilities of its parts, is an important one in the model formulation because of its implication that the attributes are value-wise independent. Thus, for Eq. 3 to be valid, the utility $U(X_i^j)$ must be independent of X_k^j for all $k \neq i$. Fishburn (13), for example, in the context of the factors determining the utility of a decision states this as the requirement that the "evaluator be able to make consistent value judgments about the levels of any one factor when the levels of all other factors are held fixed, and his judgments must not depend on the particular fixed levels of the other factors." This assumption implies the desirability of developing a set of attributes that fully describe the products under consideration that from a consumer point of view can be measured along orthogonal axes. This is discussed further in a later section on the adequacy of attribute description.

Combining Eqs. 1 and 3 gives

$$y = f\left\{\sum_{i=1}^{m} [U_i(X_i^1) - U_i(X_i^2)]\right\} \tag{4}$$

The function $U_i(X_i^j)$, it is assumed, is not dependent on the mode j (although obviously is dependent on the attribute i). That is to say, the utility derived from a certain value of some attribute, say, travel time, is the same whether this is the travel time by bus or by automobile. This assumption is to some extent validated in a later section on validation of assumptions.

Next, we assume that the function $U_i(X_i^j)$ is monotonic in X_i^j and has the diminishing marginal utility property (as is commonly assumed as the basis for theories of rational economic behavior of consumers). The form shown in Figure 2 is appropriate where high attribute values or levels are associated with high levels of utility, for instance, comfort, dependability, and safety. Attributes having an associated utility function of this form can be referred to as "comfort" attributes. The form shown in Figure 3 is appropriate for what may be termed "cost" attributes, i.e., those for which high values of the attribute are associated with low levels of utility such as cost of travel. The value of M_i is the maximum level of utility associated by the traveler with any value or level of the attribute, and obviously the value of M_i will not, in general, be the same for different attributes i. However, it is assumed to be not dependent on the mode j and to be finite.

The relations shown in Figures 2 and 3 are assumed to be of the form

$$U_i(X_i^j) = M_i h_i(X_i^j) \tag{5}$$

A specific form for $h_i(X_i^j)$ that seems reasonable is the exponential

$$h_i(X_i^j) = \left(1 - e^{-\lambda_i X_i^j}\right) \tag{6}$$

for comfort attributes i, and

$$h_i(X_i^j) = e^{-\lambda_i X_i^j} \tag{7}$$

for cost attributes i. These assumptions make it possible to specify demand Eq. 4 in terms of the attribute values X_i^j. However, X_i^j is not measurable for qualitative attributes so that the demand equation must be written in terms of Q_i, the attribute-satisfaction ratings.

We let the attribute-satisfaction rating $Q_i(X_i^j)$ be measured on a semantic differential scale with (k + 1) scale intervals 0, 1, ..., k and assume the following direct proportionality relation between $Q_i(X_i^j)$ and $U_i(X_i^j)$:

$$Q_i(X_i^j)/k = U_i(X_i^j)/M_i \tag{8}$$

where M_i is the maximum utility associated with attribute i, which may be illustrated for, say, a cost attribute with k = 6 (a 7-point scale) as shown in Figure 4. Combining Eqs. 5 and 8 and writing Q_i^j for $Q_i(X_i^j)$ give

$$Q_i^j = kh(X_i^j) \tag{9}$$

If the semantic differential scale does not have a 0 origin, then appropriate adjustments must be made. If, for instance, a k-point scale (1, 2, ..., k) is used (as is the case for these data), the relations (and their inverses) for the exponential form of $h(X_i^j)$ in Eqs. 6 and 7 are respectively

$$Q_i^j = 1 + (k - 1)\left(1 - e^{-\lambda_i X_i^j}\right) \tag{10}$$

for comfort attributes,

$$Q_i^j = 1 + (k - 1)\, e^{-\lambda_i X_i^j} \tag{11}$$

for cost attributes,

$$X_i^j = \frac{1}{\lambda_i} \log\left[(k - 1)/(k - Q_i^j)\right] \tag{12}$$

Figure 2.

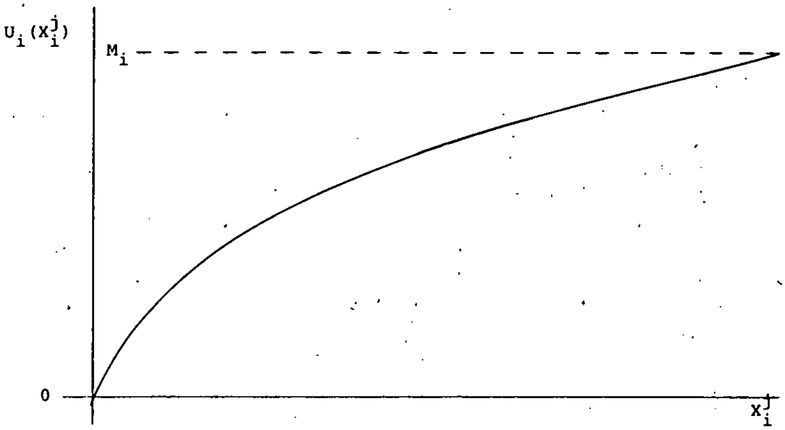


Figure 3.

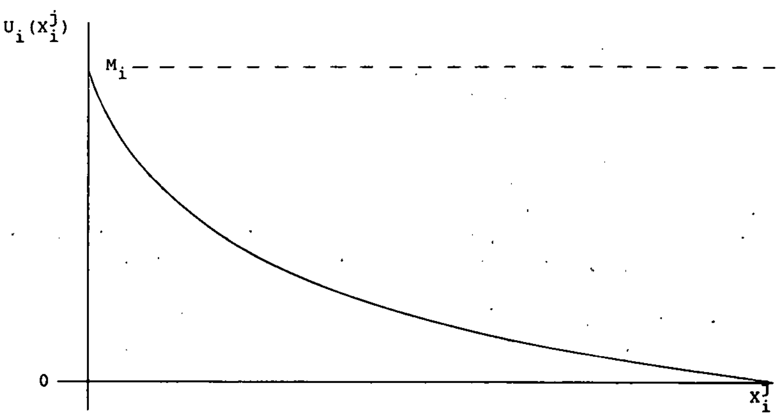
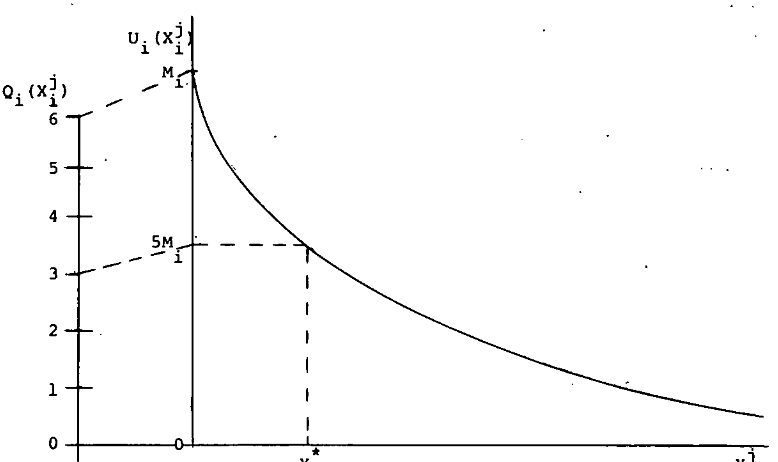


Figure 4.



for comfort attributes, and

$$X_i^j = \frac{1}{\lambda_i} \log [(k - 1)/(Q_i^j - 1)] \tag{13}$$

for cost attributes.

Finally, the Q/X relations hypothesized in, say, Eqs. 10 and 11 may be estimated and their validity investigated for those attributes for which a sample of observations on both attribute values and the corresponding attribute-satisfaction ratings is available. The results of this investigation are reported in a later section on validation of assumptions.

Now, we combine the demand Eq. 4 with Eq. 8 to obtain the demand equation

$$y = f\left\{\frac{1}{k}\sum_{i=1}^{m} M_i[Q_i(X_i^1) - Q_i(X_i^2)]\right\} \tag{14}$$

The variable $Q_i(X_i^1) - Q(X_i^2)$ (or $Q_i^1 - Q_i^2$) is the difference in the attribute-satisfaction ratings (measured on the same semantic differential scale) for attribute i. To simplify notation, we will write this variable as Q_i and refer to it as the relative attribute-satisfaction rating for attribute i. The m-element vector of relative attribute-satisfaction ratings Q_i will be written as Q. Equation 14 may then be written as

$$y = f\left(\frac{1}{k}\sum_{i=1}^{m} M_i Q_i\right) \tag{15}$$

or more concisely as

$$y = f(Q) \tag{16}$$

Any one of a number of forms may be proposed for the function f, the more straightforward being included in the class of functions h such that $f(Q) = h[g(Q)]$ and, where $g(Q)$ is a linear function of the Q_i,

$$g(Q) = a_0 + \sum_{i=1}^{m} a_i Q_i \tag{17}$$

where $a_i = M_i/k$. The following discussion will be confined to this class of functions. The simplest of this class is the case where h is the identity function so that

$$f(Q) = g(Q) \tag{18}$$

and

$$y = a_0 + \sum_{i=1}^{m} a_i Q_i \tag{19}$$

This has been referred to as the linear probability function.

Suppose (as is the case here) observations on the dependent variable y are dichotomous, taking on the value 1 if the individual prefers mode 1 and 0 if he prefers mode 2. This raises peculiar problems of estimation, which have been considered, for instance, by Warner (14) and Goldberger (15). It is possible to treat Eq. 19 as a classical linear regression model with the expected value of the regressand (the dependent variable) y specified as a linear function of nonstochastic regressors (explanatory variables) Q_i and to obtain classical least squares estimates of the parameters. The conditional expectation of y may then be interpreted as the conditional probability of modal choice given the Q_i. As shown by Goldberger, however, the basic classical least squares assumption of homoscedasticity is not fulfilled in the case of a "dummy" dependent variable because the disturbance term of the model varies systematically with the values of the regressors. Consequently, the classical least squares estimates although unbiased are inefficient (15, p. 238). Classical least squares estimation of Eq. 19 does not then yield "best" estimates of the coefficients. However, it should be mentioned that the heteroscedasticity problem can be alleviated by obtaining a probability-of-choice measure from respondents over the interval ($0 \le p \le 1$).

However, in addition to the difficulty caused by heteroscedasticity, the linear probability function of Eq. 19 itself may be objected to on the grounds that it is quite possible for predicted values of y to fall outside the 0, 1 interval, which is inconsistent with the definition of y as a probability. The function is thus "illogical at the ends."

Two methods have been widely used to take care of the problem of confining predicted values of the regressand to the unit interval. These are probit analysis and logit analysis, both of which essentially fit an S-shaped "sigmoid" curve to a linear function of the data. If g(Q) is denoted as the linear function, the general form of the sigmoid curve fitted by probit and logit analyses is as shown in Figure 5. In probit analysis the sigmoid function is given by the cumulative normal distribution function,

$$y = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{g(Q)} e^{-t^2/2}\, dt \tag{20}$$

where

$$g(Q) = a_0 + \sum_{i=1}^{m} a_i Q_i .$$

Nonlinear estimation yields maximum likelihood estimates of the parameters of g(Q) as shown by Tobin (16).

Logit analysis, which like probit has its origins in bioassay (17), fits the logistic curve to a linear function g(Q).

$$y = \frac{1}{1 + e^{-g(Q)}} \tag{21}$$

where

$$g(Q) = a_0 + \sum_{i=1}^{m} a_i Q_i .$$

For both probit and logit analyses, if we assume that the usual assumptions hold, both unbiased and efficient maximum likelihood estimates of the parameters of the linear function g(Q) may be obtained. No conclusive evidence has been presented to indicate that statistically one provides a better fit than the other to modal-choice data (14).

Here parameters of the demand equation will be estimated by 3 methods. First, because of its computational simplicity, ordinary least squares regression is used to estimate the linear probability function of Eq. 19. Second, nonlinear least squares regression is used to estimate the logistic function of Eq. 21 (18). Third, the demand equation is an integral part of a system of equations, and estimations are by 2-stage least squares.

DEMAND EQUATION PARAMETER INTERPRETATION AS IMPORTANCES

The concept of importance will be discussed and then defined in the context of the consumer choice model described above. As Myers and Alpert pointed out, the term importance has been used to mean many different things. It is necessary, therefore, to define carefully what is to be meant by importance here. From the point of view of the consumer, the relative importance of attributes can be said to be the ratio of the marginal utilities of attributes; that is,

$$\frac{dU_i}{dX_i} \Big/ \frac{dU_m}{dX_m} \quad \text{or} \quad \frac{dU_i}{dQ_i} \Big/ \frac{dU_m}{dQ_m} \tag{22}$$

for i = 1, 2, ..., m - 1, depending on whether the utility function is specified in terms of attribute or attribute-satisfaction ratings. From the point of view of allocating advertising funds or funds for product change, attribute importance may be defined differently. If C = dollar expenditure, importance in this case is given by

$$\frac{dU_i}{dX_i}\frac{dX_i}{dC} \Big/ \frac{dU_m}{dX_m}\frac{dX_m}{dC} \tag{23}$$

for i = 1, 2, ..., m - 1, or

$$\frac{dU_i}{dQ_i}\frac{dQ_i}{dC} \Big/ \frac{dU_m}{dQ_m}\frac{dQ_m}{dC} \tag{24}$$

for i = 1, 2, ..., m - 1, because it is assumed that preference and, therefore, sales are monotonic in U. Given the additive-utility assumption, total rather than partial derivatives are appropriate.

Methods for estimating dX/dC for quantitative attributes and dQ/dC for all attributes are outside the scope of this paper. Suffice it to say that, in the case of advertising planning, advertising pretesting procedures can be used and, in the case of product development, product clinic procedures can be applied. In the case of quantitative attributes, care must be taken to note that the model is in terms of perceived attributes and not actual attributes so that engineering and financial estimates may not suffice.

To obtain comparable importance measures for all attributes, it seems reasonable to obtain semantic differential attribute-satisfaction ratings for all attributes, even those that are quantitative. As a result, attribute importances defined in terms of Q rather than X will be considered.

Of primary interest here then is dU_i/dQ_i (i = 1, 2, ..., m). But differentiation of Eq. 8 implies that

$$\frac{dU_i}{dQ_i} = \frac{M_i}{k} = a_i \tag{25}$$

for i = 1, 2, ..., m, in Eq. 17. Thus, based on the assumption given by Eq. 8, relative importance from a consumer viewpoint is given by

$$\frac{a_i}{a_m} = \frac{M_i}{M_m} \tag{26}$$

for i = 1, 2, ..., m.

As a result, the demand model given by Eq. 15 implies that preference depends on relative attribute-satisfaction ratings and attribute importances. A validation of the assumption of Eq. 8 is provided in a later section. Means by which the a_i can be estimated have been discussed above, and results will be given below.

The hypothesis that attitude and consequently behavior are determined by the satisfaction with, and importance of, the "attitude object" has been the basis for attitudinal models in applied psychology. Fishbein (19) has suggested an additive-utility model that implies that an individual's attitude toward an object will depend on (a) how satisfactorily the object possesses certain attributes and (b) how important these attributes are to him. Confirmation of hypotheses of this kind suggests that the choice behavior of individuals can be described in terms of their satisfaction with the perceived level of modal attributes and the importance attached by them to the attributes. Bass and Talarzky (20) have used this approach in their research. Frequently, importances are estimated via regression techniques and discriminant analysis (21).

There are, therefore, precedents for this modal-choice formulation. However, this model, in contrast to the psychological models discussed above, involves no a priori specification of the coefficients as importances. The interpretation instead arises naturally as a direct consequence of the model assumptions of (a) additive utilities, (b) the particular diminishing marginal utility form of the utility function, and (c) the proportional mapping from U to Q. As mentioned previously, the assumptions b and c are validated in a later section.

SUPPLY-SIDE FORMULATION

To this point the consumer choice model has been expressed in terms of a single demand equation, and in the preceding section it was shown that estimation of the parameters of the equation would yield estimates of the relative importances of the associated attributes. However, the data that must be used to calibrate the model were "generated" by the simultaneous solution of demand and supply relations. Calibration of the single-equation demand model from such data, while ignoring the supply side, is consequently likely to yield statistically biased and inconsistent estimates of the relative importances, and these estimates may be misleading (15, pp. 280-290). It will be shown in a later section that this turned out to be the case in the illustrative example cited here. In order to obtain meaningful estimates of importances, the relevant supply-side relations must be included in the structure of the model, and the model must be calibrated by one of the techniques appropriate for systems of simultaneous equations. A discussion of these techniques is outside the scope of this paper. Goldberger provides an excellent reference textbook (15).

It is important to note that, even though the data for each of the 2 modes considered are taken via questioning the traveler, certain of the attribute values are related to other attribute values because of supply considerations. Suppose that for mode j some of these supply considerations can be expressed by an equation relating the value of attribute r to the values of other attributes i. Simple equation forms that may be thought appropriate for specific supply relations are, for instance, the additive form

$$X_r^j = b_r^j + \sum_i b_i^j X_i^j \qquad (27)$$

or the multiplicative form

$$X_r^j = b_r^j \prod_i b_i^j X_i^j \qquad (28)$$

where the b are coefficients to be estimated. The additive form may be, for example, appropriate for the automobile mode for, say, a relation describing the value of the attribute out-of-pocket cost as an additive function of the various other attributes such as traffic, travel time, and parking costs. Any number of other more complex equation forms may, of course, be hypothesized; these two are suggested only as possible simple forms. Moreover, as before, some of the attribute values X_i^j may be difficult or impossible to measure, in which case it is necessary to resort to the use of the corresponding attribute-satisfaction ratings Q_i^j in estimating the relations.

Assume the first p of the attributes (i = 1, ..., p) on the right side of Eqs. 27 and 28 are expressed in terms of their satisfaction ratings (Q variables) and the next q (i = p + 1, ..., p + q) are expressed in terms of attribute values (X variables). Also assume attribute r on the left side is expressed as a satisfaction rating.

As before, assume that the exponential relations given by Eqs. 12 and 13 exist between X_i^j and Q_i^j (i = 1, ..., p, r) so that

$$X_i^j = \frac{1}{\lambda_i} \log \left[(k - 1)/Q_i^{j*}\right] \tag{29}$$

where

$Q_i^{j*} = (Q_i^j - 1)$ for cost attributes, and
$Q_i^{j*} = (k - Q_i^j)$ for comfort attributes.

Substituting for X_i^j (i = 1, ..., p, r) from Eq. 29 in Eq. 27 then yields one possible form of supply relation:

$$Q_r^{j*} = \prod_{i=1}^{p} (Q_i^{j*})^{c_i^j} \exp\left(c_r^j + \sum_{i=p+1}^{p+q} c_i^j X_i^j\right) \tag{30}$$

The coefficients c are simple arithmetic combinations of the coefficients b, λ, and k.

Suppose the exponential relations of Eq. 29 may be approximated by a linear relation over the ranges of X_i^j and Q_i^j of interest; namely,

$$X_i^j = \mu_{0i} + \mu_i Q_i^j \tag{31}$$

This form also results from assuming U to be a linear function of X. Substituting for X_i^j (i = 1, ..., p, r) in Eq. 27 then yields another possible form of the supply-side relation:

$$Q_r^j = c_0^j + \sum_{i=1}^{p} c_i^j Q_i^j + \sum_{i=p+1}^{p+q} c_i^j X_i^j \tag{32}$$

where, again, the coefficients c are simply derived from the coefficients of Eqs. 27 and 31. It should be stressed that supply-side Eqs. 30 and 32, which are derived above, are only suggested as possible forms of supply-side relations that have some plausibility and are relatively simple to estimate. They will be referred to as the nonlinear and linear supply equations respectively. It is important to note that attributes included in the demand equation may be correlated because of correlation with a third variable rather than because of direct causal relations.

Table 2 gives the correlation of semantic differential ratings of dependability, out-of-pocket cost, riding time, walking time, and waiting time for automobile and transit. For the automobile, relatively high correlations exist between dependability and riding time and between out-of-pocket cost and riding time because of supply-side considerations. Supply-side relations involving these variables as well as dependability and waiting time were developed for transit. It is beyond the scope of this paper to develop these equations here. However, for this mode-choice problem, supply-side model development has been discussed by Sherret (22) and will be further discussed in a forthcoming paper.

SIMULTANEOUS-EQUATION MODEL FORMULATION

Having discussed the demand-side and supply-side relations, we can now propose a simple simultaneous model structure. We assume for purposes of illustration that both the demand and supply relations are linear; more complex equation forms (in the same variables) may be substituted without changing the basic structure of the model. Then,

$$y = a_0 + \sum_{i=1}^{m} a_i Q_i \tag{33}$$

where

$$Q_i = Q_i^1 - Q_i^2 \tag{34}$$

for i = 1, ..., m, and

$$Q_i^j = c_{0i}^j + \sum_{k=1}^{p} c_{ki}^j Q_k^j + \sum_{k=p+1}^{p+q} c_{ki}^j X_k^j \tag{35}$$

for i = 1, ..., m and j = 1, 2.

Equation 33 is the demand relation expressing the probability of modal choice in terms of the relative attribute-satisfaction variables Q_i, with the coefficients a_i (i = 1, ..., m) being the importances of the modal attributes that are to be estimated. Equation 34 is simply a set of identities defining the relative attribute-satisfaction ratings Q_i as the difference in attribute-satisfaction ratings for mode 1 minus mode 2. These identities provide the link with the supply-side relations of Eq. 35 that express for modes 1 and 2 separately the relations existing between the attributes of the modes on the supply side. Equation 35 indicates that there exist supply relations for all the m attributes of both modes 1 and 2. Although this may be true in general, it is likely that in any given model formulation some of the Q_i^j will be considered exogenous to the model—in each of which cases the coefficients of all the variables on the right side of the relevant supply relation will be 0 with the exception of the particular Q_i^j for which the coefficient is 1.

In the model the variable y and all those Q_i^j for which supply relations exist are the endogenous (i.e., jointly determined) variables. The remaining Q_i^j and the X_i^j are the exogenous (i.e., externally specified) variables of the model. As a simple example, suppose that on the demand side the probability y of preferring mode 1 to mode 2 is a function of m = 2 attributes (total travel time and comfort) expressed as their relative attribute-satisfaction ratings $Q_1 = Q_1^1 - Q_1^2$ and $Q_2 = Q_2^1 - Q_2^2$. On the supply side for mode 1 (automobile), Q_1^1 (travel time) is a function of the exogenous variables Q_3^1 (traffic) and X_4^1 (distance). On the supply side for mode 2 (transit), Q_1^2 (travel time) is a function of the exogenous variables Q_5^2 (total riding time) and X_6^2 (time between departures). The automobile comfort variable Q_2^1 is a function of traffic Q_3^1 and travel time Q_1^1, and transit comfort is exogenous. The model may then be written as

$$\left.\begin{aligned} y &= a_0 + a_1Q_1 + a_2Q_2 \\ Q_1 &= Q_1^1 - Q_1^2 \\ Q_2 &= Q_2^1 - Q_2^2 \\ Q_1^1 &= c_{01}^1 + c_{11}^1 Q_3^1 + c_{21}^1 X_4^1 \\ Q_1^2 &= c_{01}^2 + c_{11}^2 Q_5^2 + c_{21}^2 X_6^2 \\ Q_2^1 &= c_{02}^1 + c_{12}^1 Q_3^1 + c_{22}^1 Q_1^1 \end{aligned}\right\} \tag{36}$$

where the variables Q_1^2, Q_1^1, Q_1, Q_2^1, Q_2, and y are the jointly determined endogenous variables of the model, and the remaining ones are considered exogenous. To obtain consistent estimates of importance, we must obtain estimates of the coefficients a_0, a_1, and a_2 via an appropriate simultaneous-equation estimation procedure.

The important point to note is that, even though the data used to calibrate this model of consumer choice came from questioning consumers (the demand side), in general it is still necessary to introduce supply-side relations in order to obtain consistent estimates of the importance of product attributes. Because the nature of the supply side will vary from industry to industry, it is the objective of this paper to focus on the demand side.

Another point that needs emphasis here is that this model has been developed in terms of perceived levels of attributes. If consumer perception differs widely from, say, engineering fact, it may be difficult to validate what are a priori realistic supply-side relations. In that case, there would appear to be no choice but to work with single-equation demand models. This problem is discussed further below.

It should be mentioned that the estimated relative importance will depend on the pair of modes (or products) the traveler (or consumer) is asked to choose between. This arises, of course, from the fact that model calibration and associated statistical inference require the assumption of fixed or nonstochastic values of the explanatory variables (i.e., relative attribute-satisfaction values). If another pair of modes leads to significantly different relative attribute-satisfaction ratings, then the model will need to be recalibrated. In most cases, the supply equations will change as well. In either case, recalibration is required.

This need for recalibration is not a retraction of the assumption that U_i and, therefore, M_i are independent of the mode (or product) under consideration. It is simply a result of the fact that a given mode pair may not provide sufficient variability of the attribute values X_i. However, it does seem likely that validity of the assumption of additive utilities would depend on the range of X_i as well. For these reasons, it is likely to be necessary to recalibrate these models by using a number of different mode pairs if choice between a number of modes is of interest.

ADEQUACY OF ATTRIBUTE DESCRIPTION

A major question to be answered before we proceed to develop a simultaneous-equation, importance-estimation model is whether it will be possible to predict consumer choice based on estimated importances and relative attribute-satisfaction ratings. The issue being specifically addressed here is whether the set of (15) attributes fully (or at least adequately) describes the alternative modes from a consumer point of view. The relative importance of specific attributes is not at issue here. The argument is that, if the set of relative attribute-satisfaction ratings does not allow the prediction of mode choice with some degree of success, there would seem to be little sense in attempting to explain behavior based on the data. For this reason, it is desirable to perform a discriminant analysis (23). The discriminant analysis results are given below.

Item	Value	Item	Value
n_1	60	p_2	0.487
n_2	57	P_0	0.500
n	117	P	0.812
K	0.051	z	6.25
p_1	0.513	D^2	84.18

In all cases group 1 refers to the sample choosing automobile in preference to transit, and group 2 refers to the sample choosing transit. The notation used in the tables is as follows:

n_1 = group 1 sample size;
n_2 = group 2 sample size;
$n = n_1 + n_2$ = total sample size;
$K = \log_e(n_2/n_1)$ = classification rule criterion;
$p_1 = n_1/n$ = a priori probability of classification in group 1;
$p_2 = n_2/n$ = a priori probability of classification in group 2;
$P_0 = (p_1)^2 + (p_2)^2$ = "chance" probability of correct classification;
$P = m/n$ = proportion of sample correctly classified by discriminant-classification rule;
$z = (P - P_0)/\sqrt{P_0(1 - P_0)/n}$ = statistic to test significance of difference in proportions $(P - P_0)$; and
D^2 = Mahalonobis sample distance statistic.

In interpreting the above results, one should bear in mind that P is the proportion of individuals correctly classified within the sample by the sample discriminant-classification rule and is consequently an upward biased estimate of the correct classification rate of the population (24, 25). Comparison of P_0 and P, therefore, gives an overly optimistic view of the predictive power. However, P appears to be much better than the chance probability P_0, and the statistical test of z against the critical z value confirms that the difference is statistically significant (3.72) at better than the 0.01 percent level. The D^2 statistic also confirms a highly significant difference in the sample means.

To resolve the question of the extent of the bias in the estimates of the correct classification rates P, we used a "jackknife" estimation method. The method is similar to that of Lachenbruch (26), but to reduce the computation involved we based the estimates on 10 different discriminant functions per sample rather than the n suggested by Lachenbruch.

The resulting approximately unbiased estimates of correct classification rates, P′, are compared to the corresponding biased estimates P as follows:

Item	Value
Biased	
n	117
P	0.812
P_0	0.500
z	6.25
Unbiased	
n	110
P′	0.736
P_0'	0.505
z	4.85
Difference	
(P - P′)/P	0.94

Also given above are the "chance" probabilities P_0 and P_0', which give the appropriate comparisons for P and P′ respectively; the z values to test the differences between P and P_0 and between P′ and P_0'; and the difference P - P′ expressed as a fraction of P. The chance probabilities P_0 and P_0' are different as a result of the slightly smaller sample sizes used in the jackknife estimates.

The results indicate that there is an appreciable upward bias in the correct classification estimates P, but the unbiased estimate P′ is still very highly significantly different from the chance correct classification rate. The conclusion that there is significant discriminatory power in the data, thus, is not changed by a knowledge of the bias in P. Moreover, because the analysis was in terms of relative attribute-satisfaction ratings (i.e., difference), these results support the view that the semantic differential technique provided interval-scaled data—a requirement of the demand model.

Interpretation of the constant term in the demand equation can assist in determining the nature of omitted attributes in the linear model

$$y = a_0 + \sum_i a_i Q_i \tag{37}$$

where y is the probability of preferring automobile, and the constant term a_0 indicates the probability that the typical individual will prefer automobile to transit if all the Q_i are zero, i.e., if his satisfactions with the 2 modes are equal for all attributes.

For the sample under study, the a priori probability of preferring automobile was 60/117 = 0.513. The estimated value of a_0 was 0.477. The null hypothesis $a_0 = 0.513$ cannot be rejected even at the 50 percent level. Based on these findings and those of the discriminant analysis, it would appear that the original set of 15 attributes provides an adequate description of the 2 modes in question from a consumer-choice point of view.

The sample discriminant function coefficients associated with the 15 attributes are as follows:

Attribute	Coefficient	Attribute	Coefficient	Attribute	Coefficient
1	-0.06	6	-0.26	11	0.12
2	0.36	7	-0.10	12	0.05
3	0.02	8	0.18	13	0.17
4	0.03	9	-0.03	14	0.51
5	0.22	10	-0.09	15	0.25

It is important to note that these weights have often been referred to as relative importances in the literature (3, p. 18; 5, p. 370). As discussed in the section on supply-side formulation, these weights are not consistent estimates of importances as defined in the preceding section on importances. It is true that in the 2-group case discriminant analysis weights will be proportional to those of a regression analysis with a dummy-dependent variable implying that the linear demand Eq. 19 could be estimated in either way. Note, however, that there is no classical linear regression model equivalent to discriminant analysis for more than 2 groups and that only the regression model permits statistical inference regarding the relative importance of attributes. Statistical inference using discriminant analysis must be confined to the statistical significance of a particular set of attributes in predicting group membership, not to the individual relative importance of the attributes.

REDUCTION OF SEMANTIC REDUNDANCY

Developing a set of attributes that fully describe a group of products from a consumer point of view is a tedious process. Potential attributes and their end points must have meanings clear to the respondent. In general, it is not possible to develop a list that does not contain some semantic redundancy. Usually the initial list will become quite long. One of the authors used 65 semantic differentials to describe automobiles in a product clinic designed to pretest Chevrolet's Vega.

Figure 1 shows the 15 attributes for which satisfaction ratings were obtained. It is clear that they may contain semantic redundancy. An equal-tails test of the null hypothesis that the true population correlation coefficient for any pair of variables is 0 gives critical points of 0.182 at the 5 percent level and 0.238 at the 1 percent level. Examination of the correlation matrix indicated that, of the 205 elements to one side of the principal diagonal, 67 were greater than 0.238, demonstrating that, statistically speaking, many highly significant correlations existed.

These high intercorrelations give rise to the problem of multicollinearity if these correlated attributes are included as explanatory variables in a multiple regression model. The problem of multicollinearity in regression analysis is a perplexing one arising frequently in econometric studies; it is discussed, for example, by Goldberger (15, pp. 192-194). The problem arises in interpreting the estimated coefficients of the regression because, if high intercorrelations exist between some, or all, of the explanatory variables, it becomes difficult if not impossible to distinguish among the separate influences of the explanatory variables and obtain a reasonably precise estimate of their relative importances. Multicollinearity has the effect of producing large standard errors of the coefficients for the explanatory variables of an equation; as intercorrelations become higher, confidence in the reliability of the coefficient estimates is reduced (15, pp. 192-194).

Because of this problem and the additive-utility assumption, it is desirable to reduce the original set of attributes to a smaller set by removing those attributes that are highly correlated to others because of semantics. Care must be taken from the outset to identify those correlations that are likely to be due to supply-side relations and those that are due to semantics. This is accomplished most simply by establishing on an a priori basis those attributes that are likely to be correlated for supply-side reasons, e.g., automobile out-of-pocket cost and traffic. The objective here is to suggest a technique for handling the problems caused by semantic redundancies and also for assisting in the development of a nearly orthogonal set of attributes.

It seems reasonable to suppose that the traveler thinks in terms of a smaller number of (orthogonal) decision "factors" or "dimensions" than the 15 attributes given in the questionnaire. In fact, the demand model is constructed on the basis of additive utilities. But several attributes, for example, comfort and pleasantness, may actually be closely related to the same dimension of the mode-choice process because comfort and pleasantness when applied to a mode of transportation may mean about the same thing to people.

This hypothesis is supported by a correlation of 0.7 between, for example, attributes 1 (comfort) and 5 (pleasantness). Hence, it seems likely that several attributes are closely related to essentially the same dimension of the modal-choice decision. The problem arising out of this hypothesis—that of analyzing the basic dimensionality of a sample of observations on a large number of variables—can be addressed by factor analysis (27, p. 4).

A principal-components type of factor analysis on all 15 relative attribute-satisfaction ratings (Q_1) was performed. Varimax rotation of the first 9 principal components was also performed as an aid to interpretation. The results are given in Table 3.

Nine of the possible 15 principal components are given in Table 3. The choice of the 9 factors can be justified by the fact that the 88 percent of variance explained is substantial, but equally important these 9 factors may be interpreted as modal-choice "decision factors" in a way that is intuitively satisfying. For example, attributes 5 (pleasantness), 1 (comfort), and 7 (noise) have the highest loading in factor 1; 10 (traffic) and 8 (accidents) have the highest loading in factor 2; 4 (frequency) and 15 (waiting time) have the highest loading in factor 3. Conversely, attribute 14 (walking time) is the only variable with a high loading in factor 4, and this is consistent with the "prior" that walking time is relatively independent of other mode attributes. It was difficult to interpret the factors beyond the ninth as "different" dimensions of the modal-choice decision. It is interesting to note that Green and Rao have suggested that at least 8 attributes be used to describe a product (6, p. 38).

In general, the principal-components analysis of a set of variables that are prospective regressors in a multiple regression equation may be used in alleviating the multicollinearity problem in 2 ways. First, the principal-components solution may be used directly as suggested, for example, by Kloek and Mennes (28). The m-element vector of observations on the original variables is replaced by the p-element vector of linear combinations of the variable (i.e., factor "scores"), which are obtained by multiplication of the original variables by the loadings given in the principal-components factor matrix. These p-factor scores are then used as the explanatory variables of the regression.

Figure 5.

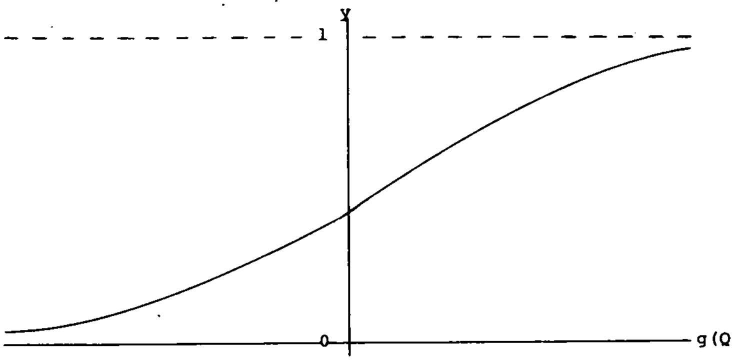


Table 2. Correlation matrix of semantic differential ratings.

Mode	Attribute	Dependability	Cost	Riding Time	Walking Time	Waiting Time
Automobile	Dependability	1.0000				
	Cost	0.3303	1.0000			
	Riding time	0.5855	0.4429	1.0000		
	Walking time	0.0671	0.0232	-0.0429	1.0000	
	Waiting time	0.2618	0.1585	0.2871	-0.0425	1.0000
Transit	Dependability	1.0000				
	Cost	0.4545	1.0000			
	Riding time	0.4463	0.4746	1.0000		
	Walking time	0.1560	0.2328	0.2468	1.0000	
	Waiting time	0.7252	0.3880	0.4615	0.3765	1.0000

Table 3. Summary of varimax rotation results.

Rotated Factor		Attribute	
Number	Description	Number	Factor Loading
1	Physical comfort	5	0.90
		1	0.87
		7	0.74
		6	0.68
		11	0.62
		13	0.33
		9	0.33
2	Congestion	8	0.87
		5	0.38
		10	0.38
3	Service frequency	4	0.90
		15	0.60
		11	0.40
4	Walking time	14	0.98
5	Weather exposure	3	0.93
6	Dependability	2	-0.81
		15	-0.45
		13	-0.40
7	Social comfort	9	0.87
		11	0.38
8	Riding time	10	0.83
		13	0.53
9	Cost	12	-0.85
		13	-0.52

Obviously, however, the regression coefficient estimates will not be the same for the 2 regressions. In fact, the difficulties involved in interpreting the coefficients of the factor score regression represent the major drawback of the use of this method in structural analysis. The interpretation of a regression coefficient as the magnitude of the effect on the dependent variable produced by a unit change in an explanatory variable (factor) becomes difficult where the explanatory variable is a linear combination of the observed variables (relative attribute-satisfaction ratings). Very often the sum of the weights for those attributes not loading heavily is higher than the sum of the larger weights that provided the factor interpretation. Moreover, the absence of well-tried means of testing the statistical significance of the coefficients estimated via principal-components analysis further complicates interpretation of the regression coefficients. Thus, although the method of using the principal-components solution directly in the multiple regression does remove the multicollinearity problem and is considered by some to introduce a certain objectivity to the estimation procedure, it is of little help where the aim is interpretation of the coefficients of the regression equation as structural parameters.

An alternative use of the principal-components analysis in reducing the effects of multicollinearity is to select a subset of p from the m original variable on the basis of their factor loadings in the p principal components (which account for "most" of the sample variance) and perform the regression on this subset of the original variables. The most obvious criterion is to select those p variables that have the highest loadings in each of the p components. The resulting set of variables will tend to have low intercorrelations, thus reducing (although not eliminating) multicollinearity, and the use of the actually observed variable in the regression simplifies interpretation of the associated coefficients. Furthermore, the method allows the inclusion or exclusion of any of the variables dictated by supply-side considerations on grounds of the model structure.

Use of principal-components analysis in this latter indirect way would then seem to be a much more appropriate method than the former in most instances where regression coefficients are to be interpreted structurally. Selection of a subset of the original variables so that highly intercorrelated variables are omitted is the standard procedure for dealing with multicollinearity in regression; the use of principal-components analysis in the way outlined here merely provides a systematic and rational basis for selection of the variable to be included. This view is supported by Green and Tull (5, pp. 422-426) in their review of the usefulness of principal-components analysis.

In this case, the principal-components analysis of relative attribute-satisfaction data indicates that fewer than 15 attributes adequately account for the dimensionality of the modal-choice decision; the first 9 factors are intuitively interpretable as "different" dimensions. These 9 are, moreover, fairly easily identified with attributes in the original list of 15 so that the method discussed above is helpful in selecting variables for subsequent regression analysis. Accordingly, on the basis of the principal-components analysis, the following 9 attributes were selected for further analysis:

Description	Number
Comfort in vehicle	1
Dependability of on-time arrival	2
Protection from weather while waiting	3
Exposure to undesirable behavior of others	9
Traffic	10
Out-of-pocket cost of trip	12
Total time spent riding	13
Total time spent walking	14
Total time spent waiting	15

Although many of the correlations among these 9 were still statistically significant, the very high correlations present in the 15-variable set of attributes were removed. The multicollinearity problem is, thus, still present, but its seriousness is lessened. Strictly speaking, it is now necessary to be sure that the reduced set of attributes is adequate, that is, to repeat the discriminant analysis procedure.

Although it is assumed that the retained attributes form a set that, in fact, represents the various dimensions of the modal choice as perceived by the traveler, there may still remain correlations among the relative attribute-satisfaction ratings because of supply relations. For example, examination of the correlations for the 9 attributes listed above revealed that the highest correlations occurred between attributes 12 (cost) and 13 (riding time), 10 (traffic) and 13 (riding time), and 2 (dependability) and 15 (waiting time). These correlations do not, however, arise for semantic reasons but for reasons that may be labeled supply-side oriented; that is, cost and riding time are correlated because there is a functional dependency between cost and riding time, not because travelers understand the same thing by out-of-pocket cost and total time spent riding. In this sense, the correlations between traffic and riding time and between dependability and waiting time also arise as a result of such supply-side relations (although the correlation matrix obviously does not indicate the direction of causality of the relations).

Also the semantic correlations are traveler-dependent and, hence, arise from relations on what have been termed the demand side, and the functional correlations arise from relations that are logically mode-dependent and on the supply side. In other words, the analyst must determine the relevant supply-side relations and provide the linkage between supply and demand.

Thus, correlations among these data arise for both semantic and supply-side reasons. It is important to appreciate that, although principal-components analysis is helpful in summarizing the data in a way that facilitates recognition of the former, it is of little help in distinguishing between the two. The analysis method is, in other words, unable to identify the underlying causalities that define the structure of the data. The factor analysis has been done in terms of relative attribute-satisfaction ratings rather than separately for each mode—automobile and transit. Because the modes have different supply-side relations, using relative attribute-satisfaction ratings tends to confound the supply sides leaving the semantic problems. Separate principal-components analyses for each mode lead to results that did not yield to logical interpretation even with varimax rotation.

In this case, the principal-components analysis supports the view that the "experiment" underlying the attribute-satisfaction and modal-choice data is not a simple "single-equation" economic process but a complex process of interrelated and simultaneous relations. The modal-choice decision experiment generates observations that reflect the equilibrium of supply and demand relations; a properly structured model of modal choice must then make explicit the simultaneous interaction of these supply and demand relations.

VALIDATION OF SOME CRUCIAL ASSUMPTIONS

The object of this section is to validate some of the important assumptions of the demand equation formulation given in an earlier section. The assumed relation for the exponential type of utility function and linear U to Q mapping is

$$Q_i^j = 1 + (k - 1)\left(1 - e^{-\lambda_i X_i^j}\right) \tag{10}$$

for comfort attributes and

$$Q_i^j = 1 + (k - 1)\, e^{-\lambda_i X_i^j} \tag{11}$$

for cost attributes, where k is the number of intervals on the semantic scale, equal to 7 for these data. An alternative relation between Q_i^j and X_i^j can be developed on the basis of a linear utility function and the linear U to Q mapping. It has the linear form,

$$Q_i^j = \mu_{0i} + \mu_i X_i^j \tag{38}$$

where the parameter μ_i is positive for comfort attributes and negative for cost attributes.

Equations 10 and 11 are central to the construction of the demand equation of the model, and the linear U to Q mapping assumption leads to the interpretation of the parameters of that equation as importances. It is desirable then to investigate the validity of both the exponential relations of Eqs. 10 and 11 and the linear Eq. 38 inasfar as the data allow.

In the data a sample of observations is given on both Q_i^j and the corresponding X_i^j for the following attributes:

Attribute-Satisfaction Rating	Attribute Value
Automobile mode	
Total time spent riding (QA13)	Total riding time, min (XA13)
Total time spent walking (QA14)	Total walking time, min (XA14)
Transit mode	
Frequency of vehicle departure times (QT4)	Headway of vehicle departures, min (XT4)
Out-of-pocket cost (QT12)	Fare (XT18)
Total time spent riding (QT13)	Total riding time (XT13)
Total time spent walking (QT14)	Total walking time (XT14)
Total time spent waiting (QT15)	Total waiting time (XT15)

From the sample of 117 individuals making a choice between automobile and rail transit, a subsample of 84 gave complete responses on all the variables listed above. This subsample is used to estimate the assumed Q/X relations in this section. The estimations of both the exponential and linear forms are given below.

All the attributes listed above are what have been termed cost attributes; i.e., increasing values of the attribute are associated with decreasing utility levels. This is the case simply because attribute-value measurements are not available for the comfort attributes, which tend to be qualitative attributes. Therefore, only the relations of the form of Eqs. 10 and 11 can be estimated.

Equation 10 rewritten as a regression equation is

$$(Q_i^j - 1) = \varkappa_i e^{-\lambda_i X_i^j} \tag{39}$$

where $\varkappa_i$ and λ_i are both parameters to be estimated. It is necessary to estimate relations of Eq. 39 directly by nonlinear regression in order to obtain estimates of $\varkappa_i$ and λ_i. The relations given in Table 4 were estimated by a nonlinear least squares algorithm described by Hartley (18). Before these results are studied, the following points should be made.

From comparison of Eqs. 11 and 39, it would be expected that the estimated value of $\varkappa_i$ would be equal to (k - 1) or 6, that is, independent of the attribute i if the hypothesized relation between Q_i^j and X_i^j fits the data exactly. The closeness of the coefficient $\varkappa_i$ to 6 in the results given is, therefore, an indication of the validity of the relation and, hence, the assumption of an exponential utility function and linear U to Q mapping.

The R^2 statistics given for the regression results are computed from 1 minus the ratio of the sum of squares about the exponential regression curve (the sum of squared residuals) to the sum of squares about the mean. This indicates the goodness of fit to the data of a regression curve of the form shown in Figure 6. However, the observations on Q_i^j being fitted are not continuous over the interval 1 to 7, as Figure 6 implies, but integer valued. This being the case, the appropriate curve by which to judge fit should really be a step function as shown in Figure 7.

If all observed points fell on the step function, it would be as good a fit as possible; the sum of squared residuals about the exponential regression curve would, however, obviously not be 0, and hence the R^2 statistic would be less than 1. In general, the sum of squares about the regression curve tends to be greater than that about the step function, and consequently the R^2 statistics tend to give conservative indications of the goodness of fit. As a supplemental measure of the fit of the data to the regression

Table 4. Summary of estimated exponential Q/X relations.

Attribute	Variable Q	Variable X	K Est.	K t Stat.[a]	λ Est.	λ t Stat.[b]	Regression R^2	Proportion Fitted ±1[c]
Automobile								
Riding time	QA13	XA13	7.09	1.49	0.0199	5.48	0.353	0.667
Walking time	QA14	XA14	6.08	0.34	0.0253	3.71	0.153	0.881
Transit								
Frequency	QT4	XT4	5.28	-2.26	0.0172	3.55	0.178	0.667
Riding time	QT13	XT13	5.59	-0.73	0.0148	3.91	0.192	0.512
Walking time	QT14	XT14	5.79	-0.44	0.0245	3.61	0.153	0.643
Waiting time	QT15	XT15	5.97	-0.09	0.0416	5.88	0.425	0.798

Note: Critical t (5 percent) = 1.989; critical t (1 percent) = 2.637; critical R^2 (1 percent) = 0.078.

[a]To test null hypothesis K = 6. [b]To test null hypothesis λ = 0. [c]Explanation given in text.

Figure 6.

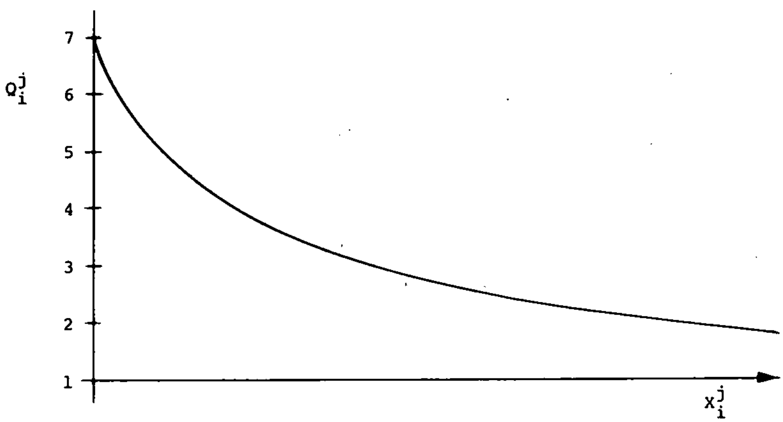
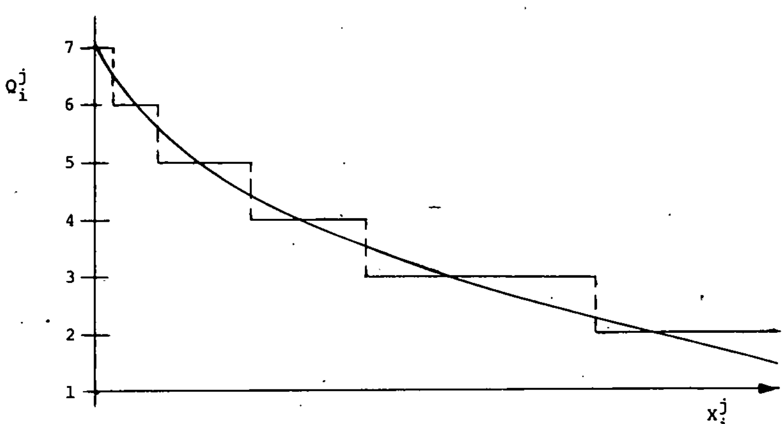


Figure 7.



curve, for each equation, the proportion of observations on Q_i^j having values within ±1 of the predicted value was computed and is given in Table 4 as "proportion fitted ±1." The t statistics given for the estimates of $\varkappa$ are the appropriate statistics to test the null hypothesis $\varkappa = 6$. The t statistic computed for the λ estimates are the familiar null t statistics.

The results given in Table 4 show a convincing fit of the exponential Q/X relation to the data for the 6 attributes included. The estimated values for $\varkappa$ are all close to 6, and the associated t statistics show that (with 1 exception) the differences from 6 are insignificant (judging significance under the usual assumptions of normality) for all estimates. The t statistics associated with λ estimates also indicate these all to be reliable. The R^2 statistics, although not very large, are in all cases highly significant and indicate reasonably close fits—given the nature of the data. For example, no stratification based on demographics has been made. The proportions of fitted values within ±1 of the observed values also indicate reasonable fits.

The regression of Eq. 39 was also performed on the data with the constant term $\varkappa$ constrained to equal 6, in order to give estimates for the parameter λ that could be compared among attributes. These results are given in Table 5. Interesting results are the values of the parameter estimates for the attributes riding time and walking time for the automobile and transit modes: viz.

	Automobile	Transit
Riding	0.015	0.017
Walking	0.024	0.027

In the demand model formulation, it was assumed that the satisfaction or utility obtained from a given modal attribute level is independent of the mode considered. The closeness of the above λ estimates provides an interesting validation of this assumption.

The results given in Table 6 are the estimated Q/X relations of Eq. 38, which may be estimated via the linear regression equation

$$Q_i^j = \mu_{0i} + \mu_i X_i^j \tag{40}$$

where μ_0 and μ_i are parameters to be estimated. For cost attributes, the regression results are for the same sample of 84 observations as were used in the nonlinear estimations. The R^2 statistics are all significant and, although not high, are close to those given for the corresponding exponential relations given in Table 5, indicating a similar fit to the data. The t statistics of μ also indicate all estimated coefficients to be significantly greater than 0 at a 1 percent confidence level. As expected for cost attributes, a μ_0 of approximately 7 was obtained. The null hypothesis $\mu_0 = 7$ is not rejected at the 1 percent level in all cases but 1.

Two important assumptions of the model have been supported by the evidence provided here. The first was that the U_i could be specified to be mode independent. The second was that of a linear mapping from U to Q. This assumption is critical to the determination of importance by estimates of a_i. The assumption appears to stand up well in connection with either an exponential or linear utility function assumption. The final basic assumption used in deriving the demand relations, viz., additive utilities, implies the need to specify an attribute description that is (nearly) orthogonal from a semantic point of view. Methods for accomplishing this were discussed in an earlier section. Correlation due to supply-side relations does not cause difficulties in this regard.

ESTIMATION OF UTILITY-FUNCTION PARAMETERS OF TARGET MARKETS

One of the areas requiring additional research is that of estimating utility functions of various consumer groups—so-called target markets. The results reported here are preliminary but encouraging. Assume a demand function of the form of Eq. 19. To estimate relative importances M_i/M_n as a function of demographics requires only that the sample be stratified into different groups and an independent analysis be performed for each group. This was not possible here because of degree-of-freedom problems given the sample size available.

However, an attempt was made to estimate the Q/X relation as a function of income. Although perhaps not obvious, it turns out that it is difficult to develop unassailable hypotheses as to how changes in income will affect the λ parameter of the utility function. Only waiting time appears straightforward. The higher income is, the larger the expected $|\lambda|$ is. The following equation yields estimates by nonlinear regression:

$$Q_i - 1 = 6e^{-\lambda X_i} \tag{40}$$

where $\lambda = A + BY + CY^2$; A, B, and C are parameters; and Y is a dummy income variable. The adjusted R^2 was 0.45 compared to 0.43 for the λ = constant model (Table 5) where the λ estimate was -0.0422. The tabulation below gives $-\lambda$ as a function of income.

Income (dollars)	$-\lambda$ Value
5,000 to 7,000	0.0218
7,000 to 10,000	0.0378
10,000 to 15,000	0.0460
Over 15,000	0.0461

As expected, $-\lambda$ increases with income, indicating that dissatisfaction with waiting time increases as income increases.

ESTIMATES OF RELATIVE IMPORTANCE AND MODEL STRUCTURE

The purpose of this section is to show that estimates of the parameters of the demand equation and, therefore, estimates of importances are highly sensitive to model structure. These estimates are not only sensitive to demand-side structure but also sensitive to the insertion of a supply side into the model. Three different models are considered.

Model 1 is the single-equation linear probability model given by Eq. 19. Estimation is by ordinary least squares. Parameter estimates are inefficient, that is, are not minimum variance because of the heteroscedasticity problem. Also the model structure is poor because the function is illogical at the ends. Of course, ignoring the supply side implies that the estimates are not only inefficient but also inconsistent. Given that this model and discriminant analysis yield identical estimates of relative importances, this is probably the most frequently applied statistical inference model for determining attribute importances.

Model 2 is also a single-equation importance-estimation model; the logistic function demand model is given by Eq. 21. Estimation is by nonlinear least squares. The estimation procedure would yield the best unbiased estimates if the data used to calibrate the model were not the result of supply and demand interaction. Hence, the estimates are inconsistent.

Model 3 is a simultaneous-equation model incorporating the supply side developed by Sherret (22). The model has the general form given by Eqs. 33, 34, and 35. Five supply equations were developed. Because the model was the linear probability demand function, parameter estimates are still inefficient. However, the estimation procedure used, essentially 2-stage least squares, yields consistent estimates of the parameters. Hence, model 3 parameter estimates are consistent but inefficient.

Table 7 gives the estimates of relative importance obtained by each of the 3 models. For comparison purposes, 4 attributes are shown: walking time (Q14), dependability

(Q2), waiting time (Q15), and riding time (Q13). The 2 single-equation models (1 and 2) yield very different results. Both yield 1 parameter estimate that is insignificant. In fact, waiting time and riding time reverse roles in the 2 models, 1 of the 2 being insignificant and, therefore, least important in both models. Both models 1 and 2 imply that walking time is most important and dependability is next most important. In terms of the t statistic, model 2 provides lower variance estimates.

Model 3 yields estimates of relative importance that are very different from those of either model 1 or model 2. All of the parameter estimates are significant, in fact, for all 4 attributes; the t statistic is highest for model 3. Moreover, dependability is found to be most important, walking time second, riding time third, and waiting time least important. The rank-order importances for the 3 models are as follows:

Attribute	Model 1	Model 2	Model 3
Dependability	2	2	1
Walking time	1	1	2
Riding time	4	3	3
Waiting time	3	4	4

Although the results of model 3 seem most sensible to the authors, the point is that they are very much different from those of the other 2 models. It seems that supply-side considerations simply cannot be ignored as well as the demand-side considerations.

As an aside, it should be mentioned here that in practice it would be wise to obtain measures of importance directly from consumers in addition to obtaining them by the statistical inference technique suggested above. This can be done via the semantic differential with end points "very important/very unimportant" (29). Paine et al. (30) measured attribute-satisfaction ratings and importances for the mode-choice decision problem via the semantic differential. Their results regarding relative importance were similar to those obtained above in that reliability of destination achievement was found to be most important and travel time was next, where travel time included expected value of travel time and dependability of on-time arrival. They also found comfort attributes way down the list in terms of importance for the work-trip mode choice. Paine et al., however, determined only rank-order importances and made no attempt to relate their results to the choices people actually make.

APPLICATION OF RESULTS

The purpose of this section is to illustrate how the estimated importances can be used along with the attribute-satisfaction data in advertising or product planning or both. Mean relative attribute-satisfaction ratings divided by first choice of automobile and transit are as follows:

Attribute	Automobile	Transit
Dependability	0.67	-1.70
Walking time	1.73	0.42
Riding time	0.78	-1.08
Waiting time	1.97	0.25

As expected, both groups give automobile the edge for walking and waiting time but disagree concerning dependability of on-time arrival and riding time.

Table 8 gives mean attribute-satisfaction ratings for automobile and transit separately by first choice of automobile and transit. Assume that the question of interest is how to improve patronage of transit by advertising.

The last column gives the difference between mean ratings of transit given by those choosing transit and those choosing automobile. Along with the automobile ratings, it provides some information for estimating $\Delta Q/\Delta C$, that is, the degree to which it may

Table 5. Summary of estimated exponential Q/X relations for κ constrained to 6.

Attribute	Variable Q	Variable X	Est. λ	Regression R^2
Automobile				
Riding time	QA13	XA13	0.0150	0.332
Walking time	QA14	XA14	0.0235	0.152
Transit				
Frequency	QT4	XT4	0.0258	0.128
Riding time	QT13	XT13	0.0171	0.186
Walking time	QT14	XT14	0.0271	0.151
Waiting time	QT15	XT15	0.0422	0.425

Note: Critical R^2 (1 percent) = 0.078.

Table 6. Summary of estimated linear Q/X relations.

Attribute	Variable Q	Variable X	μ_0 Est.	t Stat.[a]	μ Est.	t Stat.[b]	Regression R^2
Automobile							
Riding time	QA13	XA13	6.98	-0.05	0.0641	6.68	0.352
Walking time	QA14	XA14	7.04	0.19	0.1319	3.84	0.152
Transit							
Frequency	QT4	XT4	6.21	-3.09	0.0722	4.45	0.194
Riding time	QT13	XT13	6.42	-1.43	0.0587	4.71	0.213
Walking time	QT14	XT14	6.67	-0.86	0.1087	3.95	0.160
Waiting time	QT15	XT15	6.57	-2.03	0.1455	8.02	0.440

Note: Critical t (5 percent) = 1.989; critical t (1 percent) = 2.637; critical R^2 = 0.078.
[a]To test null hypothesis $\mu_0 = 7$. [b]To test null hypothesis $\mu = 0$.

Table 7. Comparison of importance-estimation models.

Attribute	Model 1 Est. Coef.	t Stat.	Rel. Import.	Model 2 Est. Coef.	t Stat.	Rel. Import.	Model 3 Est. Coef.	t Stat.	Rel. Import.
Q14	0.0706	3.569	1.000	0.6091	3.589	1.000	0.0804	4.232	1.000
Q2	0.0525	2.712	0.744	0.4333	2.802	0.711	0.1027	2.936	1.277
Q15	0.0447	2.063	0.633	0.2283	1.547	0.375	0.0493	2.110	0.613
Q13	0.0233	1.139	0.330	0.3577	2.286	0.587	0.0647	2.903	0.804

Note: Critical $t_{0.025,111}$ = 1.981.

Table 8. Mean attribute-satisfaction ratings.

Attribute	Automobile Ratings: First Choice Automobile	First Choice Transit	Rail Transit Ratings: First Choice Automobile	First Choice Transit	Difference
Dependability	5.42	4.23	4.75	5.95	1.20
Walking time	6.52	6.53	4.78	6.10	1.32
Riding time	5.05	4.45	4.27	5.54	1.27
Waiting time	6.67	6.35	4.70	6.10	1.31

be possible to change the transit ratings of people who choose automobile. Walking time may be ruled out immediately on the assumption that people know how far it is to the nearest transit stop. Given the attribute importances, the decision to advertise regarding dependability, riding time, or waiting time (frequency of service) depends on the $\Delta Q/\Delta C$ estimates. These estimates could be obtained via pretesting ads with automobile commuters. As discussed earlier, the product of relative importance $\Delta U/\Delta Q$ and $\Delta Q/\Delta C$ is the test criterion. However, because dependability is twice as important as waiting time and 50 percent more important than riding time and because commuters likely are aware of the schedules, it would seem that dependability would get the nod.

From the point of view of product planning, rail transit patronage would seem to be severely hampered because of fixed routes and the associated walking time required. This suggests the possibility of developing multimode transportation systems. Such systems are currently under study (31).

SUMMARY AND CONCLUSIONS

The object of this paper is to outline and illustrate a methodology for estimating the relative importance of product attributes. Product-attribute descriptions were developed in terms of attribute-satisfaction ratings obtained by a particular type of semantic differential. This was required because of the qualitative nature of many attributes. Satisfaction ratings, rather than attribute ratings, were obtained because of the apparently insurmountable difficulties in obtaining reliable measures of the latter for qualitative attributes.

The use of attribute-satisfaction ratings rather than attribute ratings required the development of a family of demand relations specified in terms of attribute-satisfaction ratings. It was shown that relative importances could be defined in the context of the parameters of these relations.

In a choice between 2 products, the probability of preferring product 1 to product 2 was determined to depend on the consumer's satisfaction with both products on each product attribute (relative attribute-satisfaction ratings) and the relative importance of each of these product attributes. Attribute importance was determined to be proportional to the maximum utility obtainable from any level of the attribute.

It was argued that correlations among attribute-satisfaction ratings were likely to arise for 2 reasons: The first is the existence of supply-side relations; the second is semantic redundancy in the set of attributes. Failure to explicitly specify these supply-side relations will lead to inconsistent estimates of importances. Failure to handle the semantic-redundancy problem will lead to importance estimates with unduly high variance.

It was suggested that discriminant analysis and principal-components type of factor analysis be used in an iterative fashion to develop a set of attributes that fully describe the product from a consumer point of view but are as orthogonal as possible.

The demand-side relations were developed on the basis of 3 fundamental assumptions: additive utilities, exponential utility function specified independent of the product, and linear mapping from utilities to attribute-satisfaction ratings. Empirical evidence of the validity of the latter 2 assumptions was provided. Some evidence was provided that it may be possible to estimate relative importance as a function of demographic variables.

It was shown that estimates of relative importances vary greatly depending on model specifications. It was argued that the most frequently used statistical inference model is likely to lead to importance estimates that are both inefficient and inconsistent. A methodology is suggested that can lead to estimates that are both efficient and consistent.

Finally, an attempt was made to illustrate how relative attribute-satisfaction ratings and relative importances can actually be used to facilitate advertising or product planning or both.

In conclusion, it appears that, although considerable time and money will be required to develop an importance-estimation model based on the methodology described above, the payoff in terms of improved understanding of the consumer decision-making process can be considerable.

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Workshop 6

ANALYTICAL STRUCTURES

OBJECTIVES

Identify, review, and evaluate the various analytical structures currently used and proposed for travel demand forecasting.

Identify and recommend improvements.

Develop a recommended program of research.

EXAMPLES

The analytical structure of a travel demand forecasting technique is the way it is formulated, manipulated, sequenced, and solved (generally symbolically or mathematically). The structure fundamentally affects many of its characteristics, including its sensitivity to alternative transportation proposals, and its prediction characteristics. Examples of analytical structures are direct versus indirect, abstract versus mode specific, aggregate versus disaggregate, behavioral (causal) versus associative, optimizing versus simple predictive, correlative versus trend, multimodal versus unimodal, econometric versus multinomial logit, simultaneous versus simple regression, and incremental versus iterative.

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Report

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The view of Workshop 6 is that analytic structures cannot be considered independently of transportation theory, that neither is likely to develop in meaningful ways outside of the context of real problems, and that the structure of the real problem dictates or at least suggests the structure of the analytic tools required for its solution. Nor can travel demand estimation models be viewed independently of the remainder of the urban planning process. Economic development, urban land use, urban activity patterns, and population growth all have impacts on future travel patterns. General questions to be considered about any analytic structure for forecasting travel demand must include at least the following: Are the results sensitive to land use? Are the results sensitive to transportation policies and at what levels? How can the results be disaggregated for equity analyses? Are the results transferable at some or any level of aggregation? If transferability exists, can it be used to eliminate the need for further origin-destination studies except possibly to answer new behavioral questions?

The interactions among transportation supply, urban activity distribution, and travel demand are areas where research is badly needed. The estimation of future travel demand and the evaluation of impacts of various transportation options cannot be accomplished satisfactorily without a full consideration of these interactions. Research is needed in developing and improving analytical structures that quantitatively describe these interactions. The research should include short-run, small-change (marginal), long-run equilibrium, and dynamic models. Attention should be given to the effects of land use regulations and their impact on the control of traffic and possible use for that purpose. Short-range models are required to provide quick response to developers' proposals in terms of transportation impacts. Models should have capability of investigating land use management as a means of protecting the transportation system.

There is a need for research to explore systematically analytic structures for aggregation of data related to transportation system attributes. The following dimensions, as well as others, must be explored:

1. Effects of zone size including access

and egress links due to the spatial dispersion of trip ends within analysis zones;

2. Aggregation of paths, submodes, and modes where the analysis requires such aggregation;

3. Time aggregation, including time-of-day effects, aggregate capacity constraints, and aggregated measures of impedance and performance;

4. Aggregation across population and income groups; and

5. Relation between market segments and other aggregations with a view to adequate definition of market segments.

Until such time as generally accepted aggregation methods are found, the problem should explicitly be addressed by the developers and users of models. Publications documenting model development should include a section suggesting aggregation methods to be used with the models and analyzing the possible effects of aggregation on the model's performance. Similarly, reports on the calibration of the models should carefully specify the aggregation methods used and their effects.

There is a need for the forecasts to be stated in probabilistic terms in the sense that at least some measure of the variability of the estimates should be provided. In this direction, studies should be made to explore the use of Monte Carlo and gaming techniques as well as closed-form models of uncertainty related to making probabilistic forecasts.

A large part of the information required for comprehensive evaluation and impact analysis is created as part of the existing UTP process or is relatively easily derivable from its output. To make efficient use of these data requires the development of efficient methods for storage and retrieval of the information; effective and extensive post-processing tools, including evaluation models, manipulating and summarizing programs, and batch and interactive computer graphics systems; compatibility between these tools and the information methods to ensure fast and easy processing; and efficient analytical structures for "pivot-point" analysis compatible with the information methods.

These tools can be used to obtain fast demand estimates and rapid response to decision-oriented questions that are functions of these estimates.

Transportation planning is a continuous process and not a set of unrelated projects. Workshop 6 proposes that continuing transportation planning agencies be charged with maintenance of comprehensive historical data and a continually updated data set. The updated set is intended to be used with the tools described above for short-range, small-scale planning. In this case model sophistication is being traded for more up-to-date input data. The resulting time series data can be used for the testing and refinement of the operational models. There is a need for research to define a minimal, standard data set and methods for its acquisition and processing.

There is a need for models that reflect the effects of operator behavior on travel demand estimates. In particular, the effects of the quality of management need to be considered.

Current models not only fail to adequately treat the questions related to systems management but also give little attention to marketing effects. The effects of marketing need to be better understood, and its relation to value-oriented decisions on other than a utility basis needs to be described. Models that relate marketing to transportation forecasts and to transportation variables are needed.

Travel demand estimation models could legitimately be used to limit or manage traffic on either a local or area-wide basis. The purpose might be to meet ambient air quality standards, produce desired life-styles, or reduce noise and accidents. To do this, the models would have to produce not necessarily flows or links but perhaps vehicle-miles of travel by time of day, trip numbers and lengths, person-miles of travel, and possibly speeds and travel times. The models need to be capable of dealing with automobile-free zones, parking, management policies, capacity restraints, and so on.

Resource Paper

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This paper has as its major goal the initial formulation of a research program on analytical structures for travel demand forecasting and the discussion of the motivations for this formulation.

By travel demand forecasting is meant the process of predicting the travel that will occur when a given transportation system is provided within a given activity system. (By activity system is meant all aspects of the world that are not parts of the transportation system, but that do have effects on that system.) This definition of travel demand assumes that we are looking at trip-making decisions only and, therefore, can ignore long-range changes in the activity system caused by travelers' changing their places of residence and work, except as those changes may be externally specified. The long-range changes in the activity system are left for the activity shift and land use modelers, although it is recognized that the transportation system is an important determinant of those long-range changes.

By analytical structure is meant 2 things: (a) primarily, the form of the travel demand forecasting function, whether it be a closed mathematical expression or an algorithm; and (b) to a lesser extent, the independent variables used in the forecasting process. More details and motivation for this definition are given later.

This paper is structured into 3 somewhat unequal sections. Section 1 includes extended definitions of demand models and analytical structures and a listing of some alternative structures that have been applied to the travel demand forecasting problem. Section 2 discusses the factors that must be considered in deciding on appropriate analytical structures for travel demand forecasting, and identifies a number of areas of necessary research. Section 3 brings all of these together as a concise initial formulation of a program of research in the area of analytical structures.

DEFINITIONS AND ALTERNATIVES

Analytic Definition

Because we are concerned with forecasting travel demand, it is useful to develop an analytic definition with a basis in consumer demand theory as it has been developed in the field of microeconomics (7). Beginning with the preferences of individual consumers, Henderson and Quandt postulate utility functions that state the level of utility associated with the purchase of quantities Q_i of a number of goods.

$$U(Q_1, Q_2, \ldots, Q_n) \tag{1}$$

Also, the consumer's budgetary limit is expressed as

$$\sum_{i=1}^{n} P_i Q_i \leq Y \tag{2}$$

where P_i is the price of the ith good, and Y is the total budget, or income, of the consumer. When U is maximized subject to the budgetary constraint, the following relations are obtained among the variables:

$$Q_i^{\circ} = D_i(P_1, P_2, \ldots, P_n, Y) \tag{3}$$

for all i, where Q_i° is the optimal quantity of good i purchased by a consumer with income Y. The functions $D_i(\cdot)$ are demand functions in the classical economic sense. They relate the quantity of a good consumed to the prices of all goods and to the income level of the consumer.

In theory all goods that contribute to the consumer's utility must be included in each demand function. Practically, however, it is impossible to find significant relations between the prices of many goods and the demand for others. We, therefore, group the subset of all prices that significantly affect the quantity of good i into a vector P. These prices include (a) the price of good i itself and (b) the prices of goods that are substitutes for good i.

Using the vector P, we can rewrite the demand function as follows:

$$Q_i^{\circ} = D_i(P, Y) \tag{4}$$

This equation represents the demand function for an individual. The summation of these functions to obtain total demand can be accomplished, at least theoretically, by assuming that individuals can be grouped into subsets of the total population with similar utility functions and income levels. Each subset can be described by socioeconomic variables, S, which include Y. This leads to the following functional form for total demand functions:

$$Q_i = D_i(P, S) \tag{5}$$

To adapt this general formulation to transportation demand, we must recognize that transportation is a good that is a complement to the demand for many other goods. Consumers travel to the corner to purchase bread; they travel downtown to purchase meals at restaurants; they travel to Florida to purchase sun in the winter; they travel to their working places to trade their labors for incomes. Transportation is therefore termed an intermediate good. Although it is a complement to many other goods, the quantity of transportation consumed does not contribute positively to the utility function, U. The demand for transportation is a derived demand: It is due to the demand for other goods rather than to its own contribution to the consumer's utility.

One approach to transportation demand forecasting, therefore, would be to model the demand for the final goods and services that result in transportation consumption. To date, however, this has proved to be too difficult. Instead, trips are typically classified according to trip purpose (class of final good), and the demand for transportation for each purpose is modeled separately. Also, an additional class of independent variables, measuring the attraction or intensity of the final activities, A, is added to the demand functions. Therefore, when the subscript i in Eq. 5 refers to a transportation good, V^n_{klm} (trips for purpose n from origin k to destination l by mode m), the general demand function becomes

$$V^n_{klm} = D^n_{klm}(P, S, A) \tag{6}$$

Another characteristic of transportation is that the traveler "pays" in a number of ways when he consumes transportation. There are a number of "prices" that include not only money paid but also time consumed, discomfort experienced, and risks endured. These and other prices can be classified together as level-of-service variables, L. The level-of-service variables have an added dimension not present in the prices, P. For each price, P_i, there exists a vector of level-of-service variables, $L_i = (P_i, t_i, c_i, s_i, \ldots)$ where P_i = price, t_i = travel time, c_i = comfort index, and s_i = safety index.

Our final general analytical expression of a travel demand function is obtained by substituting L for P:

$$V^n_{klm} = D^n_{klm}(L, S, A) \tag{7}$$

Equation 7 serves as the starting point for considerations of the analytical structure of travel demand forecasting techniques. It is useful to summarize the major ways in which this function differs from Eq. 5, the general demand formulation.

1. Because there are many costs associated with travel, monetary prices, P, are replaced by level-of-service variables, L.
2. Because transportation is a derived demand, travel must be predicted by trip purpose and must be a function of the activities, A, available at the destination.

The overall goal of this paper is to formulate a program of research that will lead to answers to the following questions:

1. What forms of the function D^n_{klm} are appropriate for various kinds of travel demand forecasting?
2. What variables belong in each of the sets of independent variables shown in Eq. 7?

Some Alternative Structures

Before discussing the factors that must be considered in answering the above questions, we should classify and list some of the major types of analytical structures for travel demand forecasting that have been developed to date. The purpose is not to include all existing forecasting procedures, but rather to illustrate each class of structures with a typical example. The general classes of procedures are sequential aggregate, direct aggregate, sequential disaggregate, and direct disaggregate. These classes are described in the sections that follow.

Sequential Aggregate

The urban transportation planning process (UTP) is a prime example of a set of sequential travel forecasting procedures. Because this process has been used so extensively for so many of the travel forecasts made for the past 15 years, it will be described very briefly here, with emphasis on the structural aspects.

Trip generation is the first sequential step, involving the prediction of total trips from an origin or to a destination by trip purpose (6). The independent variables are most commonly in the socioeconomic and activity classes used in Eq. 7. The functional form is usually linear. Symbolically,

$$T_i^n = \sum_1 b_1^n S_{i1} + k_1^n$$
$$T_j^n = \sum_1 c_1^n A_{j1} + k_2^n \qquad (8)$$

where

T_i^n = trips of purpose n generated in origin i,
T_j^n = trips of purpose n attracted to destination j, and
b_i^n, c_i^n, k_i^n = empirical parameters.

Typical socioeconomic variables used are average annual income, average number of automobiles owned, number of workers per household, and percentage of households having an income greater than a specified value. Typical activity-system variables used are zonal population, acres of land in various land use categories, and zonal employment.

The second sequential step is trip distribution, the prediction of trips from origin to destination. The independent variables are the trip ends resulting from the previous step plus level-of-service variables. Symbolically,

$$T_{ij}^n = f_n(T_i^n, T_j^n, L_{ij}) \qquad (9)$$

where

T_{ij}^n = trips of purpose n from origin i to destination j,
T_i^n, T_j^n = results of the trip generation step, and
L_{ij} = level-of-service variables between i and j.

The 2 most common functional forms are the gravity model and the opportunity model. A typical version of the gravity model is as follows:

$$T_{ij}^n = T_i^n \frac{T_j^n t_{ij}^{\beta_n}}{\sum_k T_k^n t_{ik}^{\beta_n}} \qquad (10)$$

where

t_{ij} = travel time from i to j, and
β_n = empirical parameter.

A typical version of the opportunity model is as follows:

$$T_{ij}^n = T_i^n e^{-L_n V_j^n}\left(1 - e^{-L_n T_j^n}\right) \qquad (11)$$

where

$V_j^n = \Sigma T_k^n$ = "subtended volume,"
k = all destinations for which $t_{ik} < t_{ij}$, and
L_n = empirical parameter.

These models are "share" models; they divide the total trips from i, T_i^n, among all destinations by using a fraction that, when summed over all destinations, equals 1. Travel time by a single mode, usually highway, is typically the only level-of-service variable used although, in some applications, a generalized cost has been used that is a linear combination of travel time, distance, and out-of-pocket costs. The level-of-service variable enters the opportunity model in an indirect way only. It affects the ranking of destinations from each origin, which in turn affects the subtended volumes that enter the model directly.

In some applications of both the gravity and the opportunity models, adjustments of T_j^n are made after initial application of Eq. 10 or 11 in an attempt to force the total trips to each destination ($T_{\cdot j}^n = \sum_i T_{ij}^n$) to equal the original T_j^n. This constraint, though logical, is not guaranteed by the functional form of either distribution model. Following adjustments of the original T_j^n, the equations are applied again. Iteration through application of the equations and adjustment of the original T_j^n continue until a desired level of correspondence between each T_j^n and $T_{\cdot j}^n$ is reached.

The third sequential step is modal split, the prediction of trips by mode from origin to destination. The independent variables are the trip interchanges resulting from the previous step plus modal level-of-service variables. Symbolically,

$$T_{ijk}^n = f_{nk}(T_{ij}^n, L_{ijm}, S_i, A_j) \tag{12}$$

where

T_{ijk}^n = trips of purpose n from origin i to destination j by mode k,
T_{ij}^n = results of the trip distribution step,
L_{ijm} = level-of-service variables for all modes m between i and j,
S_i = socioeconomic variables of travelers in i, and
A_j = activity-system variables in j.

Many approaches have been used to develop functional forms, f_{nk}, for modal-split models. The most commonly used prior to the past 3 or 4 years were regression or table look-up models based on the relative levels of service offered by each mode (4). Typically, origin zones have been classified by income level and automobile ownership, and for each subgroup linear equations or tables are developed that relate fraction of trips by automobile and transit to time and cost ratios or differences. Symbolically,

$$P_{ijk}^n = \frac{T_{ijk}^n}{T_{ij}^n} = f_{nk}^m\left(\frac{t_{ija}}{t_{ijt}}, \frac{c_{ija}}{c_{ijt}}\right) \tag{13}$$

or

$$P_{ijk}^n = \frac{T_{ijk}^n}{T_{ij}^n} = g_{nk}^m\,(t_{ijt} - t_{ija},\ c_{ijt} - c_{ija})$$

where

P_{ijk}^n = fraction of travel for purpose n between i and j by mode k,
t_{ija}, t_{ijt} = travel times by automobile and transit,
c_{ija}, c_{ijt} = costs by automobile and transit, and
m = income and automobile ownership group.

Various time and cost variables have been used, and often more than one of each has been used. Time has been divided into in-vehicle time, waiting time, and access time, for example. Cost has been divided into out-of-pocket cost, tolls, parking fees, fares, and total operating costs.

More recently, the following functional form has been used for f_{nk} (17, 20):

$$P_{ijt}^n = \frac{1}{1 + e^{h_k(L_{ijm})}} \tag{14}$$

and

$$h_k(L_{ijm}) = C_k + \sum_1 a_k^1(t_{ijt}^1 - t_{ija}^1) + \sum_1 b_k^1(c_{ijt}^1 - c_{ija}^1)$$

Again, times and costs have been divided into various variables. The constant C_k, as well as the parameters a_k^1 and b_k^1, allows the relative characteristics of modes not measured by times and costs (such as comfort, convenience, and modal "image") to be represented in the model. The function h_k can be interpreted as a difference in consumer utility between travel by transit and travel by automobile.

Direct Aggregate

In contrast to the sequential application of a number of models in the UTP process, direct aggregate procedures involve the prediction of travel demand by origin, destination, and mode with a single equation whose general form is given in Eq. 7. The original application of these procedures has been to the prediction of intercity trips between large zones, typically entire urban areas. More recently, application to urban areas has taken place. Functional forms that have been used for direct aggregate equations may be placed in the following major groups.

Independent Mode-Specific Equations

$$T^n_{ijk} = f^n_k(L_{ijm}, S_i, S_jA_i, A_j) \tag{15}$$

In the present models of this type, 3 forms of the function f^n_k are most common.

1. The product form (21) was applied to intercity travel for business and personal purposes.

$$T^n_{ijk} = a^n_{ok}\, P_i^{a^n_{kl}}\, P_j^{a^n_{2k}}\, Y_i^{a^n_{3k}}\, Y_j^{a^n_{4k}} \prod_m \left(c_{ijm}^{b^n_{mk}}\, t_{ijm}^{c^n_{mk}}\right) \tag{16}$$

where

P_i, P_j = populations,
Y_i, Y_j = average incomes,
c_{ijm} = travel costs by mode m, and
t_{ijm} = travel times by mode m.

2. The linear-log form (5) was applied to automobile work trips in a metropolitan area. The socioeconomic and activity-system variables are labor force at origin, employment at destination, median income at origin, and number of automobiles per person at origin. The level-of-service variables for both automobile and transit are in-vehicle travel time, out-of-vehicle travel time, line-haul cost, and out-of-pocket cost.

$$T^n_{ijk} = M^n_k(S_{io}A_{jo})\left(\sum_{m,l} a^n_{kml} L_{ijml} + \sum_{m,l} b^n_{kml} \ln L_{ijml} + \sum_l c^n_{kl} S_l + \sum_l d^n_{kl} \ln S_l\right) \tag{17}$$

where

M^n_k = constant term,
l = variable number,
S_{io}, A_{jo}, S_l = socioeconomic and activity-system variables, and
L_{ijkl} = level-of-service variables.

3. The product-exponential form (5) was applied to automobile shopping and transit work trips in a metropolitan area. The activity-system variables in the model for automobile shopping trips are number of households at origin, number of persons per household at origin, median income at origin, number of automobiles per person at origin, and density of retail trade employment at destination. The level-of-service variables for the automobile shopping-trip model include all listed for the linear-log

form, with the exception of out-of-vehicle travel time for the transit mode. For the transit work-trip model, the activity-system variables were the same as those used in the linear-log form. The level-of-service variables included no automobile model variables. The transit variables used were the same as those for the linear-log form.

$$T^n_{ijk} = M^n_k \prod_{m,l} L_{ijml}^{a^n_{kml}} e^{b^n_{kml} L_{ijml}} \cdot \prod_{l} S_l^{c^n_{kl}} e^{d^n_{kl} S_l} \tag{18}$$

where the variables are as defined for Eq. 17.

Independent Mode-Abstract Equations

$$T^n_{ijk} = f^n(L_{ijm}, Y_i, Y_j, A_i, A_j) \tag{19}$$

This general representation only differs from Eq. 13 in that the function f^n is independent of mode, k. The prime example of this model is the following form developed by Quandt and Baumol (18). Because it was developed for intercity travel for all purposes, no purpose superscript is used.

$$T_{ijk} = a_o P_i^{a_1} P_j^{a_2} Y_i^{a_3} Y_j^{a_4} c_{ijb}^{a_5} t_{ijb}^{a_6} f_{ijb}^{a_7} \left(\frac{c_{ijk}}{c_{ijb}}\right)^{a_8} \left(\frac{t_{ijk}}{t_{ijb}}\right)^{a_9} \left(\frac{f_{ijk}}{f_{ijb}}\right)^{a_{10}} \tag{20}$$

where f_{ijk} is the frequency of service; and the new variables, c_{ijb}, t_{ijb}, and f_{ijb}, are the cost, time, and frequency for the "best" mode with respect to each parameter: the cheapest cost, the fastest time, and the most frequent service.

A distinct advantage of a mode-abstract direct demand equation is its ability to predict the demand for new modes without changing the functional form of the model or its parameters.

Modal Share Models

$$T^n_{ijk} = f^n_2(A_i A_j Y_i Y_j L_{ijm}) \frac{f^n_{1k}(L_{ijk})}{\sum_m f^n_{1m}(L_{ijm})} \tag{21}$$

As the general form of this model indicates, these models include 2 separable functions: one to predict total trips from i to j(f^n_2) and a second to predict the share of these trips that will use mode k(f^n_{1k}). Therefore, this model can be classed as a direct aggregate model or as a partially sequential model.

The prime example of this model is McLynn's composite analytic model developed for intercity travel for all purposes (15). In that model, the function f_{k1} and f_2 are as follows:

$$f_{1k} = a_{ok} c_{ijk}^{a_{1k}} t_{ijk}^{a_{2k}} f_{ijk}^{a_{3k}} \tag{22}$$

$$f_2 = b_o P_i^{b_1} P_j^{b_2} Y_i^{b_3} Y_j^{b_4} \left(\sum_m f_{1m}\right)^{b_5} \tag{23}$$

The 2 functions are typically estimated sequentially: First the f_{1m} functions are estimated, and then their sum is obtained as a variable to be used in the estimation of f_2.

Both of the analytical structures discussed above have been developed and applied to aggregated travel data: data for entire zones whose sizes range from fractions of square miles for urban applications to entire metropolitan areas for intercity applications. Modeling at either of these levels of aggregation smoothes out most of the variations of the individuals who actually make the travel decisions being modeled. For this reason, much of the recent demand modeling effort has addressed the problem of predicting the travel decisions of individual travelers. Initially, these studies were concerned only with the mode-choice decision. The models developed were individual traveler applications of the utility model form shown in Eq. 14 (9, 10, 22, 23). When applied to individuals, the dependent variable can only take on the values 0 or 1, requiring a different set of estimation procedures to be used. In the initial models of this type, only 2 modes were included, leading to a binary-choice situation. More recently, multiple-choice models have been developed (19).

Building on the earlier work in modeling the individual mode-choice decision, researchers have developed equations to model not only mode choice but also destination choice and the choice of whether to make a trip.

Charles River Associates (3) developed a sequence of individual choice models based on the assumption that travelers first choose whether to travel, then where to travel, then what time to travel, and finally what mode to use. Because of this assumed sequence of choices and the use of inclusive prices, the models must be calibrated in the reverse order of the assumed order of choice. They are presented in that order here.

1. The modal-choice submodel is based on a binary choice between automobile and transit.

$$\frac{P^n_{ija}}{1 - P^n_{ija}} = \exp\left[a^n + \sum_{1} b^n_1(L_{ijal} - L_{ijtl}) + \sum_{1} c^n_1 S_{il}\right] \tag{24}$$

where

P^n_{ija} = fraction of trips by purpose n (work or shopping) by household i to destination j made by automobile rather than transit,
L_{ijal}, L_{ijtl} = automobile and transit level-of-service variables, and
S_{il} = socioeconomic variables.

The socioeconomic variables are automobiles per worker in the household, indicator for race, and indicator for occupation. The level-of-service variables are waiting time (assumed to be 0 for automobile trips), in-vehicle travel time, and operating, parking, and fare costs.

2. The time-of-day-choice submodel is based on a binary choice between traveling in both directions during off-peak hours for shopping or traveling in at least one direction during a peak hour. The shopping purpose is the only one modeled.

$$\frac{P_{ijo}}{1 - P_{ijo}} = \exp\left[a + b(IP_{ijo} - IP_{ijp}) + \sum_{m} c_m S_{im}\right] \tag{25}$$

where

P_{ijo} = fraction of shopping trips made by household i to destination j completely during off-peak periods,
S_{im} = socioeconomic variables,
IP_{ijo}, IP_{ijp} = inclusive prices for off-peak and peak shopping trips,
IP_{ijo} = $\sum_{1} b^n_1 L_{ijklo}$,
b^n_1 = parameters from Eq. 24, and
L_{ijklo} = level-of-service variables for the mode used during off-peak travel.

IP_{ijp} is similarly defined for peak-hour shopping trips. The socioeconomic variables used are indicator for sex of the head of household, number of workers per number of residents in the household, and number of preschool children in the household.

3. The destination-choice submodel is based on a multiple-option choice of traveling to each of a number of destinations for shopping. The shopping purpose is the only one modeled.

$$\frac{P_{ij}}{P_{im}} = \exp[a_1(IP_j - IP_m) + a_2(A_j - A_m) + a_3(IP_j \cdot S_i - IP_i \cdot S_i)] \tag{26}$$

where

P_{ij}, P_{im} = fraction of shopping trips to destinations j and m by household i,
A_j, A_m = activity-system variables for destinations j and m,
S_i = socioeconomic variable for origin i,
IP_j, IP_m = inclusive prices for shopping trips to j and m,

$$IP_j = \sum_1 b_1^n L_{ija1},$$

b_1^n = parameters from Eq. 24, and
L_{ija1} = level-of-service variables for automobile trips to destination j.

IP_m is similarly defined for trips to m. The activity system variables are the fraction of total retail employment occurring in each destination. The socioeconomic variable, used with the inclusive price in the interaction term, is the number of preschool children in household i. No level-of-service variables for transit trips were used.

4. The trip-frequency-choice submodel is based on a binary choice between making 0 or 1 shopping trip per day. The shopping purpose is the only one modeled.

$$\frac{P_i}{1 - P_i} = \exp(a_1 IP_i + a_2 IE_i + a_3 Y_i) \tag{27}$$

where

P_i = probability that household i will make a shopping trip,
Y_i = family income of household i,
IP_i = inclusive price to household i = $\sum_j IP_j P_{ij}$, and

IE_i = average shopping opportunity = $\sum_j A_j P_{ij}$.

IP_j, P_{ij}, A_j, and P_{ij} are obtained from Eq. 26.

Direct Disaggregate

The set of equations presented above is the disaggregated analog of the UTP sequential process. A disaggregated analog of the direct aggregate models also has been postulated and calibrated (2). The functional form of this model is as follows:

$$\frac{P_{ijk}}{P_{ij'k'}} = \exp\left[\sum_1 a_1(A_{j1} - A_{j'1}) + \sum_1 b_1(M_{k1}^1 - M_{k'1}^1) + \sum_1 c_1 Y_i(M_{k1}^2 - M_{k'1}^2) + \sum_1 d_1(L_{ijk1}^1 - L_{ij'k'1}^1) + \sum_1 \frac{e_1}{Y_i}(L_{ijk1}^2 - L_{ij'k'1}^2)\right] \tag{28}$$

where

P_{ijk}, $P_{ij'k'}$ = fraction of total trips from household i going to destinations j and j by modes k and k′ (either j and j′ or k and k′ may be the same, but not both),

A_{j1}, $A_{j'1}$ = activity-system variables,
M^{p}_{k1}, $M^{p}_{k'1}$ = modal variables,
L^{q}_{ijk1}, $L^{q}_{ij'k'1}$ = level-of-service variables, and
Y_1 = household income variable.

As estimated by Ben-Akiva, the following variables were used:

1. Activity-system variables, A_{j1}—number of jobs in wholesale and retail establishments in the zone of destination j and indicator for CBD destinations;
2. Modal variable in separate term, M^{1}_{k1}—indicator for automobile usage;
3. Modal variable in interaction term with income, M^{2}_{k1}—indicator for automobile usage;
4. Level-of-service variables in separate terms, L^{1}_{ijk1}—out-of-vehicle travel time and in-vehicle travel time; and
5. Level-of-service variable in interaction term, L^{2}_{ijk1}—out-of-pocket cost.

This model was calibrated for automobile and transit trips for the shopping purpose only and does not deal with trip-making or time-of-day choices. It, therefore, represents a model that can be used to divide total shopping trips from a household among the available modes and destinations.

This concludes a brief survey of the major classes of analytical structures that have been applied to travel demand forecasting or proposed for application. In later sections, I will refer to these structures to illustrate the issues involved in the choice of an appropriate analytical structure for a given travel forecasting problem.

FACTORS AFFECTING ANALYTICAL STRUCTURE

Two questions were posed as the overall goal of a program of research to be developed by this workshop:

1. What forms of the function D^{p}_{k1m} are appropriate for various kinds of travel demand forecasting?
2. What variables belong in each of the sets of independent variables shown in Eq. 7?

The factors discussed below must be considered in answering these questions.

Travel Demand Theories

Theoretical constructs that can be applied to travel demand are available in 2 general fields: economics and psychology. We have drawn on classical demand theory to develop a starting point for our definition of the analytical structure of travel demand forecasting. This discussion includes not only the basics of classical theory but also the adjustments and extensions that make possible its application to travel demand.

Other theoretical developments can be analyzed in the same way. This is done in this section for the alternative approach to consumer theory developed by the economist Lancaster and for the behavioral theory of choice developed in psychology. (The resource paper for Workshop 5 should be referred to for a more complete discussion of the theories underlying travel demand forecasting.)

As stated by Lancaster (8), the following assumptions, each of which differs from the classical theory, are the essence of his approach:

> 1. The good, per se, does not give utility to the consumer; it possesses characteristics, and these characteristics give rise to utility.
> 2. In general, a good will possess more than one characteristic, and many characteristics will be shared by more than one good.
> 3. Goods in combination may possess characteristics different than those pertaining to the goods separately.

When the nature of transportation as a derived demand with many "prices" is considered, the relevance of Lancaster's approach to travel demand becomes evident. Transportation is a good with a number of characteristics that give rise to disutility, but is nevertheless consumed in combination with other goods because it makes possible the consumption of those goods. The other goods have 0 utility until they can be reached; then they provide utility that exceeds the disutility of transportation.

Without going any deeper into Lancaster's approach than the 3 assumptions quoted above, I shall provide a theoretical basis for expanding the single-valued price of classical economics to a vector of characteristics—the level-of-service variables—and for including measures of the activity system. This can be shown by developing the analog of Eqs. 1, 2, and 3, which arise from Lancaster's approach.

Utility functions now state the level of utility associated with the purchase of the quantities Z_i of a number of characteristics.

$$U(Z_1, Z_2, \ldots, Z_n) \tag{29}$$

These characteristics are obtained by engaging in a number of activities, j, each at level W_j. The relation between the vector of characteristic quantities, Z, and the vector of activity levels, W, is

$$Z = BW \tag{30}$$

where B is a matrix of elements b_{ij}, each of which is the amount of characteristic i provided per unit of activity j.

The amount of each good, k, consumed is Q_k, which depends on the consumption of goods in each activity, as represented by the following relation between the vector of goods consumed, Q, and W:

$$Q = AW \tag{31}$$

where A is a matrix of elements a_{kj}, each of which is the amount of good k consumed per unit of activity j.

As in the classical theory, a budget constraint exists. In matrix notation,

$$PQ \leq Y \tag{32}$$

If U could be maximized subject to the constraints shown in Eqs. 30, 31, and 32, the following relations would be expected:

$$Q_k^{\circ} = D_k(P, Y, W, A, B) \tag{33}$$

Although Lancaster provides no general solution in terms of forms of the demand function $D_k(\cdot)$, he does discuss a number of implications of his approach. As an example, Eq. 33 provides a theoretical base for including measures of each of the following in demand functions in general and in travel demand functions in particular:

P = prices of goods,
Y = income level of the consumer,
W = activity levels of the consumer,
A = consumption of goods per unit of activity, and
B = provision of characteristics per unit of activity.

A second implication occurs when a new good, such as a new mode of transportation, is considered. In the classical theory, this situation requires the reformulation of the utility function, U, in an additional dimension before estimates can be made of the effects of this new good on the former equilibrium state. Before the new good is available, there is no way to estimate the changes to the utility function. Because in Lancaster's approach the utility function is dimensioned by characteristics rather than goods, it remains unchanged when new goods are added. To revise the demand functions, therefore, if no new activities are expected, requires only adding to the dimensions of Q, A, and P. Because Q and P are variables, only a new row of coefficients of A must be determined, based on the amount of the new good that is consumed in each of the activities. This is a much more straightforward task than formulating a new utility function based on consumers' responses to a situation that does not yet exist.

In many cases, a new good may result in new activities. This can also be represented by expanding the dimensions of A, B, and W. New columns must be added to A and B to represent the consumption of goods and production of characteristics of these new activities. This also can be done much easier than adding a dimension to the utility function.

In summary then, Lancaster's approach provides a number of bases for travel demand forecasting that are not provided by the classical theory. This added power has been recognized by a number of travel demand model developers. Others have gone beyond classical theory in ways that can only be supported by Lancaster's approach. His approach, therefore, can probably be profitably explored further by demand model developers.

One attempt to explore this approach has sought to formulate a general equilibrium model that adapts Eqs. 29, 30, 31, 32, and 33 to transportation (3). This is done by concentrating on the following classes of goods: transportation, consumer goods with fixed locations in the short run (work, home), and consumer goods available at many alternate locations (groceries, entertainment).

Although no tractable solution has been obtained with this formulation, 3 types of further work may be warranted.

1. Continue searching for a utility function form that results in a closed-form solution in terms of demand functions, $D_k(\cdot)$, for the transportation variables;
2. Continue exploring the existing formulation, as far as it has been developed, for its implications on suitable analytic structures; and
3. Search for realistic revisions of the formulation that will result in useful demand functions.

Both in the classical theory of the consumer and in Lancaster's formulation, only monetary prices are considered. Lancaster deals with multiple characteristics, but only price has a budget limit. In transportation demand work, it is often useful to consider time as a price also and to recognize that each traveler has a limited budget of time available for transportation or, in general, for the consumption of all goods. It is desirable, therefore, to expand Eqs. 2 and 32 to include a time budget that must be greater than or equal to the time used in consuming each good or in carrying out each activity. This added constraint can be expected to be more important for transportation demand analyses, where alternatives can have significant time variations, than for general demand modeling.

In the area of psychology, a theory of rational choice behavior has been developed (11). Its basic assumptions are that a decision-maker can rank possible alternatives in order of preference and will always choose from the available alternatives the option that he considers most desirable. These assumptions lead to the specification of utility functions that measure the desirability of an alternative, i, to a decision-maker with characteristics S_j.

$$U(Z_i, S_j) \tag{34}$$

where

Z_i = vector of attributes of alternative i, and
S_j = vector of characteristics of decision-maker j.

The decision-maker maximizes his utility by choosing the alternative with the highest value of the function; or, in the case of random variables, the decision-maker chooses the alternative for which his utility is maximized with some probability, P_i.

To make probabilistic choice models tractable, an axiom on choice behavior developed by Luce is often used. Termed the independence-of-irrelevant-alternatives axiom, it requires that the relative odds of 2 alternatives being chosen be independent of the presence or absence of third alternatives. Symbolically, if i and k are 2 alternatives, both of which are chosen part of the time, and if there exists another set of alternatives $n_1, n_2, \ldots$, then

$$P_i/P_k = f(Z_i, Z_k, S_j) \tag{35}$$

and this function is not affected by the presence or absence of any of the alternatives $n_1, n_2, \ldots$.

This is a critical axiom to accept because it has important benefits and costs. One benefit is that, in the modal-choice case, for example, it allows demand to be predicted for new modes before they are built, if all of the Z variables are based solely on generic attributes of the modes, such as travel time and cost. On the other hand, an important cost is that, when such a new mode is introduced, the reduction in usage of all existing modes will be a constant percentage. These characteristics do not exist when some of the Z variables are mode-specific (for example, a dummy variable that is 1 for the transit mode and 0 otherwise). This, however, is equivalent to replacing Z_i and Z_k in Eq. 35 with Z_{in} and Z_{kn}, which implies rejection of the independence-of-irrelevant-alternatives axiom.

The theory of rational choice behavior provides a powerful tool for the development of disaggregated demand models. It is not, however, a perfect tool. Additional development of the theory of rational choice behavior, with the goal of providing a more realistic model for travel demand forecasting, appears to be a worthwhile effort.

Data for Travel Demand Forecasting

The effects of data availability on the analytical structure of travel demand forecasting procedures can be described in terms of the data limitations that now exist, the present needs for new data types and new survey procedures, and the problems caused by the use of the available data when present estimation procedures are applied.

The major source of data for travel demand model development continues to be the home interview survey, which has been conducted in every major city of the United States. The data obtained from this survey are deficient for all kinds of demand modeling work for a number of reasons, including these two.

1. The data have been collected by sampling large metropolitan areas with relatively low sampling rates—typically 2 to 10 percent. Any subdivision of the results into a large number of cells (by origin, destination, mode, and purpose, for example) results in a large number of observations of either 0 or 1 trip. These surveyed trips must be factored to represent 0 or 10 to 50 trips, and the factored trips are much too "lumpy" for advantageous use in model development.
2. The tedious process of interviewing, filling out forms, coding, and keypunching can only be done for large surveys by relatively untrained people who must work fast. The net result is that many of the data that result are inaccurate and often are not complete because of the inability of the interviewee to remember all of the details requested.

Additional problems occur when these surveys are used for behavioral disaggregate demand modeling.

1. Home interview surveys only produce data on the trips actually made. Information on the use of alternate modes must be reconstructed from other sources, after the fact, in order to use the data in the development of disaggregated models. Similarly, information on potential trips for households that did not make trips of various kinds may be required, but are not available from the data.
2. Accurate disaggregate modeling at the household level often requires ignoring the

machine-readable data obtained from surveys in favor of returning to coding forms, which include more precise location information (street address versus traffic zone, for example). This greatly increases the costs of disaggregated modeling.

3. The definition of a trip in home interview surveys is an arbitrary one requiring a single mode and purpose. This definition is then modified somewhat by forming new "linked" trips. Often, however, what is desired in behavioral modeling is a "tour" composed of a number of trips that take a traveler from home to one or more destinations and then back home. To obtain such tours often requires a return to coding-form analysis.

Another important source of data for demand modeling work is the U.S. census, which collects a wide range of income, activity-system, and some trip-making data. Because these data must be aggregated to some geographical unit greater than the household to meet confidentiality requirements, they are mainly useful in aggregate rather than disaggregate model development. Expanded data on work trips are available from the 1970 census, and it is possible to consider the development of an aggregate work-trip model based on census data and network data only. Drawbacks remain, however: The degree of aggregation, especially of destinations, often is high, and the data are collected only every 10 years.

The paragraphs above imply a number of needs for new kinds of travel data and for new data collection methods. When disaggregated demand modeling is contemplated, a number of the limitations of existing home interview data can be overcome by designing surveys better suited to these models. Because it is not necessary to have data obtained from entire metropolitan areas to develop these models, surveys can be designed with high sampling rates in relatively small areas. Data recording can be modified to preserve as much locational information as necessary and to represent tours rather than arbitrarily defined trips. Information on alternative modes and destinations can be requested explicitly. Better trained and higher paid interviewers can be used to help improve the reliability of the data. These changes will remove a number of limitations of present travel data, but will only make the obtaining of accurate data more critical. Research aimed toward the improvement of survey data accuracy should be undertaken. Also, methods of integrating survey data with engineering information, such as travel times on highway and transit facilities, should be improved.

With regard to the use of travel data to develop travel demand models, a number of problems can be identified. These problems depend not only on the use of the data but also on the estimation procedures.

As pointed out, there are definite advantages in developing mode-independent demand functions. Such functions require, however, that each alternative mode be described by using the same variables. This raises the problem of developing a set of variables that are meaningful for all modes. The major problem arises when one attempts to describe automobile transportation in terms of variables such as frequency and cost; the variables are relatively straightforward for common-carrier modes. Should automobile cost be out-of-pocket cost only or out-of-pocket cost plus operating cost or both of these plus depreciation, insurance, and other fixed costs? These problems often make the use of mode-independent models impractical.

A second data-estimation problem is multicollinearity among 2 or more variables. As an example, for any mode, both travel time and fare will be strongly related to distance and, therefore, to each other. How can a model be developed that includes both time and cost variables when the estimation procedure cannot accurately determine their parameters because of multicollinearity? Often, this question can only be answered by conducting special experiments or studies to determine the relative effects of 2 or more collinear variables.

A third data-estimation problem is the choice of accurate proxy variables to take the place of ones that theoretically belong in a demand formulation but that are not available. As examples, retail employment may be used as a proxy for shopping opportunities or occupation indicator as a proxy for income. The model developer must analyze the suitability of each proposed proxy variable before accepting it as a potential variable.

In summary, the analyst who must develop demand forecasting procedures by using available data must choose his analytical structure carefully to ensure that he will not be defeated by a lack of the proper data. Also, the analyst who is asked to specify his data needs before a survey strategy is developed should be able to recommend survey procedures and questions that will provide a maximum of data useful for demand modeling.

Demand Estimation Methods

The estimation methods discussed in this section are the distribution model calibration procedures, linear regression, nonlinear regression, and simultaneous equation estimation.

Distribution Model Calibration Procedures

For both the gravity model and the opportunity model (Eqs. 10 and 11), specialized calibration procedures have been developed. In the case of the gravity model, t^{β} is replaced by a generalized distance function f(t), and the values of this function for each value of t are determined such that the actual distribution of trip lengths is matched. In the case of the opportunity model, the parameter L is determined such that the actual average trip length is matched. In both cases, the actual observations, T_{ij}, are not used in the calibration, but instead more aggregate characteristics are matched. Each of these procedures is limited to the particular analytical structure of the corresponding trip distribution model.

Linear Regression

This general parameter-estimation procedure requires that the functional form of the model, or a transform of it, be linear in the parameters. This limits the use of linear regression to functional forms of the following types:

$$Y = a_o + \sum_i a_i x_i \tag{36a}$$

$$Y = a_o + \sum_i a_i \ln x_i \tag{36b}$$

$$Y = a_o + \sum_i (a_i x_i + b_i \ln x_i) \tag{36c}$$

$$\ln Y = a_o + \sum_i a_i x_i \tag{36d}$$

$$\ln Y = a_o + \sum_i a_i \ln x_i \tag{36e}$$

$$\ln Y = a_o + \sum_i (a_i \ln x_i + b_i x_i) \tag{36f}$$

where

Y = either trips, T, or a probability variable $P/(1 - P)$ or P_i/P_j, where P_i is the probability of making a specified trip;
a_i = coefficients to be estimated; and
x_i = independent variables.

The untransformed versions of Eqs. 36d, e, and f are

$$Y = \exp\left(a_o + \prod_i a_i x_i\right) \tag{37a}$$

$$Y = e^{a_o} \prod_i x_i^{a_i} \tag{37b}$$

$$Y = e^{a_o} \prod_i x_i^{a_i} e^{b_i x_i} \tag{37c}$$

Each of the models presented in Eqs. 8, 14, 16, 17, 18, 20, and 22 through 28 can be expressed in one of the forms shown in Eq. 36. However, because of limitations on the independent variables in disaggregated models, linear regression was not used to estimate the equations.

Linear regression is based on the minimization of the sum of the squares of a linear error term. When the dependent variable is transformed, as in Eq. 36, the untransformed error term is no longer linear. In Eq. 37, if U is the transformed error term, then the untransformed error term is e^U, and in each case it has a multiplicative effect on Y. Often this effect is not desirable and, therefore, linear regression is not applicable to the calibration of models such as those of the form of Eq. 36.

A number of modifications of simple linear regression, or ordinary least squares procedures, have been developed. Some of these are

1. Generalized least squares, where observations or error terms or both are weighted to take account of the variation in reliability among observations; and
2. Constrained regression, where some parameters are constrained to equal prespecified values (more flexible constraints are discussed below).

These modifications do not significantly affect the cost of using linear regression and often prove to be useful in travel demand estimation.

Nonlinear Regression

A number of nonlinear regression procedures exist. They overcome the restriction that the model to be calibrated, or a transform of it, be linear in the parameters. However, this requires that the solution method be an iterative programming or direct search procedure, and these procedures are significantly more costly than ordinary least squares. Some of the available features of these procedures are

1. Replacement of the additive (in the linear transform) error term of linear regression with a general error term, depending on the model formulation;
2. Inclusion of constraints on the coefficients, including inequality constraints involving either single coefficients or functions involving both coefficients and independent variables (these constraints can represent theoretical considerations such as the proper signs for the coefficients of price and socioeconomic variables); and
3. Incorporation of procedures to determine maximum likelihood coefficient estimates such as those typically used in multiple logit models (Eq. 26).

Simultaneous Equation Estimation

These methods are essentially methods of determining the best parameters for systems of simultaneous equations usually based on 2-stage least squares procedures. They allow model calibration in the situation where supply and demand functions are shifting simultaneously, as they do over time and across zones. Because few time series data sets or models exist in travel demand forecasting and because demand functions are usually assumed to be fixed in cross-sectional models, little use has been made of simultaneous equation estimation methods.

The most common statistical estimation procedure, ordinary least squares, severely limits the number of functional forms available for travel demand forecasting. Many functional forms cannot be estimated by using this procedure, and, in addition, the number of independent variables is usually limited because of multicollinearity. Only by using more costly procedures, and by developing specialized procedures, can these limitations be overcome.

Structural Characteristics

Three critical structural characteristics of demand forecasting procedures are summations, elasticities, and zonal aggregations. Early demand forecasting procedures stressed the summations of demand by mode, by mode and destination, and by mode, destination, and origin as quantities over which the analyst should have significant control. More recently, the influence of economics has been felt, and the elasticity of trip-making with respect to activity system and level-of-service variables has become more important to the analyst. The effects of aggregation on demand procedures have always been important to the transportation analyst. In this section, each of these terms is formally defined, and their theoretical ranges are stated. The nature of these measures for a number of the analytical structures discussed above is then displayed.

1. The following summations of predicted trips by origin, destination, and mode (T_{ijk}) are of concern to the transportation analyst:

$$T_{ij.} = \sum_k T_{ijk} = \text{trips by zone pair} \tag{38a}$$

$$T_{i..} = \sum_j \sum_k T_{ijk} = \text{trips by origin} \tag{38b}$$

$$T_{.j.} = \sum_i \sum_k T_{ijk} = \text{trips by destination} \tag{38c}$$

$$T_t = \sum_i \sum_j \sum_k T_{ijk} = \text{total trips} \tag{38d}$$

In the UTP models, these summations are typically predicted in reverse to the order shown above, and an important part of each sequential step is to ensure that the previous predictions, taken as "control totals," are preserved.

2. The formal definition of the elasticity of trip-making from i to j by mode k, with respect to any independent variable, w, is

$$e(T_{ijk}:w) = \frac{\partial T_{ijk}}{\partial w} \cdot \frac{w}{T_{ijk}} \tag{39}$$

Elasticity is a dimensionless number that represents the percentage of change in trip-making from i to j by mode k (T_{ijk}) for each percentage of change in the independent variable w. For a number of independent variables, a more specific name is given. These are indicated below:

$e(T_{ijk}:t_{ijk})$ = direct time elasticity,
$e(T_{ijk}:t_{lmn})$ = time cross elasticity (in this case, only one of subscripts l, m, n need be different from i, j, k), and
$e(T_{ijk}:Y_i)$ = income elasticity.

Similarly, specific names can be given for the elasticities of other level-of-service and activity-system variables.

Economic theory leads to the following statements of the ranges within which the various elasticities can be expected to occur: (a) Direct level-of-service elasticities are less than or equal to 0; (b) level-of-service cross elasticities are greater than or equal to 0; (c) income and similar activity-system elasticities are greater than or equal to 0, unless T_{ijk} represents an inferior good. Equation 39 can also be generalized to apply to the summations shown in Eq. 38, resulting in the elasticity of trips by zone pair, origin, destination, or total trips with respect to any independent variable.

3. A critical question to be answered for each alternative travel demand forecasting procedure is the range of zone sizes for which the procedure is valid. Because of the analytical structure and the magnitude of the coefficients of the socioeconomic and activity-system variables in many models, they are limited to the range of zone sizes for which they were calibrated. If the zone sizes are to be changed greatly, the model will require recalibration.

To explore the conditions that will require recalibration, we must divide both socioeconomic and activity-system variables into 2 classes: (a) scaling variables, such as zonal population and employment, which express the "size" of the zones; and (b) rate variables, such as automobiles per household and dollars of sales per square foot of retail store area. In the remainder of this discussion, we can limit ourselves to the scaling variables, for these are the critical ones in zonal aggregation considerations.

A useful index for any demand model is the sum of the exponents of all scaling variables that are multiplied together. For example, we may have a multiplicative model that predicts T^n_{ijk} by using the following scaling variables and coefficients: (origin population)$^{0.8}$ and (destination employment)$^{0.7}$. In this case, our index is 1.5, which suggests that, for each 1 percent change in zone size, trips will change by 1.5 percent.

As this index begins to vary significantly from 1 for models that predict T^n_{ijk}, we will expect changes in zone size to require recalibration. We will term this aggregation index the AI.

When these summations, elasticities, and aggregation indexes are obtained for the models discussed previously in this paper, the following characteristics of the models are discovered.

Urban Transportation Process

Trip Generation (Eq. 8)

Equation 40c is the major deficiency of the standard trip generation approach: Total trip-making for a zone does not change as level-of-service variables change. The equations, are, however, usually insensitive to zone size.

$$T^n_{i..} \text{ (obtained directly)} \tag{40a}$$

$$T^n_{.j.} \text{ (obtained directly)} \tag{40b}$$

$$e(T^n_{i..}:L_{1mn}) = 0 \tag{40c}$$

for all subscript values.

$$e(T^n_{i..}:S_{11}) = \frac{c^n_1 S_{11}}{T^n_{i..}} \tag{40d}$$

$$AI = 1.0 \tag{40e}$$

Trip Distribution (Eq. 9)

Equation 41d shows that in the gravity model (Eq. 10) a change in level of service from i to any destination affects the number of trips to all destinations. Usually, only the L_{im} for the automobile mode is used. The elasticity for other modes is 0 if this is done. Equation 41e indicates that the level-of-service variables for all other origins are irrelevant. Equation 41f shows that the activity system has no effect on trip distribution beyond its effect on T_i^n and T_j^n, as represented in the trip generation step.

$$T_{ij}^n. \text{ (obtained directly)} \tag{41a}$$

$$T_i^n.. \text{ (constrained to equal } T_i^n) \tag{41b}$$

$$T_{\cdot j}^n. \text{ (sometimes constrained to approximate } T_j^n) \tag{41c}$$

$$e(T_{ij}^n.:L_{im}) = \beta_n\left(\delta_{jm} - \frac{T_{im}^n.}{T_i^n..}\right) \tag{41d}$$

where $\delta_{jm} = 1$ if $j = m$ and 0 if $j \neq m$.

$$e(T_{ij}^n.:L_{lmk}) = 0 \tag{41e}$$

when $l \neq i$.

$$e(T_{ij}^n.:A_l) = 0 \tag{41f}$$

for all values of l.

$$AI = 1.0 \tag{41g}$$

In addition, Eqs. 41a, b, c, e, and f also hold for the opportunity model (Eq. 11). The differential in Eq. 42a is 0 except when m = j and the ranking of destinations from i changes because of the change in t_{ij} (the differential is positive in this case) and when $m \neq j$ and the ranking of j changes, which will only occur when $|t_{ij} - t_{im}| \leq |dt_{im}|$ (the differential is negative in this case). These conditions imply that the elasticities of trips to all but a few destinations are zero.

$$e(T_{ij}^n.:L_{im}) = -L_{im}L_n \frac{dV_j^n}{dt_{im}} \tag{42a}$$

$$AI = 1.0 \tag{42b}$$

Modal Split-Binary Choice (Eq. 14)

Equations 43b and c indicate the symmetrical nature of the binary-choice model. Equations 43d and e point out that only the travel variables for the various modes connecting i and j have an effect on T_{ijk}.

$$T_{ij}^n. \text{ (constrained to equal } T_{ij}^n) \tag{43a}$$

$$e(T_{ijk}^n:L_{ijk}) = \frac{-a_k L_{ijk}}{1 + e^{-h_k}} \tag{43b}$$

$$e(T_{ijk}^n:L_{ijn}) = \frac{a_k L_{ijn}}{1 + e^{-h_k}} \tag{43c}$$

$$e(T^n_{ijk}:L_{imk}) = 0 \tag{43d}$$

$$e(T^n_{ijk}:L_{imn}) = 0 \tag{43e}$$

$$e(T^n_{ijk}:S_i) = 0 \tag{43f}$$

$$AI = 1.0 \tag{43g}$$

Direct Aggregate Procedures

Product Form (Eq. 16)

In Eq. 44, travel time is used as a typical level-of-service variable. All elasticities and cross elasticities for T_{ijk} are constants and are 0 for level-of-service and activity-system variables not associated with zones i and j. The elasticities of the various summations all have a form similar to Eq. 44e; the simple elasticities are weighted by the appropriate trip share ($T_{ijk}/T_{ij.}$ in the equation shown). Because the simple elasticities are both positive and negative, it is possible that the elasticities of the summations with respect to level-of-service variables will be positive, which is contrary to economic theory. The use of constrained regression to prevent this is infeasible because of the large number of constraint equations required (one for each i-j pair) and cannot ensure that predictions will have the proper summation elasticity, because the shares will change in the future. Zonal aggregation can cause a problem if the coefficients in Eq. 44g sum to a number significantly different from 1.

$$e(T_{ijk}:t_{ijn}) = c_{nk} \tag{44a}$$

$$e(T_{ijk}:t_{imn}) = 0 \tag{44b}$$

$$e(T_{ijk}:S_i) = a_{1k},\ a_{3k} \tag{44c}$$

$$e(T_{ijk}:A_i) = 0 \tag{44d}$$

$$e(T_{ij.}:t_{ijn}) = \frac{\sum_k c_{nk} T_{ijk}}{T_{ij.}} \tag{44e}$$

$$e(T_{ij.}:t_{ijn}) = 0 \tag{44f}$$

$$AI = a^n_{1k} + a^n_{2k} \tag{44g}$$

Linear-Log Form (Eq. 17)

All elasticities and cross elasticities for T^n_{ijk} are linear functions of the respective independent variables, inversely proportional to T^n_{ijk}. Zero elasticities occur whenever the independent variable of concern is not associated with the i-j zone pair. The elasticities of the "scaling" activity-system variables (S_{io}, A_{jo}) are both unity, resulting in an aggregation index of 2. The elasticities of summations all take on a form similar to Eq. 45d. Because a^n_{kki} and b^n_{kki} can be expected to be negative and the remaining parameters can be expected to be positive, but small in magnitude when compared with the direct parameters, these elasticities will normally have the proper sign. It is possible to ensure that this will be the case by using constrained regression.

$$e(T^n_{ijk}:L_{ijml}) = \frac{M^n_k S_{io} A_{jo}}{T^n_{ijk}} (a^n_{kml} L_{ijml} + b^n_{kml}) \tag{45a}$$

$$e(T^n_{ijk}:S_{io}) = 1 \tag{45b}$$

$$e(T^n_{ijk}:S_l) = \frac{M^n_k S_{io} A_{jo}}{T^n_{ijk}} (c^n_{kl} S_l + d^n_{kn}) \tag{45c}$$

$$e(T^n_{ij}.:L_{ijml}) = \frac{S_{io} A_{jo}}{T^n_{ij}.} \sum_k M^n_k (a^n_{kml} L_{ijml} + b^n_{kml}) \tag{45d}$$

$$AI = 2.0 \tag{45e}$$

Product-Exponential Form (Eq. 18)

All elasticities and cross elasticities for T^n_{ijk} are linear functions of the respective independent variables, independent of the level of T^n_{ijk}. Zero elasticities occur whenever the independent variable of concern is not associated with the i-j zone pair.

$$e(T^n_{ijk}:L_{ijml}) = a^n_{kml} + b^n_{kml} L_{ijml} \tag{46a}$$

$$e(T^n_{ijk}:S_l) = c^n_{kl} + d^n_{kl} S_l \tag{46b}$$

$$e(T^n_{ij}.:L_{ijml}) = \sum_k \frac{T^n_{ijk}}{T_{ij}.} (a^n_{kml} + b^n_{kml} L_{ijml}) \tag{46c}$$

$$AI = 1.0 \tag{46d}$$

Independent Abstract Mode Procedures (Eq. 20)

Equation 47 indicates significant discontinuities for the elasticities of "best" modes and other modes. The 0 cross-elasticity of Eq. 47c when $m \neq b$ is especially troublesome. Equation 47 indicates that the elasticities and cross elasticities of this model are independent of the mode of trips, k, as would be expected in an abstract mode model.

$$e(T^n_{ijk}:P_l) = a_1 \tag{47a}$$

$$e(T^n_{ijk}:t_{ijk}) = \begin{cases} a_9 \text{ when } k \neq b \\ a_6 \text{ when } k = b \end{cases} \tag{47b}$$

$$e(T^n_{ijk}:t_{ijm}) = \begin{cases} 0 \text{ when } m \neq b \\ a_6 - a_9 \text{ when } m = b \\ a_6 \text{ when } k = b \end{cases} \tag{47c}$$

$$e(T^n_{ij}.:t_{ijl}) = \begin{cases} a_9 \dfrac{T_{ijl}}{T_{ij}.} \text{ when } l \neq b \\ a_6 - a_9\left(1 - \dfrac{T_{ijl}}{T_{ij}.}\right) \text{ when } l = b \end{cases} \tag{47d}$$

$$AI = a_1 + a_2 \tag{47e}$$

Modal Share Models (Eqs. 21, 22, and 23)

Equation 48 indicates that the elasticities and cross elasticities with respect to travel time by a given mode are directly related to the share of trips using that mode. The parameter b_5 should be in the range of 0 to 1, with a value near 0 expected. If it is 0, the elasticity of total trips by zone pair (Eq. 48e) will be 0. If it is 1, the direct time elasticity (Eq. 48b) will be simply a_{2k}, and the cross elasticities (Eq. 48c) will be 0, as in the product form of Eq. 16.

$$e(T^n_{ijk}:P_i) = b_1 \tag{48a}$$

$$e(T^n_{ijk}:t_{ijk}) = a_{2k}\left[\frac{T_{ijk}}{T_{ij\cdot}}(b_5 - 1) + 1\right] \tag{48b}$$

$$e(T^n_{ijk}:t_{ijm}) = a_{2m}\frac{T_{ijm}}{T_{ij\cdot}}(b_5 - 1) \tag{48c}$$

$$T^n_{ij\cdot} = f_2 \tag{48d}$$

$$e(T^n_{ij\cdot}:t_{ijk}) = a_{2k}b_5\frac{T_{ijk}}{T_{ij\cdot}} \tag{48e}$$

$$AI = b_1 + b_2 \tag{48f}$$

Disaggregate Separable Decision Models

Modal Choice (Eq. 24)

In a similar fashion to Equations 43a, b, c, d, and e, Eq. 49 indicates that the elasticities of travel by a given mode with respect to the independent variables are directly proportional to the value of the independent variables, the value of their coefficient, and the fraction of traffic not using the given mode. The elasticities of travel with respect to variables not associated with origin i or destination j are all 0. Also, as expressed in the independence-of-irrelevant-alternatives axiom, the elasticity of travel by any mode with respect to level-of-service variable of any second mode does not depend on the characteristics of any mode except the second. Let

$$h^n_{ij} = a^n + \sum_1 b^n_l(L_{ijal} - L_{ijtl}) + \sum_1 c^n_l S_{il} \tag{49a}$$

Then Eq. 24 becomes

$$\frac{P^n_{ija}}{1 - P^n_{ija}} = \exp(h^n_{ij}) \tag{49b}$$

$$e(T^n_{ija}:S_{il}) = c^n_l S_{il}(1 - P^n_{ija}) \tag{49c}$$

$$e(T^n_{ija}:L_{ijal}) = b^n_l L_{ijal}(1 - P^n_{ija}) \tag{49d}$$

$$e(T^n_{ija}:L_{ijtl}) = -b^n_l L_{ijtl}(1 - P^n_{ija}) \tag{49e}$$

$$e(T^n_{ija}:L_{mnkl}) = 0 \tag{49f}$$

$$T^n_{ij\cdot} \text{ (constrained to equal } T^n_{ij}) \tag{49g}$$

$$AI = 1.0 \tag{49h}$$

Other Decisions (Eqs. 25, 26, and 27)

The remaining decisions—time of day, destination, and trip frequency—all have basically the same structure as the modal-choice structure of Eq. 24. Their elasticities and summations, therefore, also have the same characteristics.

Direct Decision Model (Eq. 28)

Equation 28 also has the same structure as Eq. 24 and, therefore, its elasticities have the same characteristics. However, because it is not a sequential model, the elasticities of trip summations are expressed differently.

$$e(T_{ij.}:L_{ijkl}) = d_l L_{ijkl}\left(\frac{T_{ijk}}{T_{ij.}} - \frac{T_{ijk}}{T_{i..}}\right) \tag{50}$$

This equation indicates that the elasticity of trips by all modes from i to j with respect to an independent variable is directly proportional to that variable, its coefficient, and the difference between trips by the mode of that variable as a fraction of total trips between i and j and the same trips as a fraction of total trips from i.

This concludes a summary of the structural characteristics for the set of currently used demand forecasting procedures described in an earlier section. It is obvious that these procedures have a wide range of characteristics and that in some cases the analytical structure itself does not ensure that all characteristics will agree with economic and travel behavioral theory. When these procedures are used, the analyst must investigate carefully the resulting characteristics, to be sure that all aspects of his model are realistic.

After determining the characteristics of a number of forecasting procedures, we can list a number of desirable characteristics. Research can then be done to search for analytical structures that satisfy those desires. This approach to the development of improved analytical structures for travel forecasting has, to some extent, influenced past developments in the field (14, 16, 18, 24). Some of the kinds of desirable characteristics are as follows:

1. The mathematical form of critical elasticities and cross elasticities should be as specified,
2. The effects of the aggregation of traffic zones on model predictions should be as specified,
3. The variation in competition between pairs of modes should be reflected in the model, and
4. The effects of adding new modes on summations of trips should be as specified.

Integration Into Analysis Systems

A number of desirable characteristics of transportation analysis systems place critical constraints on demand forecasting procedures and create requirements for a number of specialized kinds of procedures. Four examples of these characteristics are discussed in this section.

Consistent Estimation of Network Equilibrium

Manheim (12) has discussed the need for transportation analysis systems that use a consistent set of level-of-service variables, consistent both with the demand procedure and with the supply procedure. He points out that this requirement is violated in the UTP procedures when final values of level-of-service variables are not used during the trip distribution and modal-split phases. As a result, demand is erroneously estimated, and the final level-of-service variables are incorrect.

To modify present transportation analysis systems so that they can be consistent, less cumbersome demand procedures than those now used are desirable. Because of their structures, direct demand models have been seen as logical candidates to meet this requirement. In large measure, this accounts for their use in DODOTRANS, one of the first transportation analysis systems that explicitly attempts to estimate network equilibrium in a consistent manner (13). As discussed in the previous section, however, present direct demand models have structural characteristics that are not satisfactory. Therefore, improved models are needed—ones that have the ease of application of the direct demand models and are as controllable as the present UTP procedures. Manheim has proposed a family of analytical formulations to meet these objectives. These models, the general share models, can be expressed either as a sequential set of models or as a direct model.

Pivot-Point Procedures

Often, the analyst is faced with the following situation: The details of the existing travel pattern in an analysis area are known (all interzonal trips and level-of-service variables by mode), and the effects on the transportation system of relatively small changes on this travel pattern are desired. Usually the analyst has a number of choices. The first is to manually estimate the effects. The second is to perform a complete analysis from trip distribution through traffic assignment. The remaining choices fall somewhere in between, involving only partial use of the UTP, based on assumptions that trip distribution or that modal split will not change. Regardless of the choice made, very little of the existing information will be used and, therefore, the resulting estimates may differ from the existing situation more because of calibration errors than of the proposed changes.

Pivot-point procedures have been designed to improve the analyst's forecasts when he is faced with the situation just described. They allow changes in travel to be estimated, based on changes in the transportation system. These procedures minimize the calibration problem by using the existing data and by specifying the elasticities of travel-making with respect to the available level-of-service data. The equation used for estimating changes, based on the total differential of a function, is the following:

$$\Delta T^n_{ijk} = T^n_{oijk}\left[\sum_1 e(T^n_{ijk}:S_1)\frac{\Delta S_1}{S_{o1}} + \sum_1 e(T^n_{ijk}:A_1)\frac{\Delta A_1}{A_{o1}} + \sum_m e(T^n_{ijk}:L_m)\frac{\Delta L_m}{L_{om}}\right] \tag{51}$$

where

ΔT^n_{ijk} = change in trips from i to j by mode k for purpose n,
o = old or former value,
S_1 = socioeconomic variable,
A_1 = activity-system variable, and
L_m = level-of-service variable.

Regardless of what the demand model structure is, the elasticities can be assumed to be constant for small changes. Equation 51, therefore, becomes generally applicable for predicting the effects of small changes. For larger changes, explicit functional forms of the elasticities (arc elasticities) can be used.

The most significant impact of pivot-point procedures is on the design of analysis systems. They also, however, have an effect on demand modeling. They imply that much effort should be put into obtaining good estimates of elasticities, for these alone are needed to use Eq. 51. Because elasticities can best be estimated when a change is observed, this implies that many careful before-and-after studies of transportation should be carried out.

Dynamic Transportation Analysis

As stated in the introduction, we assumed that transportation demand can be divided into short-run and long-run phenomena, and we will concentrate on modeling the short-run situation. Actually, however, there is a continuous variation in effects over time from short run to long run. To reflect this continuity in our models, we must construct dynamic systems by using variables that have a range of lag times, as discussed by Ben-Akiva (2). Such a system would incorporate both land use models and travel prediction models into a set of demand models that would provide predictions of both the long- and the short-range effects of transportation.

Although such an approach is useful as a method to incorporate the time dimension into travel forecasting, it will generate new problems in the areas of empirical estimation, data collection, and convergence of the solution. Work should begin on a study of these problems so that in the future dynamic transportation modeling can be started.

Aggregation of Disaggregate Procedures

To incorporate disaggregate travel demand forecasting procedures into analysis systems, methods of interfacing these procedures with aggregate zonal data must be developed. If the models are applied directly to zonal averages of socioeconomic, activity-system, and level-of-service variables, the major advantage of disaggregated procedures will be lost. Some way must, therefore, be found to incorporate the distributions of zonal variables into the application of the procedures.

One approach that has been suggested is the sampling from these distributions by using Monte Carlo simulation techniques to obtain observations of the independent variables required to predict trips. For some models, it may be possible to analytically obtain the expected value of trips, based on incorporating all of the relevant distributions of variables. This is an area in which research should begin, both to look for alternate approaches and to test the various proposed methods to determine their usefulness and accuracy.

RECOMMENDED PROGRAM OF RESEARCH

In this part of the paper, all of the suggestions for further research included in the previous part will be brought together as a unified program of research in the area of the analytical structure of travel forecasting procedures. Each recommended area of research will be given a priority rating and a recommended time frame for carrying out the research.

Travel Demand Theories

1. Lancaster's approach to consumer utility and demand should be expanded to be applied directly to travel demand. The implications of this approach to estimating the demand for transportation as a part of activities that have utility to the consumer should be explored with a view toward developing additional theoretical guidelines to the travel demand model developer. The priority is medium, and the time frame is 3 to 8 years.

2. Work should be continued on the development of a general equilibrium model that concentrates on transportation demand prediction. The work done to date (3) should be continued in the following areas: (a) searching for a utility function form that results in demand functions with a closed form, (b) exploring the existing formulation for its implications on suitable analytic structures, and (c) searching for realistic revisions of the formulation that will result in useful demand functions. The priority is medium, and the time frame is 3 to 8 years.

3. Work should be begun on the incorporation of the total travel time constraint into economic theories of the consumer because of the importance of travel time as a deter-

minant of travel demand. The priority is medium, and the time frame is 1 to 5 years.

4. The theory of rational choice behavior, as developed in psychology, should be developed further, with a view to its application to travel behavior in particular. The goal should be to develop a framework that can be used to construct more realistic models for travel demand forecasting. The priority is high, and the time frame is 1 to 5 years.

5. Work should continue on the testing of alternative assumed sequences of traveler choice. Because these sequences are so crucial to both aggregate and disaggregate sequential models, the effects of alternative assumptions on model accuracy should be determined for a number of classifications of trips, including urban work and shopping trips and intercity business and pleasure trips. The priority is medium, and the time frame is 1 to 5 years.

Data for Travel Demand Forecasting

1. Work should begin on developing travel survey methods that will provide the data needed for disaggregated demand modeling in the most accurate and efficient manner possible. This work should proceed from the development of alternative designs through the conducting of prototypical surveys, the use of the data obtained in model estimation, and the evaluation of the methods for future use. The priority is high, and the time frame is 1 to 3 years.

2. Research into methods of improving the accuracy of survey data should be carried out, including alternative methods of monitoring and recording travel data and of integrating survey data with engineering information. This is an area where the usefulness of new technology, such as automatic vehicle (and perhaps people) locator systems, should be explored. The priority is medium, and the time frame is 3 to 8 years.

3. Specialized surveys and studies should be designed and conducted to help provide answers to questions not answered by present demand procedures because problems of multicollinearity prevented all relevant variables from being included. For example, careful before-and-after studies and controlled experiments should be conducted to learn more about the responses of travelers to fare, time, and frequency changes. The priority is high, and the time frame is 1 to 5 years.

Demand Estimation Methods

Research should be carried out by statisticians to develop accurate and unbiased estimation procedures for use in travel demand model development. The concentration should be placed on analytic structures that have theoretical appeal but have not been used to date because it has not been possible to estimate their parameters. The priority is medium, and the time frame is 3 to 8 years.

Structural Characteristics

1. The various analytical structures that have been developed or proposed should be studied carefully to determine their characteristics: elasticities, cross elasticities, aggregability, summations, and ability to balance trip origins and destinations by zone. Characteristics that can be, or are always, contrary to theory should be pointed out, and changes to the structures should be proposed to prevent such characteristics from occurring. The priority is high, and the time frame is 1 to 5 years.

2. As proposed analytical structures are found that have promising characteristics, work should be done to calibrate them to determine their applicability to actual travel phenomena. Alternative structures should be compared by using criteria based on goodness-of-fit measures, ease of calibration, and constancy of parameters. The priority is high, and the time frame is 1 to 10 years.

3. Research should be conducted to proceed from alternative specifications of the

structural requirements of demand models to the determination of analytical structures that satisfy these requirements. The alternative sets of specifications should be generated with particular demand estimation problems in mind, such as predicting the demand for a new mode by a particular market segment or predicting the effects of relatively minor changes in operating policies. The priority is medium, and the time frame is 3 to 8 years.

Integration Into Analysis Systems

1. Research should be carried out to determine methods by which the existing analysis systems can be modified to provide for the consistent estimation of travel demand, both by modifying the structure of those systems minimally and keeping the present demand procedures and by incorporating new procedures better suited to the consistent estimation of network equilibrium. The priority is high, and the time frame is 1 to 3 years.
2. Research should be carried out to develop new analysis systems that will incorporate a wide range of demand procedures in an efficient system that consistently estimates network equilibrium. The limitations placed on demand procedures by these systems should be determined and removed if necessary to provide for the realistic estimation of travel demand. The priority is medium, and the time frame is 3 to 5 years.
3. Research should be carried out to develop demand models that will be efficient for use in consistent network equilibrium prediction systems. The general share models should be examined in this light, and recommendations should be made on their further development or on alternative directions of improvement. The priority is medium, and the time frame is 3 to 5 years.
4. Research should be conducted to develop pivot-point procedures as integral parts of transportation analysis systems and to develop the demand models and data needed to make these procedures useful for a wide range of small-scale transportation prediction problems. The priority is high, and the time frame is 1 to 3 years.
5. The feasibility of developing a dynamic system of models to incorporate short-term demand estimation and long-term land use predictions should be studied. Such a study should address the data requirements that this approach will generate, the estimation problems, and the convergence problems. The result should be a program of work to provide the necessary data and tools to allow the calibration of such a model in the future. The priority is medium, and the time frame is 3 to 8 years.
6. Methods to interface disaggregate demand models with aggregate zonal data in analysis systems should be developed and tested. Also, the possibility of eliminating the zonal aggregation of the data needed for demand models should be explored, taking advantage of the data directly available from home interview surveys and from the census. These research tasks should be addressed both to the use of disaggregated models with existing and with predicted future socioeconomic, activity-system, and level-of-service data. The priority is high, and the time frame is 1 to 3 years.

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IMPLEMENTATION PROGRAM

Conference participants concluded that travel demand forecasting is entering into a new era in which are emerging a stronger behavioral basis for travel demand models, a coherence and unity of direction of current work, and the potential for major improvement in practical capabilities for forecasting future travel in the context of today's urban transportation decision-making needs. To achieve the promise of this new era requires a coordinated action program that involves

1. Immediate improvements to present forecasting capabilities to simplify them, add new capabilities, and increase their validity;
2. Immediate use of techniques now available such as disaggregate models, direct demand models, and market research techniques;
3. Research to develop a deeper understanding of travel behavior to extend the range of situations for which consumer responses can be predicted;
4. Supporting research to develop substantial improvements in practical methods necessary to implement increased understanding of travel behavior;
5. Immediate development of improved forecasting methods for priority problem areas; and
6. A major program of information dissemination and training to improve the capabilities of professionals involved in state and local transportation planning.

The implementation program, which is given in the pages that follow, comprises the recommendations of the conference workshops. Work in any one of the 6 major areas can be done for general application to transportation decision-making or for specialized application to particular problems that relate to energy, the environment, mobility of special groups, new systems, subareas, low-capital options, and transportation planning procedures. The elements of the program are interrelated, and all are essential to improving the practice of travel forecasting. A summary of the program follows.

IMPROVE EXISTING FORECASTING CAPABILITIES
- Simplify and streamline present procedures
  - Turn-around time
  - Aggregate sketch-planning technique
  - Transit analysis techniques
  - Computing environment

Add new capabilities to present procedures
  - Incidence of transportation benefits
  - Energy, air quality, and noise impacts
  - Practical methods for analyzing time-staging strategies
  - Design volumes
  - Parking capacity restraint
  - Pivot-point analysis
  - Richer variety of demand models
  - General supply functions

Improve validity of present procedures
  - Consistency of the UTMS
  - Improved trip distribution procedures
  - Generalized equilibrium procedures
  - Improved equilibrium procedures
  - Sensitivity analysis of present forecasting methods

PUT EMERGING TECHNIQUES INTO PRACTICE

Apply prototypes of improved forecasting methods
  - Disaggregate demand models
  - Direct demand models

Use market research techniques
  - Consumer perceptions of level of service
  - Short-cut approaches to constructing demand models
  - Attitudinal and conventional forecasting techniques

Develop improved data bases
  - Data specifications for improved demand models
  - Dissemination of disaggregate data bases
  - Existing disaggregate household data
  - Monitoring and analysis of travel trends
  - New data collection guidelines
  - Improved data collection methods

INCREASE UNDERSTANDING OF TRAVEL BEHAVIOR

Learn from effects of transportation system changes on current travel behavior
  - Development of methods
  - Rapid-response data collection

Identify attributes
  - Perceptions of safety, security, and reliability
  - Incorporation of marketing variables
  - Identification of comfort-convenience factors
  - Perceptions of system and route reliability

Develop theoretical models of travel behavior
  - Applications of economic theory
  - Applications of theory of rational choice behavior
  - Alternative sequences of travel decisions
  - Comprehensive models of travel decision-making
  - Commodity dependence and independence
  - Other directions

Interrelate location, automobile ownership, and travel decisions
  - Automobile ownership
  - Land use linkages
  - Sensitivity testing and related land use management issues
  - Spatial organization-travel demand model
  - Dynamic size-spatial organization-transport model
  - Subarea models
  - Interaction structures of small areas
  - Integration of urban processes

PROVIDE A BASIS FOR DEVELOPMENT OF SUBSTANTIALLY IMPROVED CAPABILITIES

Analyze structures of travel demand models
  - Exploration of structural characteristics
  - Development of new structures
  - Empirical testing of alternative structures
  - Aggregation methods
  - Empirical analyses of aggregation and scale in travel analysis

Improve model estimation methods
  - Model stability over time and space
  - Classification procedures to improve model transferability
  - Estimations methods
  - Simultaneous estimation of service and demand
  - Comparative analyses of data requirements
  - Derivation of demand parameters from link volumes
  - Measures of uncertainty

Improve equilibrium computing methods
  - Research and development of computational methods
  - Modification of existing analysis systems
  - Development of new integrated forecasting systems
  - Integrating demand models and equilibrium procedures
  - Pivot-point procedures
  - Combining long-term and short-term equilibrium
  - Equilibrium methods with disaggregate models

Integrate forecasting systems
  - Exploration of alternative design concepts
  - Computer laboratory to support transport planning

Develop transport-facility supply models

IMPROVE METHODS FOR PRIORITY PROBLEM AREAS

Develop understanding of energy-transportation relation
  - Energy implications for forecasting requirements
  - Energy-related attributes of service
  - Effects of significant changes in energy-related attributes

Improve forecasts of effects of control strategies for environmental quality
  - Corridor traffic noise
  - Regional air pollution effects of transportation facilities
  - Microscale air and noise impacts
  - Consequences of the null alternative decision
  - Travel demand and activity patterns with in context of network supply constraints based on environmental quality
  - Resource and energy needs, transportation systems, and urban structure

Identify mobility needs of special user groups
  - Transportation requirements, characteristics, and behavior of special groups
  - Public responsibility for private mobility
  - Mobility-accessibility measures

Improve forecasting methods for new transportation systems and services
  - Simplified modal choice models for rapid estimation of patronage for new options or technology
  - Identification, measurement, and quantification of attributes
  - New forecasting methods
  - Changing perceptions of new services
  - Taxonomy of new systems and options
  - Demonstration project surveillance methodologies
  - Urban transportation product laboratory
  - Demand models for forecasting new systems market
  - Demonstration of forecasting methods in new systems projects
  - Transportation management characteristics

Develop forecasting methods for subarea and corridor studies
  - Methods using previous area-wide forecasts
  - Methods for synthesizing subarea forecasts
  - Aggregation and extraction procedures

Develop forecasting methods for short-run low-capital options
  - Identification of attributes
  - Development of demand models
  - Refinement of models
  - Simplified forecasting methods
  - Economical data sources
  - Group travel options
  - Peak hour
  - Influence of marketing strategies

Improve transportation planning procedures
  - Presenting results of forecasts
  - Prototype transportation planning studies
  - Incentives for experimentation and innovation
  - Planning information to aid local and state agencies to implement national policy

DEVELOP PROGRAMS FOR INFORMATION DISSEMINATION AND FOR TRAINING

Develop ways to disseminate information to professionals
  - Rapid dissemination of current information
  - State-of-the-art reviews
  - Guidelines for selecting forecasting techniques
  - Documentation of model specifications

Undertake training programs

Develop ways to disseminate information to the laity
  - A lay guide to travel forecasting procedures
  - Policy implications of results of demand research

Obtain feedback to evaluate current capabilities
  - Monitoring of developments abroad
  - Periodic review and appraisal of progress

Program Area 1

Existing Forecasting Capabilities

A body of research results already exists that builds on present forecasting capabilities and can be used to improve current travel forecasting practice. Almost all of these improvements can be achieved within a period of 3 years, and many can be achieved even more quickly.

The major existing travel forecasting capabilities are based on a 4-step sequential process consisting of trip generation, distribution, modal split, and network assignment. Various models exist for each of these steps. This program area discusses a number of modifications and additions that should be made to substantially improve the usefulness, responsiveness, and validity of these existing systems.

1. Simplify and streamline present procedures.

Turn-around time—Current transportation models require weeks, and in many instances months, for their application. Methods should be developed to reduce this turn-around time to days or ideally hours. This would allow models to be used more frequently and to be more responsive and many more alternatives to be analyzed.

Aggregate sketch-planning techniques—Procedures are required to enable rapid exploration and analysis of a variety of transportation and land use alternatives for a region (or subregion) before detailed travel forecasts are produced for a few alternatives selected for further study. Research should be conducted to develop alternative sketch-planning techniques, such as modified forms of the conventional models or of the TRANS or DODOTRANS systems or new approaches.

Transit analysis techniques—Improvement in present capabilities is needed for the analysis of transit service in both large and small urban areas. In large areas, major route changes or implementation of totally new service is often considered in specific corridors. In small cities, new local service or existing service tailored to meet specific requirements is usually considered. Transit analysis with existing planning tools is difficult, for they do not provide answers fast enough or at the required level of detail. Capabilities to be added should allow efficient exploration of a variety of schedule, route, and pricing options.

Computing environment—Most present forecasting capabilities were developed for batch-processing computing environments. Substantial efficiencies could be achieved in the use of existing methods if the computational environment were provided with capabilities such as problem-oriented language structures to simplify use of computer programs, on-line interactive computing environment, and interactive computer graphics.

2. Add new capabilities to present procedures.

Incidence of transportation benefits—Effective post-processing and data-summarizing tools should be added to the UTMS package (the urban transportation model system as implemented in various forms by the Federal Highway Administration, the Urban Mass Transportation Administration, and others) so that those who benefit from level-of-service increases as a result of a transportation improvement can be identified by factors such as socioeconomic status, trip purpose, and geographic location. The aid of computer graphics in this context for rapid visual display of the incidence of travel benefits should be investigated.

Energy, air quality, and noise impacts—Existing forecasting capabilities should be made more useful by adding a capability for fast determination of resultant air and noise pollution in a given section of a region under various transportation system plans. Procedures for identifying energy requirements should also be added.

Practical methods for analyzing time-staging strategies—Too often, long-range transportation system plans are developed and approved without a thorough review of the sequence in which the plan elements should be implemented. Based on the number of plans that have been rejected in recent years because certain links were no longer acceptable to the public or elected officials, planners must develop and analyze alternative strategies for implementing transportation plans. This requires efficient methods for using models to make incremental forecasts for analyses of staging strategies. The plan selected after staging analysis may be substantially different from and more economical than a plan selected in the traditional way.

Design volumes—One useful product of travel forecasts is the provision of travel volumes to the facility designer. Present techniques require much hand adjustment of region-wide travel volumes and in many instances do not provide enough detail for the designer. Improved methods are required for developing design parameters and also for producing estimates of the range of uncertainty in design volumes.

Parking capacity restraint—Present network assignment models do not have enough sensitivity to changes in parking policy or pricing. Because these factors have a great effect on travel mode choice to the central business district, assignment processes should accurately reflect changes in parking conditions.

Pivot-point analysis—A key problem is how to analyze quickly the effects of various small changes in the transportation system of a region. One useful way is to use the results of a previous network assignment as a starting point and estimate the effects of small changes in terms of deviations from that point. The forecasting capabilities should be equipped with a procedure for performing such pivot-point analyses based on approximate knowledge of travel demand elasticities and interzonal flows.

Richer variety of demand models—The user of existing models is free to insert any modal-split formulation he wishes. That freedom should also be extended to other steps of the process, including generation, distribution, and network assignment. Present capabilities in the system should be generalized to allow use of a rich variety of alternative forms, especially those resulting from direct demand aggregate and disaggregate model estimation approaches.

General supply functions—At present, procedures are available for determining the travel time over a link as a function of the volumes flowing over that link at various points in the network assignment process (e.g., through use of volume-delay curves). More general capabilities should be developed to allow the level of service over a link to be multidimensional (e.g., average time, variance of time) and to be a function of volumes on specified subsets of links (e.g., delay at an intersection experienced by one flow is a function of volumes on all links at the intersection).

3. Improve the validity of present procedures.

Consistency of the UTMS—Steps, such as the following, must be taken to make the UTMS an internally consistent estimation system: (a) The same level-of-service variables must be consistently considered in each stage of forecasting trip generation, distribution, modal split, and assignment; (b) a broad set of level-of-service variables should be available for use; and (c) trip generation must be made sensitive to these level-of-service variables.

Improved trip distribution procedures—In forecasting the distribution of trips among alternative destinations, transit as well as highways should be considered (even where transit is the second best mode). Present trip distribution procedures use only the travel time of the single fastest mode. These procedures should be modified to use all of the significant level-of-service variables (e.g., parking price, automobile walk time, transit access time) of all relevant modes.

Generalized equilibrium procedures—Present minimum path algorithms used in network assignment procedures use treé-trace algorithms based on a single level-of-service variable, such as time or distance, or other variables, such as transfer penalties and fares coded into the network as links. A full set of service variables should be incorporated into the path-finding routines so that policy options such as fares, parking charges, or reductions of transfers can be more accurately reflected. It should be possible to vary the weights of the different service variables by market segment such as trip purpose or income.

Improved equilibrium procedures—Present network assignment models do not necessarily reach a true state of equilibrium between traffic flow and system capacity. This condition must be achieved if network flows are to be realistic forecasts. Improvements to present models should be made that incorporate innovations already demonstrated such as incremental assignment, the perturbation methods developed in Great Britain, or other methods.

Sensitivity analysis of present forecasting methods—All travel forecasting methods are based on external estimates or assumptions, such as population forecasts and trip generating rates. The sensitivity of various steps in the travel forecasting process to external estimates or assumptions should be explored in case studies in 1 or 2 selected urban areas. A greater understanding of the magnitudes of sensitivity or insensitivity would be of great practical use; for example, in corridor or other subarea studies, it would be useful to know which portions of the forecasting process could be held constant or varied.

Program Area 2

Emerging Techniques

Since the development of the basic 4-stage sequential approach on which present forecasting capabilities are based, further research has produced new methods and techniques. The major results are as follows: (a) direct demand models that combine the steps of generation, distribution, and modal split (and possibly the path selection portion of network assignment) into a single step and that use aggregate data in a deterministic model; (b) disaggregate models that use disaggregate data in a probabilistic model (substantial work has been done to produce models for forecasting mode choice, and recent work has demonstrated the feasibility of developing disaggregate models for simultaneous choice of mode and destination and, in the future, for generation and path as well); and (c) market research techniques, such as attitudinal surveys and scaling methods, for which the feasibility and usefulness of applications to transportation have already been demonstrated.

1. Apply prototypes of improved forecasting methods.

Although recent research has developed a number of promising new demand forecasting approaches, none has been suitably tested in real-world applications. In 3 to 5 selected areas where current corridor or subarea studies are under way, the new forecasting approaches should be applied in parallel with traditional techniques to provide a basis for comparative evaluation of the advantages and disadvantages of each approach.

Disaggregate demand models—A number of good disaggregate demand models have been developed, but few have been applied. Procedures must be developed for interfacing disaggregate demand models with various levels of aggregate travel data, including both network and activity system data. To apply these models in a theoretically satisfactory way requires further work on the problem of aggregation. However, pragmatic short-cut procedures are now available, and the application of disaggregate models should begin immediately in parallel with longer lead-time research on aggregation. Substantial experience has been gained with disaggregate models of mode choice, and these can be used directly and immediately in a number of prototype applications. Prototype models of simultaneous choice of mode and destination should be applied now in 2 selected transportation studies and extended later to choice of trip frequency and time of day. In parallel with these prototype applications, research should be conducted to develop immediately useful aggregate methods that have sounder theoretical and empirical bases. Procedures such as Monte Carlo sampling should be explored and tested. Also, procedures for using data directly available from home interview surveys and the census should be studied.

Direct demand models—The feasibility of calibrating direct demand models with data already collected by urban transportation studies has already been demonstrated for trip generation and modal split. The next step is to use these models in planning studies and to include destination choice as well. Conventional or aggregate data should be used in the calibration and application of direct demand models in ongoing transportation studies. However, the use of disaggregate data may have to be undertaken on a prototype basis.

2. Use market research techniques.

Market research results cannot be used directly in explicit demand models for travel forecasting purposes. However, they are useful in a preliminary stage to improve the application of direct aggregate models or disaggregate models and should be used immediately in prototype applications to achieve further improvements. Development of pragmatic methods for producing operational demand models in conjunction with the use of market research techniques and in parallel with the use of other procedures can and should be undertaken in a prototype application in a specific transportation study.

Consumer perceptions of level of service—Market research techniques should be used to identify level-of-service attributes that most strongly influence travel decisions in a variety of different situations. The results should then be used in designing further data collection for use in either aggregate or disaggregate demand modeling.

Short-cut approaches to constructing demand models—Market research methods should be used to develop and apply short-cut approaches to the construction of demand models.

Attitudinal and conventional forecasting techniques—One of the promising future directions for the development of improved travel forecasting techniques appears to be the expanded use of attitudinal techniques. There is, however, considerable uncertainty at the present time as to the viability of such techniques, their relative cost and accuracy when compared to more conventional methods, and the areas where their use is most appropriate. A carefully controlled comparison should be made of attitudinal versus conventional travel forecasting techniques, based on their parallel application in one or more case studies. Detailed data should be developed on the time and resource requirements associated with each technique, data requirements, results obtained, and their significance within the overall transportation planning process. Particular emphasis should be placed on clear identification of problem areas and questions that may be effectively addressed by some techniques but not others. The results should be documented in the form of a manual offering guidelines for the future use of each technique, including the areas where use of attitudinal models appears worthwhile and the procedures that should be followed in their application.

3. Develop improved data bases.

The prototype applications described above can proceed immediately and can use data already collected or data collected in special surveys that are relatively small in size and scope and designed for the prototype studies. In addition to these specialized efforts, however, more comprehensive and extensive data sets should be developed as part of continuing transportation planning activities, which include travel surveys and other forms of data collection.

Data specifications for improved demand models—Specifications for data requirements for use in direct aggregate and disaggregate demand models should be developed immediately. One method of developing these specifications is to bring together the practitioners who are about to initiate general travel surveys and the researchers experienced in these demand modeling methods so that data requirements for both can be satisfied in the same data collection efforts. This is a high-priority task that should be undertaken immediately so that maximum gain can be achieved from forthcoming surveys. This work should proceed from the development of alternative designs through the conducting of prototypical surveys, the use of the data obtained from the model, and the evaluation of the methods for future use.

Dissemination of disaggregate data bases—One or more sets of disaggregate data should be developed and made readily accessible as a basic data source for the development of more sensitive demand models, especially those using disaggregate techniques. Such data should consist of carefully designed samples; data at the household or individual level should consist of socioeconomic data and travel characteristics for choices made and not made. Some of these data sets should represent conditions before and after changes are made in the transportation system.

Existing disaggregate household data—Conventional home interview surveys represent a rich source of data, and ways should be devised for using them more effectively in developing disaggregate models.

Monitoring and analysis of travel trends—In past analyses, travel behavior was assumed to be stable over time. Data collection and analysis are required to establish whether that is true and, if not, to determine the rates of change. This program must be carried out in enough cities so that a variety of geographic, political, and social conditions are monitored.

New data collection guidelines—Present guidelines for data collection and analysis should be reviewed in light of current forecasting needs and research results, and new guidelines should be developed if appropriate. Necessary areas for research and appraisal include (a) sample selection and size, (b) instrument design, and (c) data processing techniques and supporting software. Particular attention should be given to intrahousehold resource allocation, identification of attitudes, marketing impacts, and time series effects.

Improved data collection methods—Research should be carried out on methods of improving the accuracy of survey data, monitoring and recording travel data, and integrating survey data and engineering information. This is an area where the usefulness of new technology, such as automatic vehicle locator systems, should be explored. Specialized surveys and studies should be designed and conducted to help provide answers to questions not answered by present demand procedures because problems of multicollinearity prevented all relevant variables from being included. For example, careful before-and-after studies and controlled experiments should be conducted to learn more about the responses of travelers to fare, time, and frequency changes.

Program Area 3

Travel Behavior

Greater understanding of the mechanisms and characteristics of travel behavior is essential and will yield a substantial increase in the accuracy of forecasts, in the range of situations for which accurate estimates of future travel behavior can be developed, in the transferability of forecasting methods from one situation to another, and in the corresponding cost efficiencies.

1. Learn from effects of transportation system changes on current travel behavior.

Development of methods—Data collection and analysis procedures for before-and-after studies should be established, and procedural manuals should be prepared. Attention should be given to all types of changes in the transportation system, particularly short-run and low-capital projects because they are relatively easy to implement and demonstration projects of new types of systems or services because they assist in extending the range of service levels for which demand models have been calibrated. Procedures should include assessment of latent demand response, transient effects, usage by special groups, and patterns of change in public image and acceptance.

Rapid-response data collection—Infrequently occurring events such as strikes, facility closures due to repairs, and major price or service changes provide unique opportunities to observe changes in travel patterns and to gain increased understanding of travel behavior. Procedures should be established for rapid-response funding of well-designed data collection efforts in such circumstances.

2. Identify attributes.

Perceptions of safety, security, and reliability—Travelers' perceptions of personal safety, security, and system reliability appear to have major influences on demand. This is especially important for public transit systems in central cities and other areas where crime rates are generally high and for new system whose reliabilities may not be perceived by prospective users as being high. Research is needed to define these service attributes more precisely, to identify under what conditions various groups of prospective travelers weigh these attributes heavily, to develop demand models that include these attributes, and to develop supply models for estimating the performance of particular transportation systems with respect to these attributes.

Incorporation of marketing variables—Consumer demand and brand choice are known in general to be sensitive to the intensity and skill of the associated marketing efforts. For urban transport, a descriptive framework for marketing activities (market research, product planning and revision, pricing, promotion) should be developed, empirical research should be carried out to determine in a quantitative way how these variables influence demand, and the results should be disseminated to the industry and appropriately blended with other phases of demand estimation. The outputs of the models must be in a form such that operators can understand and use them in their marketing decisions. Research should be conducted to (a) investigate the extent to which marketing activities and their results can be described by existing demand models, develop appropriate formats and media for disseminating these findings to the industry (as well as for information exchange among industry-initiated efforts), and disseminate usable tools, data, and insights; (b) develop a descriptive framework for the decision quantities and background parameters characterizing market activities and their results; (c) design and execute empirical research efforts to determine the effectiveness and costs of various mixes and types of such activities including efforts to attract patronage by "social conscience" arguments, explore applicability of findings and models from the marketing-research literature, and develop and disseminate to the industry appropriate formats, media, and tools; and (d) determine means for systematically using the findings to modify the results or procedures or both of other phases of the demand-estimation process.

Identification of comfort-convenience factors—Research is needed to develop a better understanding of the different aspects of comfort and convenience as perceived by travelers. Short- and long-range transportation alternatives must be more clearly stated with respect to these features. This will alter the structure of demand models, especially the modal-split portions, by broadening the range of attributes.

Perceptions of system and route reliability—Consumer choice is probably influenced by reliability in relation to weather, intermittent congestion, and accidents. Research is needed to determine the key aspects of reliability and their influence on travel choices of mode, destination, path, and trip frequency. Procedures will also be required for predicting reliability levels resulting from transportation system changes.

3. Develop theoretical models of travel behavior.

Applications of economic theory—Economic theories of consumer utility, especially those that incorporate the concepts of activity levels and characteristics of these levels, should be explored and applied to the phenomenon of trip-making. The goal should be to develop additional theoretical guidelines for the model developer and to suggest the classes of analytical structures that are most appropriate for travel demand modeling. In addition, and if feasible, this work should be extended to the development of useful demand functions that are based on economic theoretical grounds. Lancaster's approach to consumer utility and demand should be expanded to be applied directly to travel demand. The implications of this approach to estimating the demand for transportation as a part of activities that have utility to the consumer should be explored with a view toward developing additional theoretical guidelines for the travel demand model developer. Work on the development of a general equilibrium model that concentrates on transportation demand prediction should be continued in the areas of searching for a utility function form that results in demand functions with a closed form, exploring the existing formulation for its implications on suitable analytic structures, and searching for realistic revisions of the formulation that will result in useful demand functions. Work should be begun on the incorporation of a total travel time constraint into economic theories of the consumer because of the importance of travel time as a determinant of travel demand.

Applications of theory of rational choice behavior—The theory of rational choice, as developed in psychology, must be explored and applied, where applicable, to the phenomenon of trip-making. The goal should be to explore the implications of the theory for the model developer and to suggest the classes of analytical structures that are most appropriate for travel demand forecasting. Experiments should also be conducted to test the theories against actual travel behavior to determine the validity of the underlying assumptions, such as the independence of irrelevant alternatives.

Alternative sequences of travel decisions—Work should continue on the testing of alternative assumed sequences of travel choice. Because these sequences are so crucial to both aggregate and disaggregate sequential models, the effects of alternative assumptions on model accuracy should be determined for a number of classifications of trips, including urban work and shopping trips and intercity business and pleasure trips.

Comprehensive models of travel decision-making—A carefully structured, comprehensive program of research is required to develop a more coherent understanding of the mechanisms underlying the travel decision-making process. The program should focus particularly on (a) basic structure of the decision process and its relation to the structure of activities performed by varying decision units generating a demand for travel; (b) major factors impacting on the decision process, including structure of decision unit and nature of primary demand; (c) coherent set of behavioral data bases for subsequent analysis; (d) sensitivity (and insensitivity) of decision-making to service parameters and other controllable factors; (e) interrelation of long-run versus short-run decisions on travel behavior; and (f) interrelations among choice of frequency, destination, route, modal choice, and time of travel.

Commodity dependence and independence—An ultimate objective in travel demand modeling is to characterize each alternative choice in terms of its attributes with sufficient completeness that the same parameter values can be used to characterize each choice, i.e., to specify the consumer's utility function wholly in terms of attributes and independent of the commodities—the travel choices. Thus, abstract mode models are one form of this condition. Research is needed to develop more extensively the theory behind the property of commodity independence and, as knowledge of attributes is improved, to attempt to develop commodity-independent travel demand models.

Other directions—In addition to the above, alternative theories of travel behavior should be developed.

4. Interrelate location, automobile ownership, and travel decisions.

A major impact of transport change is its influence on the location of both individuals and firms. The response of individual decision-makers (individuals, firms) to changes in the transport system is a subject that impacts the manner in which cities develop. For individuals the transport system influences choice of residence location, rents, and automobile ownership. For firms the transport system influences market area, customer transport costs, and therefore sales. The system also impacts the job markets and, therefore, influences the location of industrial and commercial activities. Research is needed to produce models to forecast the interactions of transportation and land use as reflected in the interaction of location and travel decisions.

Automobile ownership—In past prediction methods, automobile ownership was related largely to variables of income and demographic composition independent of transportation system characteristics. Now, however, the wide range of new options being considered—energy, air quality, short-term and low-capital options, new systems—raises the possibility that some kinds of automobile ownership decisions may be significantly affected in the future by transportation system characteristics. Further, in some situations, automobile ownership may conceivably be reduced. Research to develop improved automobile ownership forecasting models should assume that location and automobile ownership choices are interrelated until proved otherwise.

Land use linkages—Land use growth allocation models now exist that are sensitive to transportation network changes. However, these models have not been used in most transportation studies, and their capabilities have not been fully used in measuring the effect of proposed transportation systems on land use. Methodology should be developed to ensure that these land use implications are studied in each urban area.

Sensitivity testing and related land use management issues—Urban structure information is an exogenous input to a travel demand forecasting model and could be varied systematically to explore the sensitivity of output. It would be particularly interesting to compare the magnitude of the resulting variations with those that would result from varying other exogenous inputs, particularly, transport system supply-side variables. The degree of "control" that could be exercised on transport flows by regulating land use could also be explored. In particular, it would be possible to estimate the extent of the land use regulation needed to achieve particular levels of flow.

Spatial organization-travel demand model—The next step is to begin to develop models of spatial organization. Experience in the United Kingdom suggests that some modestly useful results and insights can be obtained by using relatively simple land use and urban activity models. A number of these were recently developed but have not been specifically associated with travel forecasting models. A useful research project, there fore, would be to make the connection.

Dynamic size-spatial organization-transport model—A travel forecasting model needs to be connected to a demographic model for the study area, an economic model for the study area (which would also predict overall income and car-ownership levels), a population-population activity-housing distribution model, and an economic activity distribution model. Because the time structure of change is complicated (many different lags are involved), such a model system will only be adequate finally if it is a dynamic structure in which the different time rates of change appear explicitly in some way. Development of this system is a major, expensive, multiagency task that should involve a number of projects and begin with a number of pilot efforts.

Subarea models—Existing land use models measure the impact of transportation system change on land use only at the broadest of regional scales and leave many of the more detailed situations for hand analysis. Models should be developed to forecast the interaction of land use and transportation on a subregional basis.

Interaction structures of small areas—Current transportation planning for small areas must be sensitive to 2 important aspects: (a) how small areas function or are affected by large-area transport systems design and (b) evaluation of the impacts of the location and design of facilities in the large systems context. Existing models provide an inadequate picture of small area functions and interrelations. In small areas, interaction occurs at a scale (a few blocks), in a fashion (personal friendships, gossip), and by modes (walking, casual social intercourse) that are not well represented in large-scale transport and land use models. Fine-scale assignment models fit only a small part of this complex. These neighborhood interactions have important interfaces with large-scale traffic generators. Models of local interaction and land use should recognize the interactions and interfaces and be usable for a number of transportation planning purposes. They can estimate the impacts of nearby changes on neighborhood conditions and the disruption (as distinguished from relocations) that results from various decisions that impact the community directly, be used in a free-standing mode with external inputs to estimate the impacts of internal changes, and be used to generate inputs to large-system demand simulation.

Integration of urban processes—Good practice requires that modeling, indeed any research process, be made as modular (i.e., nonmonolithic) as possible. However, transportation modeling must be coordinated with efforts of other groups and agencies (water, sewer, energy, ecosystems) to a greater extent than in the past. This does not mean that the models should be physically integrated or become all things to all people. Rather, without holding up current research efforts, the agencies that have projects under way should meet periodically and work toward uniformity of units and formats for input and output data in the nontransportation areas.

Program Area 4

Improved Capabilities

Although increased understanding of travel behavior is essential to improved forecasting capabilities, it is not by itself sufficient. The understanding must be transformed into practical demand functions that are part of a coordinated set of models, including supply models and network equilibrium procedures, for predicting flows in networks, and these models must be related to models for predicting other types of impacts and to the total set of analysis tools supporting transportation planning.

1. Analyze structures of travel demand models.

Exploration of structural characteristics—The various analytical structures that have been developed or proposed should be studied carefully to determine their characteristics: elasticities, cross elasticities, aggregability, summations, and ability to balance trip origins and destinations by zone. Characteristics that can be or are always contrary to theory should be pointed out, and changes to the structures should be proposed to prevent such characteristics from occurring. This work should draw extensively from related work in understanding travel behavior.

Development of new structures—Research should be conducted to proceed from alternative specifications of the structural requirements of demand models to the determination of analytical structures that satisfy these requirements. The alternative sets of specifications should be generated for particular demand estimation problems such as predicting the demand for a new mode by a particular market segment or predicting the effects of relatively minor changes in operating policies. This work should also draw extensively on research in travel behavior.

Empirical testing of alternative structures—As proposed analytical structures are found that have promising characteristics, work should be done to calibrate them to determine their applicability to actual travel phenomena. Alternative structures should be compared by using criteria based on goodness-of-fit measures, ease of calibration, and constancy of parameters.

Aggregation methods—Aggregation in

travel demand analysis, at least to some extent, is unavoidable and inherently arbitrary. There is a need for aggregation schemes that will prevent undesirable behavior of the resulting forecasting procedures and allow more effective use of disaggregate demand models. Research of the following dimensions should be done to explore systematically analytical structures for aggregation of data related to transportation system attributes, population, and market segments: aggregation of paths, submodes, and modes; time aggregation both from the standpoint of the user (different supply attributes during different times of day) and from the standpoint of the system (aggregated capacity constraints, aggregated measures of impedance and performance); aggregation on area units (zones) including access and egress links due to the spatial dispersion of trip ends within analysis zones; aggregation across population and income groups; and relation between market segments and other aggregation dimensions to adequately define market segment.

Empirical analyses of aggregation and scale in travel analysis—One of the inconsistencies in current models of travel demand is that different levels of aggregation can yield different results. Research should investigate empirically the differences in reliability resulting from different levels of spatial and demographic aggregation on estimates of total travel demand. A special consideration is the relative accuracy with which travel patterns of special groups may be estimated and forecast as a function of the absolute or relative size of that group in the total population.

2. Improve model estimation methods.

Model stability over time and space—Models that are used for medium- and long-range forecasts should be stable over time. This stability should be estimated and reasons detected for instability as a guide to future model building. In several localities, longitudinal panel studies should be undertaken on travel behavior; the studies should provide for replacing drop-out panel members and for periodically augmenting lower age groups as panel members age. The resulting analysis of the stability of travel behavior should be designed to allow for the differential effect of changed environmental factors. This in itself requires consistent attention to the body of area-wide data maintenance over time. After this allowance has been made, the longitudinal panel analysis will permit the following questions to be examined: How is travel behavior affected by changes in status, income, family composition, and unidentifiable or partially identifiable factors that also vary with time? To what extent do such changes define uniform trajectories for various population groups, and to what extent are the young following different (new) trajectories? After those mix adjustments are made that are permitted by various models, to what extent do the changed manifestations of behavior affect the stability of the outputs of the models in various respects? Do the sources of change identified in the analysis of the survey suggest means by which the performance of specific models could be improved? Where similar studies are conducted under the same controlled conditions in various localities, the same questions can be asked regarding comparisons across space rather than time.

Classification procedures to improve model transferability—There is a need to improve the transferability of models among cities so that the quantity of data needed for model calibration can be reduced. Use of classification procedures is one way of achieving this. Travel forecasting models relate to components, such as population, jobs, land use, and trips, that are subdivided into groups or classes. Research should be conducted to investigate the possibility of defining classes that are common among studies. In the United Kingdom, for example, "category analysis" trip generation procedures have been developed, which means that a number of studies use the same household categories so that trip rates in these categories are reasonably stable among cities. Particular attention should be given to development of a useful typology of "market segments" for travel forecasting purposes.

Estimation methods—Statistical research should be carried out to develop accurate and unbiased estimation procedures for use in travel demand model development. The concentration should be placed on analytic structures that have theoretical appeal, but have not been used to date because it was not possible to estimate their parameters.

Consideration should be given to Bayesian as well as classical estimation methods.

Simultaneous estimation of service and demand—Issues of equilibration and simultaneous determination of service and demand characteristics have been extensively discussed in the recent literature of travel demand forecasting. Their implications at the disaggregate level, however, have not been fully explored. An analysis should be done of the feasibility and importance of incorporating simultaneous treatment of transportation service and demand characteristics within disaggregate, behavioral demand forecasting models. The project would include development of alternative analytical structures for the simultaneous treatment of supply and demand characteristics, evaluation of potential identification and estimation problems, and analysis of the effect of the simultaneous structure on parameter values in the basic demand equations. The end product would be documentation of the importance of simultaneous treatment of service and demand characteristics at the disaggregate level and suggestions, if appropriate, of structures and procedures for such treatment.

Comparative analyses of data requirements—Use of new methods, such as disaggregate models, category analysis, and others, promises substantial reductions in required quantities of data and in costs of data collection and analysis. It is particularly important that, as results are obtained from research and prototype testing of improved approaches, a comparative analysis of data requirements of available methods be done. Systematic and consistent comparisons should be made of sample size requirements, data collection costs, uncertainty in model estimations, and the like because the state of knowledge will likely change rapidly. During the next several years, such comparative analyses should be updated frequently and disseminated rapidly.

Derivation of demand parameters from link volumes—A readily obtainable form of data is the traffic count on links of a transportation system. There may be some possibility of using these data for bounding estimates of demand models. Just as an origin-destination table or some other set of regional quantities implies something about link volumes, so link volumes seem to imply something about the travel behavior that caused the observed link volumes. Research into the possibility of transforming this inexpensive and convenient information into a rich data source seems distinctly worthwhile.

Measures of uncertainty—Presenting the outputs of any part of the demand estimation process as single "hard" numbers is misleading because the estimates are subject to uncertainty derived from "errors" in the base data and models and also to stochastic fluctuations due to like behavior in the model inputs, dangerous because the decision-maker is not warned of the chances of substantial deviations from the "expected value" offered him and is not given the capability to inject his relative aversions to various types of risks into the estimation process, and inefficient because crude methods and inputs of deriving a probabilistic "spread" of forecasts are typically at hand, although greater efficiency and accuracy are to be sought. Research should be conducted to develop methods for obtaining forecasts in probabilistic form. At the minimum, some measure of uncertainty and stochastic fluctuation should be composed from error analysis and probabilistic formulations of input data, mathematical models, aggregation procedures, and numerical processes. Preferably, a fuller representation of the "forecast distribution" (or selected ranges of it) should be obtained as input to risk analysis and other evaluation procedures; indeed, the research should largely be guided by the kinds of uses to be made of the estimates. Methods should be developed for incorporation of crude sensitivity variations and Monte Carlo procedures to serve the above purpose in the existing model structure. For the longer run, more sophisticated or efficient approaches should be investigated. Means for communicating such probabilistic information to decision-makers and community representatives should be developed.

3. Improve equilibrium computing methods.

Research and development of computational methods—Travel forecasting requires prediction of equilibrium of supply and demand in networks. Although improved demand models are essential, they are not sufficient. Substantial improvement in procedures for computing equilibrium is also essential and requires a base of theoretical research, development of practical computational techniques, and extensive experimentation with alternative techniques.

Modification of existing analysis systems—Research should be carried out to determine methods by which the existing analysis systems can be modified to provide for the consistent estimation of travel demand both by modifying the structure of those systems minimally and keeping the present demand procedures and by incorporating new procedures better suited to the consistent estimation of network equilibrium.

Development of new integrated forecasting systems—Research should be carried out to develop new integrated forecasting systems that will incorporate a wide range of demand procedures in an efficient system that consistently estimates network equilibrium. The limitations placed on demand procedures by these systems should be determined and removed if necessary to provide for the realistic estimation of travel demand.

Integrating demand models and equilibrium procedures—Research should be conducted to develop demand models that will be efficient for use in consistent network equilibrium prediction systems. The general share models should be examined in this light, and recommendations should be made for their further development or alternative directions of improvement.

Pivot-point procedures—Research should be conducted to develop pivot-point procedures as integral parts of transportation analysis systems and to develop the demand models and data needed to make these procedures useful for a wide range of small-scale transportation prediction problems.

Combining long-term and short-term equilibrium—The feasibility of developing a dynamic system of models to incorporate short-term demand estimation and long-term land use predictions should be studied. Such a study should address the data requirements that this approach will generate, the estimation problems, and the convergence problems. The result should be a program of work to provide the necessary data and tools to allow the calibration of such a model in the future.

Equilibrium methods with disaggregate models—Methods to interface disaggregate demand models with aggregate zonal data in forecasting systems should be developed and tested. Also, the possibility of eliminating the zonal aggregation of the data needed for demand models should be explored so that data directly available from home interview surveys and from the census can be used. These research tasks should be addressed to the use of disaggregated models with existing and with predicted socioeconomic, activity-system, and level-of-service data.

4. Integrate forecasting systems.

At this time, development of a single integrated system of models for all urban travel forecasting purposes should be deferred. However, it is important that progress in the field be monitored carefully and preliminary explorations be conducted so that when appropriate the development of such a system can be accomplished expeditiously.

Exploration of alternative design concepts—Alternative concepts should be developed for the design of a single integrated system of models for urban travel forecasting. These concepts should be tested against the results of in-group research and against the functional needs of various specific travel forecasting requirements, e.g., design of a demand-responsive service or long-range area-wide system planning. The result of this work should be one or more preliminary functional specifications for a travel forecasting system.

Computer laboratory to support transportation planning—A large, central, time-shared computer facility should be established to support transportation planning at both the local and national levels. On-site terminals would support interactive, responsive transportation planning by local transportation planners. Thus, the system will provide advanced planning techniques, software, and technical information to local planners. National transportation requirements can be extracted in a rapid and realistic manner by accessing the data bases provided by the execution of the local planning process on a single central computer. At the local level, this is a necessary project for speeding up the transportation planning process to a point where it can become useful to both planners and decision-makers. At the national level, the program will yield accurate assessment of nationwide transportation requirements (including new systems) and travel behavior. A variety of alternative forecasting methods should be available, including quick and approximate methods.

5. Develop transport facility supply models.

Travel demand models forecast the level and distribution of travel, based on given estimates of the service provided by a particular transportation system. In some situations, service variables such as line-haul trip time, frequency, and out-of-pocket cost are sufficient; and measures of the values of these variables can be obtained relatively easily from available data. In many other situations, however, other types of service variables are required, such as link travel time under partially congested conditions, access time, waiting time, transfer time, schedule reliability, and probability of finding a seat. Finding the values of variables such as these will require models of specific types of transport facilities. These are particularly important for low-capital options and new systems. It is essential that a major program of work in this area be undertaken.

Program Area 5

Problem Areas

Present forecasting methods for a number of transportation planning problem areas are not fully satisfactory. Improved methods should be developed quickly to be responsive to the significant issues in each of these areas.

1. Develop understanding of energy-transportation relation.

The United States faces a power crisis for a number of reasons, including continuously expanding demand and population, concerns about sulfur content of fuels and generating station locations, and delay in the technical development of alternative energy sources. These difficulties will certainly lead to relative price changes in many (if not all) types of energy and possibly to power rationing. Petroleum products, which are essential to the present forms of automobile travel, will be particularly affected. Planning for transportation under these circumstances will require an ability to choose new policies that will balance objectives of energy conservation and of minimum "cost" or inconvenience to transportation users. To do this will require a clear understanding of how patterns of demand for various types of transportation may be influenced by changes in energy costs and availability and by energy-related transport strategies, such as fuel rationing or the introduction of vehicles designed to be more efficient in energy consumption.

Energy implications for forecasting requirements—The development of an informed perspective on just what requirements planning for the energy crisis will place on travel forecasting methods is essential. A survey should be conducted of various possible solutions being proposed for national, local, and private agencies. The requirements for travel forecasting methods should be appraised by identifying the capabilities needed to predict the likely effects on travel behavior of these potential solutions. The following projects are illustrative of those that would be generated by this overview project.

Energy-related attributes of service—According to the present understanding of travel behavior, components such as fuel, oil, tire, and maintenance costs that make up the out-of-pocket cost of automobile operations seem to have small or insignificant influence on travel behavior. However, if fuel costs increase to many times the present level and if consumer perceptions of fuel (and other costs) change, travel behavior may be significantly affected. Research is needed to identify those attributes that may significantly influence travel behavior.

Effects of significant changes in energy-related attributes—Once the attributes have been identified, models should be developed to forecast the effects on consumer behavior of changes in these attributes. Because these changes will lead to attributes outside the ranges now experienced by consumers (e.g., tripling of fuel costs), careful approaches to development of demand models will be required. In view of the critical importance to decision-making of the forecasts to be derived ultimately, several approaches to development of demand models should be taken in parallel.

2. Improve forecasts of effects of control strategies for environmental quality.

Air quality and traffic noise levels can be significantly affected by changes in travel patterns. In some urban areas, control strategies being considered to achieve environmental quality objectives may significantly change travel patterns. Improved forecasting methods are essential to achieve greater confidence in identification of effects of various control strategies.

Corridor traffic noise—Existing techniques provide for the estimation of noise levels at various points in a travel corridor based on the UTMS outputs (e.g., volumes, speeds, and physical characteristics of the facility and its surrounding slopes, elevated or depressed). These relations have been used in computerized models that generate decibel contour maps. These techniques should be perfected and validated through field comparisons of model outputs and noise measurement. The results of such research should be disseminated in the form of computer programs and users' manuals to transportation agencies at state and regional levels. Although not a central element of demand modeling, such research affords a major opportunity to use demand model outputs to answer timely and important questions. In addition, the production of noise-simulating models may require stratification of demand model outputs by time of day and type of vehicle and so require substantial extensions of current demand models. This information is vitally needed for route location, build and no-build decision-making, determination of land use controls in transportation corridors, and preparation of environmental impact statements.

Regional air pollution effects of transportation facilities—To provide quicker and more meaningful information on regional air quality impacts of transportation proposals, present models that can be used for calculating overall air pollution at a regional level without full use of the transportation planning package should be refined and widely distributed. In addition, models should be developed that allow a more detailed evaluation of the effects of a new transportation project in a portion of the region to be examined in terms of its effect on pollution in other parts of the region. This would involve both the tracing of the travel impact of the new facility through the region and interfacing with pollution dispersion models.

Microscale air and noise impacts—Techniques at the microscale need to be developed to estimate air and noise effects at a corridor or project level, and the estimates should interface with regional demand forecasts. Impacts of air and noise pollution and disruption to an area are greatly dependent on details of flow such as speed change, vehicle mix, and queuing in short time periods and on specific design and control measures such as signal timing, separation of facilities, and capacities. Models to estimate traffic within neighborhoods must be developed and interrelated with regional demand models. These are important in responding to requirements for impact analysis on corridor and project levels.

Consequences of the null alternative decision—It is important to expand our knowledge of the consequences, both positive and negative, of choosing the null alternative, i.e., undertaking no major new construction. The consequences that have followed a particular decision not to build a major facility should be examined in one or more in-depth case studies. Items examined should include travel patterns, pollution, and relocation or location decisions. The original claims should be examined and analyzed as part of the project.

Travel demand and activity patterns within the context of network supply constraints based on environmental quality—Current modeling techniques work almost entirely in a "forward-seeking" manner and assume that growth in activity patterns will be accommodated by modifications in the supply of a network to meet anticipated demands. Using existing models in an iterative fashion or moving to "backward-seeking" model structures, research should be conducted to develop means of estimating the consequences on network performance of limitations on travel in a corridor or subregion. In turn, these limitations on travel might be used to develop appropriate proposals for the limitation of development or economic activity in order to maximize the efficient use of the limited supply of travel capacity. This research would recast the modeling process to more appropriately mirror the types of decision issues that are currently being faced in many cities.

Resource and energy needs, transportation systems, and urban structure—There is need for basic research on the interrelations and interreactions among resource and energy needs, transportation systems, and urban structure, particularly on how various supply limitations, environmental impacts, and indirect stresses do and will affect the functioning and well-being of human settlements, cities, or urban agglomerations and the concomitant development of appropriate or alternative policies and control mechanisms. Within this context, there is need for better understanding (and predictive tools) regarding how choices concerning the meeting of transportation and mobility needs will be made by individuals and households in relation to their choices and values concerning where and how they live, their employment, and related values and issues. The plea, in short, is for serious attention to the development of a phenomenology of transportation-urban-human system interactions under various stresses that will be imposed by impending critical resource limitations and particularly mobile energy source limitations, environmental impacts, and economic burden. The extent of the relevance of the current UTMS is not clear at this point, nor is it clear what the specific data and analytic requirements are. The need is for considerably expanded (or new) theory and support for basic research.

3. Identify mobility needs of special user groups.

The mobility needs of a number of groups in metropolitan areas are not adequately identified by present forecasting methods. Capabilities are needed to identify those needs and possible responses of special groups such as the elderly, the young, and the unemployed.

Transportation requirements, characteristics, and behavior of special groups—Current travel forecasting procedures treat only obliquely the requirements of users (or potential users) whose behavior and needs differ significantly from the norm. If we are to develop measures specific to special groups, we should know the travel requirements of these groups. This is largely a behavior question, but it bears directly on impact measures developed and used. The research project should identify the special user groups, collate available information from previous studies, develop coherent data on the behavior and requirements of the special groups, and identify criteria for use in stratifying future demand requirements. After the mobility needs of the special groups are established and policies relating to setting standards to meet these needs are established, simple models should be developed capable of quickly listing whether transport proposals are acceptably responsive to the fulfillment of such standards. For example, does a proposed new bus route configuration maximize service to the scattered residences of handicapped persons in its service area? Does a new arterial street provide equally improved access to both poor and wealthy families in the corridor through which it passes? Are station locations for a new rapid transit line located such that they minimize walking distances for elderly riders?

Public responsibility for private mobility—The question must be addressed regarding the appropriate limits of government responsibility for private mobility. It is important that consideration be given to the establishment of minimum standards of mobility.

Although it may well be true that, on the average, the level of mobility in urban communities is adequate and, perhaps, that too much money is being spent on urban transportation, it may also be true that substantial elements of urban (and rural) society have much less access to the community's goods and services than is good for society as a whole. Furthermore, it may be argued (and it can be demonstrated) that many of the urban transportation improvements of the past 20 years have left segments of society less well served in an absolute as well as relative sense than they were prior to the improvements.

Mobility-accessibility measures—Standardized measures of mobility and accessibility to apply to various subgroups and travel generators should be developed. These measures should incorporate the following transportation system dimensions: levels of service in various dimensions, automobile availability versus automobile ownership, temporal relations, transit service and form, and trip purpose. Accessibility and mobility measures need to be addressed on both a short- and long-term basis. Many levels of stratification appear to be possible and appropriate. Current techniques have the capability to produce "standard" population-wide accessibility measures. The major shortcoming in this area is in lack of data to allow sufficient detail by special groups, trip purpose, and special generators.

4. Improve forecasting methods for new transportation systems and services.

Research needs to be started now to produce substantial improvements in forecasting methods for use in planning capital-intensive research, in choosing important software options (e.g., pricing structures), in designing demonstrations, and in determining user acceptance of a new transportation alternative. Forecasting the demand for new systems includes dimensions not usually considered a part of the demand forecasting problem. There is a need not only to forecast ridership and local impacts but also to consider and to attempt to quantify the extent to which a new system may find national acceptance. Such information is of obvious value to potential manufacturers concerned with market forecasting but perhaps of more value to government policy-makers concerned with issues such as energy consumption, natural resource conservation, and capital funding planning. There is a need for greatly improved information transfer from local users of new systems to higher level planning agencies and in turn for dissemination of such information to other potential users. Existing disaggregate demand forecasting methods should be capable of producing useful results for new systems if an attempt is made to identify those attributes shared by existing and new systems and to use known responses to these attributes for calibration of models of new systems.

Simplified modal choice models for rapid estimation of patronage for new options or technology—Simplified models are required for estimating potential market share and revenue-earning capability (and land use effects) rapidly in the near future (i.e., without long-range research) for any new options or technology. Some models can be developed quickly by refining simple, disaggregate, behavioral, binary modal-choice models and by using existing data for present modes in various urban areas. The transportation supply side should be modeled to reflect attributes that are fundamental to mode choices (e.g., times and costs), measurable, and parametric. The models must be responsive to systematic sensitivity testing on attribute values, demand elasticities, and underlying trip pattern assumptions. The models should estimate choices with the new option in place for a selection of origin-destination pairs for "typical" travelers, considering ranges of attribute values, elasticities, and travel patterns, and should be checked by running them on the existing transportation system. The product would be a range of patronage estimates as functions of the input assumptions, which should provide sufficient information for an initial evaluation of the new option.

Identification, measurement, and quantification of attributes—Substantial improvement is required in understanding consumer perception of transportation system attributes. This is particularly important for the evaluation of alternative new technologies and options. Research is needed to identify attributes in related, hierarchical fashion and the process by which these attributes are filtered, combined, and perceived; identify appropriate measurement devices for various types of attributes, drawing from studies in marketing and psychology; and quantify levels of attributes of new technologies and options for selection and evaluation purposes.

New forecasting methods—Research should be conducted to develop a substantially improved set of sequential, choice-abstract, disaggregate, behavioral travel demand models. Initially, this requires the understanding and structuring of the travel choice process and the definition and quantification of transport system attributes that are most likely to be different in a new option compared with present systems. The system should include a model for estimating automobile ownership based on the supply and attributes of the highway system and other transportation and communication options. Model calibration should be based on data from demonstration projects and from existing systems that have one or more attributes in the range of probable new options and technology. The models should be responsive to use as backward-seeking models to define the attribute space of desirable new options. The models must be responsive to systematic sensitivity testing to determine the likely range of outcomes based on uncertain knowledge of the supply characteristics of new options. The models should also be applicable to use as a design mechanism for demonstrations. Investigation of the possibility of constructing time series models, as opposed to cross-sectional models, should also be included. These would be important both for determining likely transient effects of introducing new options or technology and also for determining evolutionary trends in use and impacts of the system. If time series data can be obtained and dynamic (over time) models can be developed, the final model set should be dynamic.

Changing perceptions of new services—When new services or systems are introduced, it generally takes some period of time (months or years) for travelers to "settle down" to a new pattern of usage. Consumers have one perception of the new service before they try it, but their perceptions after trying the service are generally different and influenced by their first few uses of the service; that is, their early experiences influence their perceptions and expectations. Further, their expectations are influenced by experiences of others, reported directly by acquaintances or indirectly by news media. To plan effectively for the progressive introduction of new systems and services requires a better understanding of how consumer experiences over time influence travel behavior over time. Several parallel projects should be undertaken to develop alternative theoretical models and to test them through monitoring of actual service or system innovations.

Taxonomy of new systems and options—Available demand models can be used to classify, understand, and relate various proposed new systems and options with respect to their contexts and travel needs for both individual consumers and community goals and problems. Currently available research results should be used to appraise options and to better assess their relative applicabilities to different situations. Such appraisals will assist in clarifying understanding of new options at national, state, and local levels and in guiding priorities of system developers.

Demonstration project surveillance methodologies—The uncertainty of market response to new systems is a major issue. Travel surveillance systems are required to aid in the management of demonstration projects. Such systems should be designed to provide continuous data capture and to allow assessment of demonstration effects (such as latent demand), transient effects, public acceptance, congestion reduction, and usage by the elderly and handicapped. The system design should encompass generalized methodology and supporting hardware and software. This could serve as a first step toward enhanced management of existing transportation resources. Such a system is needed to maximize the gain in understanding of the market from demonstration projects and to ensure rapid and wide dissemination of results.

Urban transportation product laboratory—An urban transportation product laboratory should be developed to provide a market analysis technique intermediate between surveys relating to nonexistent systems and actual demonstration projects. The objective is to develop deeper understanding of how consumers react to different attributes of level of service by undertaking experiments in simulated environments. Physical simulators, mockups, movies, and computer-driven video displays can provide a subject with a realistic impression of system characteristics and could serve as a means of judging public reaction to various factors. Such a product laboratory will assist in early assessment of research and development projects, reduce risk in project development, and provide information useful in making trade-off decisions in the system design process.

Demand models for forecasting new systems market—The federal government and manufacturers need to know the national implications of implementation of new systems. Research is needed to develop a methodology for determining the applicability to cities of various new systems, based on highly aggregated descriptions of city characteristics. Application of this methodology should yield for each specific new technology or service concept a quantification of potential national implementation, based on meeting travel and social requirements of identified classes of cities. The methods developed should be used periodically to produce estimates of market potentials for various types of generic systems. Because both demand and supply (cost, performance) information will be changing rapidly, these methods and forecasts should be revised periodically.

Demonstration of forecasting methods in new systems projects—Prototype designs of new systems for real cities should be undertaken to identify the critical problems associated with forecasting future travel with various systems and to test the usefulness of alternative forecasting methods. Planning demonstration grants should be used to fund a full-fledged technical study that would assume that certain particular new systems are available. The result of the study should be an appraisal of travel forecasting methods at each stage from area-wide system planning to corridor and location studies, to system design, and to operational decisions (e.g., pricing, scheduling, and other service policies) for each major type of new system.

Transportation management characteristics—Demand can be significantly affected by the quality, incentive structure, and competitiveness of transportation operating agency management. These factors, therefore, need to be subjected to systematic study and experimentation and subsequently to be incorporated into the formal analysis and estimation process and not be subjectively derived "adjustments" to model outputs. Better management, as well as better estimates, should result. Research should be conducted to analyze the behavior typical of "good" managers, the ways in which their qualities most characteristically affect the attributes of the service they direct, and the influence of those attributes on demand; analyze the background, training, and other relevant characteristics of good managers, use the results to develop methods (courses, literature, incentive schemes) for upgrading current management and providing a "sharp" new generation, test these methods, and disseminate those that are effective; investigate the effects on demand of patronage-rewarding incentives for vehicle operators and other system personnel and design and test such incentive schemes; and use the above results to develop demand models that incorporate the effects of transportation management characteristics on the attributes of service perceived by consumers.

5. Develop forecasting methods for subarea and corridor studies.

Increasing effort is being devoted to intensive analyses of multimodal options for portions of an urban area. These subarea studies are intermediate in scope, coverage, and detail between area-wide system studies on the one hand and location and design studies for a particular project on the other hand. Methods should be developed for expeditiously and economically forecasting the effects on travel of alternative plans for a portion of an urban area.

Methods using previous area-wide forecasts—Often, a subarea study is undertaken after the completion of a previous area-wide study. Forecast methods can be developed for estimating approximately the effects of adding or deleting one or a few (or modifying their characteristics) links by specific modifications of forecasts for the area-wide system (i.e., using previous network assignments for the region). Pivot-point methods may be especially useful for this purpose.

Methods for synthesizing subarea forecasts—In some situations, area-wide forecasts may be unavailable, obsolete, or rejected for other reasons. Methods should be developed for forecasting travel for subarea studies in such situations. One possible approach is to use disaggregate models for estimation with small samples and to convert them to corresponding aggregate models, of either explicit (direct) or sequential form, for forecasting.

Aggregation and extraction procedures—A key problem in subarea studies is that a high degree of detail is required for facilities within the subarea but is superfluous outside the subarea, especially in more remote portions of the metropolitan area. One approach is to extract from the basic area-wide network a detailed subnetwork for the subarea being studied and then aggregate and simplify the network and zone system outside the subarea. However, any such approach introduces some degree of bias in the results. Research is needed to develop and test on a comparative basis a variety of aggregation and extraction procedures. Such procedures should be sensitive to the need to consider in a subarea study a full range of multimodal options, including pricing and service charges as well as fixed facilities, and to identify effects on a number of market segments at a greater degree of detail than in area-wide studies.

6. Develop forecasting methods for short-run low-capital options.

Because of the increasing importance of short-run low-capital options (e.g., traffic control systems, parking price changes, flow metering, or changes in transit routes or schedules), high priority should be given to developing methods for forecasting their effects. Present forecasting methods are often too cumbersome, too expensive, and too aggregate to use effectively for analyses of such options.

Identification of attributes—More information is required on what attributes of the system (i.e., level-of-service variables) have most influence on consumer response to short-run changes and on the effects of variations in these attributes on the level and distribution of travel to develop such functions. Market research techniques should be used to identify the most significant service attributes influencing demand.

Development of demand models—Demand models should be developed that use both aggregate and disaggregate techniques and appropriate data samples.

Refinement of models—The models should be tested and refined by use of data from carefully designed before-and-after studies of specific short-run options that are actually implemented.

Simplified forecasting methods—The UTMS and similar models are often too cumbersome to use in many near-term applications. Results of preceding projects should be used to develop simple separate models or ad hoc techniques for forecasting changes in mode and submode choice, station selection, and path choice (between a given origin and destination). Also, split elasticities with respect to various service characteristics should be observed through some sort of market or before-and-after studies. These models should be simple to use (i.e., without elaborate network models) and distributed together with an instruction manual describing a real-world, before-and-after type of application and the success of the model or method.

Economical data sources—Maximum use of available data sources is important in forecasting travel for short-run low-capital options. Research should determine the feasibility of using census, economic, land use, employment, travel, and other data normally available in cities of various sizes.

Group travel options—To evaluate low-capital transportation options such as (a) the encouragement of car pooling at the place of work and via the differential pricing or control of private automobiles based on the number of passengers and (b) the encouragement of shared taxi or demand-responsive transit usage requires appropriate forecasting models. Group travel options have a great potential for reducing the need for physical facilities, but cannot be evaluated adequately by using existing models. Little is known about the cross elasticities of demand between automobile driver and automobile passenger and between automobile passenger and transit rider. Programs that encourage car pooling may in fact decrease transit use rather than influence automobile drivers to leave their cars at home. Research is required to produce models sensitive to vehicle occupancy and to the policies and variables that influence occupancy, including measures such as additional travel time required for car pooling, inconvenience of fixed schedules, reduced out-of-pocket costs, limitation of parking facilities, and opportunities for socialization. These models must include explicit consideration of the access portions of group trips.

Peak hour—Many options, such as staggering work hours, now being considered would significantly affect the duration of the peak hour and the number of peak hours per day. Yet, little is known about what affects the peak hour or, more generally, time cross elasticities of demand. Currently, most forecasting is on the basis of average daily traffic (ADT); conversion to peak-hour volumes is done after ADT network assignments. Research is required to develop greater understanding of peaking behavior (e.g., what attributes of service level can influence peaking). Theoretical and empirical research is required, as well as the development of practical procedures for use in travel forecasting.

Influence of marketing strategies—Current difficulties in making significant additions or changes to urban transportation systems put a premium on attaining maximum use of existing capacities. An inexpensive way to achieve this is by implementation of effective marketing strategies designed to stimulate public interest in the use of the facilities and to make travelers fully aware of the alternatives available to them. To develop effective marketing strategies, information is needed on people's attitudes toward the various modes of transportation and their characteristics, on their perceptions of these services, on significant differences between perceived and actual characteristics, and on unfilled transportation needs. The first phase of the study should be a motivation study designed to identify positive and negative perceptions of the service and price characteristics of the various modes of transportation available to them. These characteristics would include tangible items such as ease of access, speed, cost, and convenience as well as less tangible evaluations of comfort, safety, cleanliness, modernity, courtesy of employees, reliability, pleasant surroundings, and crowding. Depth interview, group sessions, and other appropriate motivation research techniques should be used to identify these perceptions and evaluate them for intensity and importance. The second phase should consist of the development of marketing strategies based on the data produced in the first phase. These strategies could consist of programs such as advertising campaigns in various media; educational programs, both in schools and for the general public; and informational programs on particulars such as schedules, fares, on-time performance, and more generally on future plans and improvements of the systems. The data might also show the desirability of promotional efforts to increase total traffic or to stimulate certain segments of the traffic in off-peak periods, special excursions, weekends, and so forth. In the third phase, several marketing strategies would be tested in 3 to 5 cities, and their effects evaluated. The information thus developed would be useful for developing improved marketing strategies and for developing demand models for forecasting the effects of alternative strategies.

7. Improve transportation planning procedures.

Providing improved forecasting methods is essential to improving the urban transportation planning process, but is not by itself sufficient. To fully exploit the potentials for greater responsiveness to decision-making needs that will be provided by improved methods requires that other actions be taken to improve the effectiveness of the planning process. Several specific projects to assist in achieving this were identified.

Presenting results of forecasts—Travel forecasts require large volumes of data as inputs and produce even larger volumes of data as outputs. This, together with the complexity of the forecasting methods themselves, makes it difficult for citizens and decision-makers to understand and have confidence in the results of travel forecasts and related analyses. Research should be undertaken to develop substantial improvements in ways of presenting results of travel forecasts and related analyses. This should include consideration of what information could or should be available for laymen to review; alternative media, including models, charts, maps, films, and computer-driven displays; and development, testing, and demonstration of specific techniques.

Prototype transportation planning studies—In a number of projects identified elsewhere, prototype applications were identified for improved forecasting methods in the context of ongoing forecasting efforts and in parallel to existing methods. It is likely that, within a short time after beginning such prototype applications, it will become clear that major changes in the nature of transportation planning studies are feasible and desirable. Therefore, work should be conducted to design and conduct new types of transportation studies on a prototype basis. In the study design, ongoing prototype applications of new and improved methods should be monitored and evaluated. Based on these experiences and other research, alternative "work plans" for new types of transportation studies should be developed. One or several prototype studies should be undertaken as alternatives or supplements to conventional area-wide and subarea new systems or studies.

Incentives for experimentation and innovation—At present, staffs of local transportation agencies and of consultants feel constrained in their abilities to experiment with new techniques and to develop or implement innovations in forecasting methods. Agencies funding transportation planning studies should review present policies and procedures to identify any barriers that may now exist to innovation and experimentation and should develop and implement policies and procedures to promote innovation, experimentation, and flexibility in choice of methods by local agencies.

Planning information to aid local and state agencies to implement national policy—The intent of this research is to provide local and state planners with the information needed to comply with federal regulations on a timely basis. The federal government's implemented and proposed regulations with regard to environment, land use, and other areas have or will have a significant effect on local transportation planning. The objective of this program is the development and dissemination of materials, including planning techniques and information, that will aid local planners in the interpretation and compliance of these regulations. Although particular emphasis will be placed on travel forecasting methods to be used, many other types of techniques and information will be covered as well. A most important objective of this project is that the information be timely. Requirements regarding pollution and potential regulations for energy and land use are of immediate concern. Such an effort should lead to the timely and effective implementation of national policy and an indirect cost saving to the federal government through local level savings in planning activities.

Program Area 6

Information and Training

At present, information on successes and failures with new methods becomes known only after several years. The flow of information must move in 2 directions: Documentation of new approaches must go from the research community to practitioners in state and local agencies, and the practical experiences of users of new methods, together with data bases and evaluative material, must flow from agencies back to researchers. A number of steps can be taken to improve information flow and to promote more rapid adoption of improved procedures.

1. Develop ways to disseminate information to professionals.

Rapid dissemination of current information—Because travel forecasting is so important to sound decision-making and because the state of the art will be changing rapidly during the next decade, rapid dissemination of current information to public agency staffs and researchers is essential. Rapid dissemination of such information could be achieved if there were a central repository of information on travel behavior. Such information should include data sets, completed and interim research reports, evaluations of travel forecasts after proposed changes have been implemented, and other high-priority information. Such a repository should also have a staff capable of and responsible for periodically preparing a current summary of forecasting knowledge, such as current "best inferences" on various demand elasticities. A quarterly or bimonthly bulletin or newsletter service should be established to widely circulate up-to-the-minute, brief statements of results of current research or practical experiences with new forecasting methods.

State-of-the-art reviews—Appraisals of the state of the art in particular areas of demand forecasting methods should be developed periodically. Some topics for high-priority early reviews are synthesis of current information on travel demand elasticities; state of the art in forecasting demand for short-range, low-capital options and for new transportation systems; and state of the art in land use modeling.

Guidelines for selecting forecasting techniques—Different forecasting techniques are appropriate for different situations; the methods required for a city of 550,000 are not the same as those for a city of 55,000, and those required for planning a demand-responsive transit demonstration are different from those for a statewide highway plan. This research should analyze alternative city sizes, growth rates, structures of existing and proposed transportation systems, and sets of transportation issues to be analyzed and should establish suggested guidelines for which techniques are most appropriate for different situations. These guidelines should be reviewed and revised periodically, and the revisions disseminated rapidly.

Documentation of model specifications—Too often models are developed and used without any good documentation of input requirement options available within the model and the types of output that can be called for after the model has been run. Specifications in these areas are needed for present models and any that are contemplated in the future so that users may take full advantage of the model as an analysis tool and ensure that all necessary inputs are available before the model is brought on-line in the study. Effective evaluation must also be based on statistical fit of the model to data for both present and future conditions.

2. Undertake training programs.

As new methods and techniques are tested and made available for production use, appropriate training programs for professionals in the field will have to be undertaken. A comprehensive analysis of training needs in the field of travel forecasting should be undertaken. This should include training for professionals in transportation and related agencies, both those involved directly in the technical aspects of travel forecasting and those involved only peripherally; training for new professionals entering the field; and continuing education programs. Training materials will have to be developed and methods devised for conducting the training programs.

3. Develop ways to disseminate information to the laity.

Because of the influence that forecasting methods have on local decisions, appropriate information must also be disseminated to lay people to improve the understanding and usefulness of travel forecasts.

A lay guide to travel forecasting procedures—Citizens and officials often become concerned and confused about travel forecasts, particularly when expert opinions on forecasts of future travel differ. Aids should be prepared to assist lay people to understand the value and limitations of travel forecasts and the procedures through which they are produced. Consideration should be given to the use of the media and printed publications. Topics covered should include the role of travel forecasts in transportation decision-making, basic characteristics of travelers and travel behavior, the theory underlying travel forecasting (supply-demand relations), various types of forecasting methods, data requirements, reliability of results, and the value and limitations of travel forecasts.

Policy implications of results of demand research—The results of demand research have significant implications for policy and planning decisions by elected officials. For example, results from already completed research suggest that travel is much more sensitive to service variables such as wait time, walk distance, and schedule reliability than to price (fare); yet, much attention is being devoted to reduced-fare systems and relatively little attention to service improvement policies. The results of research already completed must be disseminated not only to the research and planning community but also to local and state officials. A digest of policy implications of current research results, in lay language, should be disseminated periodically on a regular basis to appropriate officials.

4. Obtain feedback to evaluate current capabilities.

Monitoring of developments abroad—Significant advances in travel forecasting methods are being made in countries such as Great Britain, France, and the Netherlands.

At present, information on innovative developments elsewhere is known widely in the United States only after a delay of several years. A rapid reconnaissance mechanism should be established for obtaining information on current innovations in research and in practice in travel forecasting methods throughout the world and for disseminating this information rapidly to the U.S. professional community.

Periodic review and appraisal of progress—The present recommended program of actions to improve the state of the art in travel forecasting resulted from the first major and comprehensive appraisal of the field in 17 years. In the future, such a comprehensive review and appraisal should be conducted every 3 to 4 years to provide an opportunity for researchers, practitioners, and decision-makers at all government levels to monitor progress in the field as a whole and to revise priorities and directions of work.

STATE-OF-THE-ART PAPERS

Two papers presented at the conference documented the state of the art in travel demand forecasting in the United States and in Great Britain and Europe.

Brand gives an overview of current and emerging travel demand forecasting procedures and problems related to their use. He postulates and describes 4 basic travel modeling choices that are based on alternate notions of the perception of the travel environment that travelers are assumed to have as they confront choice situations. Where possible, the analytically derivable implications of each modeling choice on appropriate mathematical-analytical forms of travel demand models are described. Travel demand models that do or that might implement the modeling choices are reviewed. Existing travel models are shown to be based on a variety of assumed perceptions of the travel environment. Research questions, including combining models and modeling choices, are opened and discussed where appropriate. Several directions for further useful development of current and emerging techniques are suggested.

Wilson gives a personal account of some British and European achievements in travel demand forecasting during the past 10 years. He warns that the account may be incomplete, especially in relation to continental European countries because of language and information-availability difficulties. He begins by reviewing the studies in which modeling efforts have occurred and then describes the main innovations under the traditional headings of trip generation, distribution, modal split and generalized cost, assignment, urban activity models, and transport and related models. He concludes with a discussion of ongoing issues in research and development.

Each paper has an extensive list of references.

TRAVEL DEMAND FORECASTING: SOME FOUNDATIONS AND A REVIEW

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This paper has 2 overall objectives with regard to travel demand forecasting:

1. To bring together and discuss the rationale for various stands of previous work, and
2. To provide a common point of departure for discussion of improved use of existing methods and of development of research needs.

Hundreds of millions of dollars have been spent on travel forecasting for design and planning of urban and intercity ground transportation systems in the United States alone during the past 20 years. Only a small fraction of that money has been spent specifically for new travel demand model development. Even so, many transportation studies tried in a professional way during that period to make incremental improvements in the methods they inherited.

In the 1940s and 1950s, trip-generation models were developed to predict "generated" traffic on facilities, namely, "traffic created by one or more land uses" (62). Similarly, trip-distribution models were developed to predict shifted traffic, namely, "trips whose desire lines have shifted due to a change in origin and destination" (62). And in the 1960s as substantial new federal money became available for planning transit, modal-split models were developed to predict "diversion" of trips from highways to transit facilities. All these models, applied sequentially, provide input to shortest and multipath route-finding techniques that assign total travel by mode to links at particular locations. The models use as input data aggregate values of zonal population, employment, and link capacity and average values of zonal incomes, car ownership, and interzonal travel times and costs. They are based on aggregate travel definitions that describe what happens to facilities when changes are made to them.

More recently, a different perspective on modeling travel has emerged. This is the perspective that asks, What happens to individuals when changes are made in the transportation system? In 1962 in a university setting, Warner applied this individual-choice perspective to the just-emerging popular subject: transit-usage forecasting. He used disaggregate data to develop the first probabalistic model of individual travel behavior—(binary) modal-choice behavior. Since then, research in, but not application of, the disaggregate approach has been extensive. Generally, its purpose has been to explore the kinds of models and descriptions of travel behavior (e.g., value of time) that result if travel choices are viewed from the new perspective. Travel choices at the individual traveler level can include trip frequency (including the no-trip option), choice of destination, choice of mode, choice of time of day, and choice of route within mode.

More recently, in the 1970s, information is being sought by planning agencies on relative trip peaking at the aggregate level. This corresponds to individual choice of time of day of travel. Transportation agencies seek "to measure the magnitude of peak loads, how long they last, and the extent of accompanying congestion" (84). Descriptive models are being developed that relate travel-peaking percentages to aggregate measures of city size and socioeconomic characteristics (53); they are similar to their precursor, aggregate trip-generation models. This relative trip-peaking modeling corresponds to modeling an individual's choice of time of day of travel, which only recently has been attempted (10).

In the last few years, representing travel demand directly as a function rather than as a fixed quantity has been introduced to travel forecasting from economic demand theory. "Induced travel" as a term describes the change in travel resulting from shifts along a demand curve. The term incorporates the older aggregate descriptive terms of trip generation, trip distribution, and modal split. The first attempt to combine (short-run) travel-choice definitions and behavioral assumptions at an aggregate level was in 1963 (33) when the trip-generation and modal-choice decisions were combined and modeled by using interzonal system data in a direct demand model. The traveler was considered to evaluate simultaneously all the alternative modes available in the Northeast Corridor. Choices were not modeled separately (i.e., sequentially or indirectly). The data were limited to the relatively few intercity zonal pairs in the corridor.

Such a direct demand model was first used for an urban area in 1967 (9). Alternative-route and time-of-day choices were consciously excluded from these early direct-demand models, and the destination choice was modeled without cross relations (i.e., without cross elasticities between destinations). Because the number of choice combinations to be considered and modeled simultaneously is the product of the number of alternatives within each of the previously described sequential choices, the choice environment quickly becomes very complex and difficult to describe in a direct-demand model. Nevertheless, in 1969 a direct demand model was used (54) that explicitly considered alternate destinations for the Northeast Corridor divided into 8 "metrodistricts."

The issue of aggregate versus disaggregate "probability" models permeates the above discussion. Most urban travel forecasting is still carried out "in the field" with the earlier aggregate "choice" models by state highway departments and regional planning agencies with the help of the U.S. Department of Transportation. Research is under way with disaggregate models in several universities and in consulting firms under contract to various agencies of the U.S. Department of Transportation and a few state departments of transportation. The often-used term "disaggregate behavioral" models gives the impression that individual-choice models have a monopoly on incorporating travel behavior. That is clearly unfair, for travel demand models can be derived from behavioral assumptions independently of whether they will use aggregate or disaggregate data.

Choice behavior in disaggregate models must be interpreted as probabalistic. Deterministic choice (i.e., 0, 1 binary) behavior produces uninteresting results when aggregated over all individuals to describe aggregate behavior in a planning application. However, the probability process is assumed to be in static equilibrium (see Appendix) and incorporates no time parameter in a behavioral sense; e.g., learning or experience does not change the probabilities (43). Disaggregate travel models should, therefore, be referred to as probabilistic and not stochastic if they are used with cross-sectional data.

The generally strong arguments for using disaggregate models usually include data efficiency arguments. That is, more information on travel choice situations and behavior is usually available with disaggregate data than with aggregate data. For example, Fleet and Robertson (86) showed that aggregation of trip data to zones reduced the variation in trip-making (trip generation) between observations to only 20 percent of the value at the dwelling unit level. In the process of aggregation, nonlinear relations may also be lost by using averages of explanatory variables. However, disaggregate travel models have not yet demonstrated practical superiority in providing travel information to decision-makers. In fact, we have as yet a way to go in getting models based on individual-choice behavior into the field. [Disaggregate models of some of the conventional UTP steps (i.e., trip generation) will be easy to introduce "in the field" (31).]

However, there is little doubt that the emerging techniques (72) for using travel models based on the behavior of individuals and not the behavior of aggregate numbers of trips will accelerate our understanding of travel-choice behavior. The empirical results of the next few years should greatly improve our understanding of and our ability to base models on behavioral assumptions appropriate to the circumstances under which the modeling is undertaken. In most cases, travel models, whether aggregate or disaggregate, should be based on a well-specified structural or behavioral representation of the decision process. Such models can be disaggregate or aggregate. Models should be avoided that are merely "best fit" curves, for they are impossible to interpret. Also, whether aggregate or disaggregate, the models should be evaluated on the basis of their applicability in a given situation, e.g., ease of use or efficiency in the use of data.

Unfortunately, current travel forecasting procedures fall short of satisfying current demands on their use. The needs and requirements of today's transportation decision-makers for travel information are rapidly changing. The U.S. Department of Transportation noted in its preliminary statement for this conference (76):

> Present passenger travel demand forecasting procedures... are most responsive to the issues of the 1950s and early 1960s concerning long-range regional transportation plans and the development of information that was required to design the facilities.
>
> The planning issues of the late 60s and 70s are broader and more numerous. First, they involve a much wider range of alternatives that need to be evaluated. These include highway-transit tradeoffs, low and noncapital alternatives such as pricing schemes, new technological systems, and "do-nothing" alternatives. Second, it is now insufficient to evaluate facilities on the issues of capacity and cost alone. Additional measures have become important in the planning process and include levels of service and price. Third, the environmental and social effects of transportation-facility construction and operation must become integrated into the planning process. Fourth, the incidence of travel service, environmental, and social consequences on various groups within the study area must be considered in the evaluation of transportation facilities. Fifth, as a consequence of greater involvement by elected officials and citizens in the planning process, travel forecasts for transportation facilities must be made expeditiously and information must be summarized in a manner that facilitates communication.
>
> Travel forecasts are essential elements in reaching decisions on transportation. To be more responsive to the issues, travel forecasting methodology will have to be modified and improved. Travel forecasting procedures must be quicker and less costly to operate, be sensitive to the wide range of policy issues and alternatives to be considered, and produce information useful to decision-makers in a form that nontechnical people can understand.

In some places, current travel-forecasting models are successfully providing useful information on very short notice. However, such instances normally occur only at large agencies that have several highly trained professionals and large continuing computer budgets. Costs are high not only to continue the operation of current procedures in a given location but importantly also to initially develop and install the methods in a given region. Calibration of existing travel models and procedures takes considerable skill and effort. Until travel demand models are transferable from area to area, very high start-up costs in the form of new data collection, program development, and model calibration will continue to seriously impede the ability of the profession to produce relevant and responsive travel information for decision-makers.

TRAVEL BEHAVIOR

Travel forecasting procedures must have a basis in behavior if planners and decision-makers are to be able to understand and interpret the results of the forecasts. This is true for many reasons. The forecasts that result depend on the behavioral assumptions. Behavioral models are needed for transferability (in space and time) to situations other than those for which the models were developed. Behavioral models are needed also for evaluation, if the (usual) assumption is to be made that the tradeoffs between time and money in a travel choice situation are valid for user benefit calculations.

In travel demand forecasting, therefore, we must confront squarely the validity of our theories describing relations among people and their locations on the one hand and travel on the other. This involves consideration in particular of how and in what sequence, if any, people view the origins and destinations of their journeys and the transportation system that connects or potentially connects their origins and destinations.

A travel demand model implements in a purposeful way the understanding that the modeler has of the behavior of the system of interest. A system can be defined as a set of objects and a set of relations among those objects and among their attributes (23). Every time we make or contemplate a decision, the complexity of urban and transportation systems confronts us with a need to make a simplified and intelligible imitation of reality (i.e., a model). This involves abstracting the important parts, to us, of the decision situation that confronts us. Clearly, the set of objects that describe the travel choices confronting travelers is important in travel demand forecasting. Transportation planning concerns itself with making, or contemplating making, changes to the transportation system or changes that will affect that system. Our interest is in describing the behavior of travelers as they respond to travel choices and to changes in travel choices that confront them. The ability to predict the amount and distribution of travel in any situation is, therefore, only as good as our understanding of the underlying perceptions that travelers have of the choices that confront them.

Modeling Choices

There are developing some basic modeling choices based both on explicit statements of alternate understandings of travel-choice perceptions and decisions and on the realization that a travel demand model, like any model, is ultimately a subjective imitation of reality. The basic modeling choices are founded on differing behavioral premises, for ultimately the modeler's view of behavior in the system of interest must be the starting point.

Strategy of Paper

In this paper, certain basic modeling choices will be described at the outset. Where possible, the analytically derivable implications of each modeling choice on appropriate mathematical-structural forms of travel demand models are also described. Finally, the travel demand models that have implemented or might implement the modeling choices are described.

Issues exist when there are unsolved problems or unresolved conflicts over appropriate solutions. This paper was written specifically for a conference dealing with such problems and conflicts. We made the initial presumption in the conference, as in this paper, that issues relating to theory and practice in travel demand forecasting are researchable and in many cases can be made subject to empirical testing. [Causality, unfortunately, cannot be empirically demonstrated, although empirical results can be demonstrated to be inconsistent with certain causal chains (68).]

It may be clear from this review paper that our theory and prior understanding of how travelers perceive their travel-choice environment are weak. This is certainly not a criticism so much as a description of the state of the art of understanding choice behavior in the social sciences in general. Our weakness in understanding is evidenced by the variety of different assumed perceptions of the travel environment on which existing travel demand models can be shown to be based. This paper attempts to organize several of these perceptions into alternate modeling choices, without making strong statements about which choices seem preferable, or more plausible, to the author. All the basic modeling choices are indeed worthy of further research and application and will be shown to be combinable for still additional modeling choices.

The supplier's perspective and concern with describing and evaluating what happens to facilities when changes are made to them may be fairly credited with leading to the earlier aggregate travel forecasting models. Those models respond directly to the question of what happens to flows on transportation facilities when changes are made in the facilities.

The social science (academic) disciplines are more concerned with what happens to individuals and groups of individuals. Thus, it is no surprise that Warner's early work on individual travel-choice models took place in a university setting. [Wilson et al. (83) make the useful distinction between primarily academic disciplines concerned with analysis (i.e., the social sciences, including economics) and the professional disciplines concerned with design and policy-making (i.e., engineering, city planning, and architecture). The latter can plausibly be said to be traditionally concerned with the objects of their design and their use in the aggregate, while the former are concerned with analysis of cities and regions at all levels of (dis)aggregation.] However, the issue of aggregation has been argued to be separable from the issue of travel behavior.

The more fundamental behavioral choice is whether the attributes of travel choices are considered or perceived independently from or together with the objects or facilities that carry or support or propel the traveler. That is, the most basic behavioral modeling choice is whether travel attributes are perceived by themselves or whether they are mapped on particular supply-side choices (e.g., mode and route, or choice of technology). The argument can similarly be extended to attributes of alternative destination choices. These alternate perceptions of the travel environment imply that attributes of the transportation system can be included in travel demand models in 1 of 2 ways: as choice abstract or attribute specific, or as choice-specific attributes.

Particular names for these 2 modeling choices are not yet settled on. Manheim (44) calls the first choice the "hypothesis of commodity-independent utilities." The authors (57) of the best known example of the first type of model, the abstract mode model, have more recently referred to their model as an "attribute-specific" model. This gets away from the needlessly restrictive modal-choice emphasis indicated by their original "abstract-mode" name. In this paper, the terms choice abstract and choice specific are used to describe these 2 basic travel modeling choices.

FOUNDATIONS: BASIC MODELING CHOICES

In general, demand models relate quantities demanded to resources that must be expended to obtain those quantities. In travel demand modeling, the first behavioral question is, Whose resources? Are they the resources of the individual traveler, i.e., his money, and the use of his most basic resource, his time? (In theory, of course, the "behavioral" resources expended are always those of the "demanders.") Or are they the resources of society that provides facilities that "produce" travel, i.e., the aggregate of individual trips on the transportation system? This divergence in viewpoints or "values" has led fundamentally to the development of different kinds of travel-forecasting models. The alternate perceptions of the travel-choice environments resulting from each view provide the most basic (behavioral) modeling choice for travel demand forecasting.

That is, by whom shall the important parts of the transportation system be defined? By the supplier who considers the objects that he is able to provide, and who finds it useful to differentiate among modes, routes (path) within modes, and the locations, sizes, and technical characteristics of the means of producing transportation? Or by the individual traveler who may or may not consider the same description of the hardware of transportation as the supplier? Is there any overlap whatsoever between systems defined from each point of view? Or are the important parts of the system so defined completely disjointed? That is, does the traveler consider only the services provided by the transportation system to the complete exclusion of any identification of the objects (facilities) provided?

CHOICE-ABSTRACT TRAVEL DEMAND MODELS

Attributes

In classical utility analysis, consumers maximize some function of quantities of various commodities that can be consumed (see Appendix). Travel is, of course, a commodity. Depending on how travel is defined, the number of alternate commodities possessing utility that can be consumed is very large (i.e., ultimately all combinations of alternative trip origins, destinations, times of day, modes, and paths).

Utility theory may be modified to base utility on attributes or characteristics of the quantities to be consumed. According to Lancaster (36), "Utility or preference orderings are assumed to rank collections of characteristics and only to rank collections of goods indirectly through the characteristics that they possess.... Furthermore, the same characteristic may be included among the joint outputs of many consumption activities so that goods which are apparently unrelated in certain of their characteristics may be related in others." The traveler is assumed to derive utility, U, from the attributes, Z, consumed and obtained as a result of the transportation activity.

Simultaneous Choice: Abstract-Mode Model

The abstract-mode model (57) is derived consistent with this modification of utility theory. The model provides a striking example of the modelers' perspective on the problem determining the forecasting model that is developed.

The Northeast Corridor project, for which the model was developed, was charged with analyzing and predicting the demand for new transportation services in the corridor. This required that travel forecasts be made for travel modes that might not currently exist (the new-mode problem). Therefore, the introduction of a new mode should not change the demand function (model) derived from a utility function, $U = U(Z)$, estimated on the basis of the attributes, Z, of existing modes by using existing data (see Appendix). Technology or production function equations, $Z_m = g_m(X)$, could indeed be mode specific and describe choice environments having different attribute levels as a function of amount of travel, X. However, travel (demand) choices were to be determined only by the attributes of the choice environment so produced, independent of mode.

In the derivation of this choice-abstract, or attribute-specific, demand model, the concept of attributes is used "to define a mode in terms of the type of service it provides to the traveler and not in terms of the administrative entity that controls its operations or the sort of physical equipment it employs" (57). However, the derivation of the model did not proceed analytically from consideration of personal utility. The modification of utility theory was (only) relied on to justify characterizing modes "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" (57).

The estimated travel-forecasting equations are, therefore, not mode specific but mode-attribute specific. They take the following form:

$$V_{klm} = \phi_0 (P_k P_l)^{\phi_1} (Y_k Y_l)^{\phi_2} t_{klb}^{\theta_1} \left(\frac{t_{klm}}{t_{klb}}\right)^{\theta_2} c_{klb}^{\theta_3} \left(\frac{c_{klm}}{c_{klb}}\right)^{\theta_4} \qquad (1)$$

where

V_{klm} = volume between k and l by mode m,
P_k = population in zone k,
Y_k = median income in zone k,
t_{klm}, c_{klm} = travel time and (money) cost between k and l by mode m,
t_{klb} = travel time by fastest mode,
c_{klb} = cost by cheapest mode (not necessarily same as fastest mode!), and
ϕ, θ = parameters of the model.

This is a simplified statement of the model. Separate parameters for each variable can be added, and the variable list can be extended to include others such as frequency of service and employment. Note, however, that the model has only one set of parameters regardless of the subject mode, m, for which travel is being predicted. Thus, the equations are mode-attribute specific and not mode specific. The introduction of a new mode, if not the best mode in any attribute (and not the subject mode), does not change the travel prediction for the subject mode.

Particular assumptions are made about the perceived interaction of modal attributes in determining travel demand. For example, there are cross elasticities (cross relation) only with respect to the best competing mode in any attribute. These are equal in magnitude to the direct elasticities for the subject mode.

Young (85) changed the representation of the competing modal attributes in Eq. 1 from only the best values among all the modal choices to weighted averages of the attribute values of the competing modes. That is (58),

$$T_{ijk} = a_0 X_{ij}^{a_1} \frac{F_{ijk}}{\sum_k F_{ijk}} \tag{2}$$

where

i = origin,
j = destination,
k = mode,
a = constants,
T = travel volume,
X_{ij} = exogenous economic and demographic variables,
$F_{ijk} = D_{ijk} C_{ijk}^{a_2} H_{ijk}^{a_3}$,
D_{ijk} = number of trips by mode k,
C_{ijk} = cost (money) on mode k, and
H_{ijk} = journey time on mode k.

Consistency with the independence axiom (see next section) is obtained if the D's are removed from the product term for **F** and made a separate relative frequency term in Eq. 2. That is,

$$T_{ijk} = a_0 X_{ij}^{a_1} \left(\frac{D_{ijk}}{D_{ij}}\right) \frac{F_{ijk}}{\sum_k F_{ijk}} \tag{3}$$

Practical difficulties must be noted in completely reducing travel-related (dis)utility to mode-independent attributes. These difficulties can include quantifying the time and space restrictions from car-pooling or transit travel, as contrasted with automobile-driver travel (not to mention quantifying the comfort and privacy differences) and between transit mode combinations as represented by its several access modes (walk, park-ride, kiss-ride, feeder bus). To the extent that such differences, as they affect travel-choice behavior, can be subsumed in door-to-door travel times, departure frequencies, and fares, the abstract-mode model can be considered applicable. However, if the list of attributes that must be quantified to adequately describe travel alternatives in terms only of the perceived levels of attributes becomes extensive, the alternative modeling choice of identifying the attributes together with the modes may be more practical as a strategy. However, the new-mode problem (if relevant) must then be faced.

These 2 models, Eqs. 1 and 2, are examples of choice-abstract direct demand models, which assume that the traveler considers all the attributes of alternative travel choices simultaneously when making a travel decision. The result is a simultaneous-choice or direct demand model.

However, there is a choice-abstract modeling alternative. That is an assumption of nonsimultaneous, or sequential consideration of, system-independent or choice-abstract attributes.

Sequential Consideration of Attributes

An important alternative modeling choice is to formulate travel behavior models that are not based on the simultaneous consideration of values of attributes across all alternatives. Probability mechanisms can be proposed based on the individual's attending to different aspects of the choice situation at different times. One proposal, (75) based on earlier work by Marschak, is the notion of eliminating alternatives in a multiple-choice situation by successively considering single aspects (attributes) of the choice situation. Each successive choice is governed by one aspect selected from those included in the available alternatives "with probability proportional to its weight" (75). All alternatives are eliminated that do not include the selected aspect, and the process continues until only one choice remains. Aspects that are common to all the alternatives do not affect the choices made. Obviously, the way aspects are defined is critical. The theory might be extended to include groups of aspects (factors) not easily described by a single measure.

A scenario of the elimination-by-aspects method of modeling travel-choice behavior might be as follows:

> The most important aspect results from the trip purpose. For example, for shopping trips, only destinations containing the aspect, retail stores, are considered as alternative destinations. A more precise definition of the shopping purpose (e.g., shopping goods as opposed to convenience goods) serves to delimit further the allowable alternative destinations. The next most important aspect (following the findings of Hille and Martin, 27) is "reliability of destination achievement." Unsafe and unreliable modes and routes are eliminated. This will generally not eliminate many alternatives in U.S. urban areas because, through nonuse, most unsafe travel alternatives have been eliminated as economically nonviable. However, because random elements might be allowed, some alternatives for some individuals may be eliminated because they did not meet some stated safety threshold. The next most important aspect, comfort, with emphasis on flexibility and ease of departure, is used to eliminate the transit mode for all travelers from all origins to all destinations not near a transit line. The automobile mode is eliminated for travelers with no car (or car pool) available. The possibility of a trip is eliminated if no car is available, no transit is available to the "available" destination alternatives, and walking distance is too far to all of the available destinations not yet eliminated through the purpose and reliability aspects. Again, random elements allow this to be a probability model of choice. Other aspects of travel time are considered next, then cost, and so on, according to the sequence of importance in, for example, the Hille and Martin (27) findings.

Summary

A diagram may be useful in summarizing the travel demand modeling choices described thus far (Fig. 1). The lowest level of the hierarchy is not the result of choice forks but rather contains examples of models that have implemented or might implement the modeling choices. The elimination-by-aspects method of Tversky is not likely to be the only possible model structure that implements travel behavior that considers choice-abstract attributes sequentially.

CHOICE-SPECIFIC TRAVEL DEMAND MODELS

The alternate assumption about how travelers perceive their choice environment is that the attributes of the travel-choice environment are not perceived or at least modeled independently of the objects provided, i.e., the facilities that constitute the transportation system. This modeling choice, as before, breaks down into the behavioral modeling subchoices of (a) simultaneous consideration of all the attributes and (b) sequential consideration of the attributes.

The distinction between direct and indirect demand models has already been made. In the former, all attributes of an entire trip are assumed to be known and considered simultaneously by the traveler. As shown in Figure 2, this behavior can be described as involving the simultaneous consideration of all the attributes normally associated with each of the 5 conventional descriptors of travel: frequency, time of day, destination, mode, and path. If each path through the travel decision tree is considered an alternative travel choice whose attributes are considered simultaneously "in competition" with the attributes of all the other travel choices, the models can become very complex. The number of choice combinations to be considered and modeled simultaneously is the product of the number of alternatives within each of the travel choices. For example, a simultaneous model of travel that considers 3 modes, 2 times of day, 20 destinations, and 1 path requires the modeling of ($3 \times 2 \times 20 \times 1$) or 120 travel choices for each origin. [This number may be reduced by eliminating zero-probability choices in calibrating models that satisfy the independence axiom (see next section).] The number of explanatory variables and the allowable interactions among variables that may be assumed to explain (model) simultaneous travel behavior can multiply very rapidly for realistic travel-choice situations in urban areas.

The need for "simple robust models" has been well articulated (2). Calibrating models for large numbers of alternatives (choices) with very low probabilities of choice is difficult in the extreme. Attributing properly the separate effects of large numbers of (possibly highly correlated) attributes describing complex choice environments (where calibration techniques often require certain assumptions, e.g., normality or homoscedasticity) boggles the mind. (One may speculate that the "number of variables required to predict probability of choice is finite and rapidly approaches the limit of human discrimination.") For these reasons, travel demand models must be reduced in complexity in some plausible way.

Restricting the choices available restricts the products or attributes the traveler is assumed to evaluate in making his travel decision. Restricting the choices that are presumed available to the traveler appears to be the way in which choice-specific travel demand models can be reduced in complexity. However, this involves making some important assumptions on the separability and the sequence of travel choices.

The assumption that travelers behave as though they sequentially consider (travel) choice-specific attributes (Fig. 2) means that there is a hierarchy of travel decisions in which certain travel decisions are made independently (separately) of others. In turn, other travel choices (e.g., higher level choices like destination, Fig. 2) are made given that lower level choices (e.g., mode) are predetermined.

There are 2 ways to model such sequential travel behavior. The first assumes that the relative valuation of choice attributes is constant throughout the set of travel choices. This requires that models of the independently made lower level travel decisions be calibrated based only on a subset of attributes describing those choices. The estimated (and preserved) utilities from the lower level choices are then added to a set of attributes on the basis of which the higher level choices are made. The traveler, it is assumed, makes some sequence of choices, and the earlier choices are based on independent and separate evaluations of personal utility (separate) from the "later" conditional or "constrained" choices. For example, the time of day (shopping purpose) choice was modeled (10) on the assumption that "there is a utility associated with the trip itself which is additive to the utility or disutility associated with the choice of time of day, which is additive with the utility associated with the place to which the trip is made. . . ."

Thus, the choice of mode is modeled separately and prior to the destination choice and is assumed to be independent of the overall number of trips between the origin and destination. Similarly, the choice of time of day is assumed to be made independently of the choice of destination.

The attributes that are assumed additive must map on the (sequential) choices. Otherwise, a choice-abstract model results. If difficulty is encountered, either the travel choices can be redefined or the supply side description of choices (e.g., mode) can be abandoned and sequential choice-abstract models can be developed.

The assumption of sequential travel choices, given that travelers perceive their choices as described by attributes inseparable from choices, is a difficult assumption to make. Yet it is an attractive strategy for reducing the complexity of travel demand models because it greatly reduces the number of interaction terms in the model. The other strategy is to reduce the number of independent variables that are assumed to influence travel behavior. That is, reduce the number of attributes the traveler is assumed to evaluate in his travel decision-making process without excluding interaction. Because the attributes that the traveler evaluates are identified with particular travel choices, this second strategy for reducing model complexity is more appropriate to choice-abstract models than to choice-specific travel demand models.

A second way to model sequential travel behavior requires the still stronger (more difficult) assumption that some travel choices are made completely independently of other travel choices and that the relative valuation of choice attributes common to 2 or more travel choices is not necessarily the same in successive travel choices. This represents a third-level assumption regarding the consideration and valuation of the attributes (i.e., the relative marginal utilities) of the choice situation confronting the traveler. These 3 levels of assumptions are summarized in order from the weakest to the strongest (or most heroic) assumption.

1. All the attributes of the choice situation confronting the traveler are considered simultaneously. The complete trip is one decision. The relative valuation of the attributes is constant in any travel choice in the hierarchy shown in Figure 2.
2. There is a hierarchy of travel decisions in which certain travel decisions are made independently of other decisions. However, the relative valuation of choice attributes is constant in any complete travel decision (i.e., any single path through the travel decision tree shown in Fig. 2).
3. As in assumption 2, there is a hierarchy of travel decisions in which certain travel decisions are made independently of other decisions. However, the relative valuation of choice attributes common to 2 or more travel choices is not necessarily the same in successive travel choices.

The first assumption is the easiest to make. It requires the concomitant assumption of constant relative valuation of attributes in component travel choices of a complete travel decision.

The second (strict utility) assumption is made for ease of estimation (reducing the number of variables in the models to be estimated relative to the first and third assumptions). It requires some sequence of travel choices to be assumed for purposes of estimation as discussed above. Inclusive prices must be used to preserve the previously estimated utilities in strict utility models. The separately calibrated models using inclusive prices may be combined and applied simultaneously, or sequentially in any order.

The third assumption is the present assumption of UTP models that completely and independently estimate the different travel choices with different valuations of the independent variables in each model. The traveler, nevertheless, must face the same values of the independent variables in more than one component travel choice. For example, "the costs of the various modes influence not only the choice of mode but also the selection of destination and the determination of whether the trip should be made at all" (14). The most damaging indictment of the third assumption is that the sequence of application of the models determines the results. That is, no unique equilibrium can be reached with these models so long as flow and congestion conditions and the resulting travel costs change in any way from those used to calibrate the models. That is, even if the conventional series of models (including trip generation) were system sensitive, the sequence of their application determines the network equilibrium reached after more than one iteration. In addition, of course, the third assumption poses the problem of what appropriate value to place on user benefits (e.g., time savings) in evaluation of transportation system alternatives when different valuations of the independent variables are assumed in each component travel choice.

From the above discussion, the conclusion may be drawn that the assumption is easier to make that travel choices are separable than that travel choices are made in some sequence. This assumption implies only that the marginal rates of substitution (trade-offs) among attribute variables that govern one travel choice do not vary among travel choices. Stated another way, this means that the trade-offs or ratio of "weighted" attributes that explain one travel choice are independent of the other choices.

It is with the last statement that 2 important results from separate disciplines can be joined. In mathematical psychology, this is a statement of separability property of the independence-of-irrelevance-alternatives axiom (41, 42). In economics (utility theory), at the conditions assumed at equilibrium (see Appendix), the ratio of the marginal utilities of 2 choices is equal to the ratio of their "weighted" attributes (i.e., their revealed "prices"). The relative marginal utilities of the attributes of a choice situation can be solved for (inferred from) observed data on the choices made (61).

Thus, the assumption of separable travel choices potentially allows complex travel choices to be broken down into simple travel choices whose relative marginal utilities can be inferred from observed data. However, a sequence assumption is necessary to determine which (separable) travel choice will be "simply" modeled, the inferred relative marginal utilities from which will be preserved in the remaining travel choices. Before the possible plausibility of any sequence and separability assumptions is discussed, the important properties and implications for travel demand modeling of the independence axiom will be described.

Independence-of-Irrelevant-Alternatives Axiom

The independence-of-irrelevant-alternatives condition (41) implies that, for any 2 alternatives i and j having a positive (nonzero) selection probability, the relative odds of choosing j over i in a set containing only the 2 alternatives are equal to the ratio of their probabilities of being selected from any larger set of alternatives containing both i and j. This can be expressed as (48)

$$\frac{P_{ji}}{P_{ij}} = \frac{P(j:A_1)}{P(i:A_1)} \tag{4}$$

where

P_{ji} = probability of selecting j in a 2-element set $A_1 = i, j$;
P_{ij} = probability of selecting i in a 2-element set $A_1 = i, j$;
$P(j:A_1)$ = (nonzero) selection probability of choosing j contained in any set A_1; and
$P(i:A_1)$ = (nonzero) selection probability of choosing i contained in any set A_1.

This condition states that the odds that alternative j will be chosen over i in a set containing both are independent of the presence of irrelevant "third" alternatives in A_1. This is the separability property of the independence-of-irrelevant-alternatives axiom (41, 42).

"Strict utility" is defined by Luce (41) as being the function $h(Z_{ki})$ that satisfies Eq. 4 for the binary case i = 1, 2. That is, the relative odds of choice or share of, say, travel, P_i/P_j, between any 2 alternatives i and j are simply some function of the variables describing the 2-choice alternatives (and no others!).

$$\frac{P_i}{P_j} = \frac{h(Z_{ki})}{h(Z_{kj})} \tag{5}$$

where

P_i = probability of choosing i;
P_j = probability of choosing j;
$h(Z_{ki})$ = strict utility of i; and
Z_{ki} = (scale) variables, k, describing i.

The actual odds or probability P_i of choosing alternative i from a larger set of alternatives can vary, of course.

The binary-choice strict-utility model, Eq. 5, generalizes into a multiple-choice model only if the independence axiom holds, that is, only if the probability of a choice from a subset of alternatives is independent of what other choice alternative may also have been available. The resulting multiple-choice strict-utility model is (41)

$$P(i{:}A) = \frac{h\,(Z_{ki})}{\sum_{j\epsilon A} h\,(Z_{kj})} \tag{6}$$

for j = 1, ..., i, j, ..., where

$P(i{:}A)$ = probability of choosing i from a set of alternatives A;
$h(Z_{kj})$ = strict utility of alternative j in the set A, a monotonic function of the scale variables Z_k describing j; and
$j\epsilon A$ = complete set of alternatives between which a choice is made.

An exponential transformation of the strict utilities (and an abandonment of set notation) yields the multinomial logit formula:

$$P_i = \frac{e^{v(z_{ki})}}{\sum_{j=1}^{J} e^{v(z_{kj})}} \tag{7}$$

for j = 1, ..., i, j, ..., J.

Equation 7 says that the probability that a traveler will choose alternative i out of a set of J alternatives is directly proportional to its strict utility $V(Z_{ki})$ (a monotonic function of attributes k of the alternative i) and that the probabilities of choosing one alternative in the set of available alternatives, each with a nonzero probability of being chosen, must sum to one. ["Perhaps the most general formulation of the independence axiom is the assumption that the alternatives can be scaled so that the choice probability is expressible as a monotone function of the scale variables, k, of the respective alternatives" (75). This assumption is called simple scalability by Krantz (35).]

The function $V(Z_{ki})$ in Eq. 7 can, of course, be interpreted and estimated. In the language of the psychologist, it represents some function of the environment that stimulates a decision (70). In utility terms, it represents some function of the attributes of value to travelers of the alternative travel choices. A correct model specification is needed to capture appropriate effects on behavior of variables (attributes) describing the choice situation. A constant term, θ, in an equation for $V(Z_{ki})$, e.g., $\theta_i \prod_k Z_{ki}^{a_{ki}}$, will include the effects of all attributes not explicitly included in the model.

Separability Property

The independence axiom is a general statement that has consequences that can be tested. For example, it says that, if alternative i is preferred to j in one context (choice situation), it is preferred to j in any context for which both are available. Furthermore, if the odds of choosing i over j are 0.7 in one context, those odds will be preserved in any choice situation. The traveler is assumed to exhibit transitivity in his behavior with respect to his "strict utility" $h(Z_{ki})$ versus $h(Z_{kj})$. That is, he values the attributes, Z_k, of any choice, i, the same (ratio scale) relative to choice j regardless of the context. Thus, the probability that an alternative (choice) will be chosen is exactly proportional to its strict utility (therefore, Eq. 6). And from Eq. 5, the relative odds that an alternative will be chosen from 2 alternatives is constant and a function only of the strict utilities of the 2 alternatives. This allows the introduction of new alternatives in a model application without calibration of the model, provided the previously estimated strict utilities are preserved.

In 1962, the author used the separability property of Eq. 6 to calibrate a share model of (multiple) choice among 4 access mode (walk, park-ride, kiss-ride, and feeder bus to line-haul rapid transit) alternatives being tested in Washington, D.C. The model was calibrated with paired aggregate modal-split data from a number of surveys because of the lack of data describing the relative usage of all 4 feeder modes together. This was allowable because of the "startling" behavior of the model (Eq. 6) that "the relative substitutability of any two sub-modes without the third being available is assumed equal to the relative attractiveness of the two in the presence of the third" (6).

McLynn and Woronka (50) used this property extensively to calibrate their "single pair" market share model developed for the Northeast Corridor project (see Appendix). In their model, automobile was used as the "base mode" (16). When difficulties were encountered with certain nonsensical parameter estimates and the single-pair estimates, all single-pair equations were estimated simultaneously. From Eq. 5, it follows that such simultaneous estimation is irrelevant from the point of view of the behavioral grounding of the model, however much it may be desirable to constrain certain parameter estimates. [The derivation of the model from strict-utility considerations highlights certain of its behavioral groundings that may not be clear from the McLynn derivation (see earlier sections).]

The property of "separability" of alternatives is not restricted to alternatives among modes. Alternatives can characterize the entire range of choices of trip frequency, destination, time of day, mode, and path, as already discussed. Thus, separate choice models can be calibrated separately and later combined into a travel-demand model. However, behavioral assumptions as to the sequence of travel decisions are required, as already discussed. The separability property of the independence axiom was first explicitly recognized and used to calibrate a travel-demand model by Charles River Associates (CRA) (10).

Share models have been used in travel forecasting without recognition of their separability properties for many years. For example, the gravity model of trip distribution (77) is a share model whose standard derivation is simple and general (18).

$$\left.\begin{aligned}
V_{ij} &\sim G_i A_j Z_{ij}^k \\
V_{ij} &= C_i G_i A_j Z_{ij}^k \\
G_i &= \sum_j V_{ij} = \sum_j C_i G_i A_j Z_{ij}^k \\
G_i &= C_i G_{ij} \sum_j A_j Z_{ij}^k \\
C_i &= \frac{1}{\sum\limits_j A_j Z_{ij}^k}
\end{aligned}\right\} \qquad (8)$$

$$V_{ij} = G_i \frac{A_j Z_{ij}^k}{\sum_j A_j Z_{ij}^k} \tag{9}$$

$$\frac{V_{ij}}{G_i} = \frac{A_j Z_{ij}^k}{\sum_j A_j Z_{ij}^k} \tag{10}$$

Equation 8 states that the volumes between zones i and j are proportional to the previously estimated trips generated, G_i, and attracted, A_j, and to the attributes, k, of travel between i and j. C_i is the constant of proportionality, which is solved for in the remaining equations. The result, Eq. 9, is the usual form of the gravity model, which is equivalent to a share model, Eq. 10, for the split fraction of total trips from a zone i destined to zone j. However, the previously estimated "strict utilities" that (may have) resulted in the estimation of the G_i and A_j are not normally preserved.

In fact, of course, no transportation attributes are normally used in the estimation of the productions, G_i, and the attractions, A_j. Empirical evidence to support the use of strict utilities is the juggling necessary to bring the V_{ij}'s into line with the G_i and A_j in any gravity model application. That is, the results of the separately calibrated trip-generation and -distribution models are not (internally) consistent with each other.

The separability property implies that the conventional gravity model should be calibrated only with subregional structures (partitionings) that define distinctly different destination alternatives with nonzero probabilities of being chosen from a particular origin by a particular traveler (type) for a particular trip purpose. This would considerably simplify calibration but would appear to complicate gravity model application, i.e., predicting trip distribution (see discussion in section on applying forecasting models). An understanding of the separability property may thus lead to substantially more effective gravity models. Empirical research is clearly needed.

The derivation of the gravity model (Eqs. 8, 9, and 10) from a simple proportionality statement can easily be generalized to derive any split fraction (e.g., fraction of total regional trips emanating from an origin zone, or fraction of total interzonal trips on each mode). Each split fraction is in turn dependent on the previously derived trip universe being split. The models can then be "solved," one in terms of the next, in one multiple-choice share model. The result is similar to Manheim's "general share model" (45):

$$V_{klmp} = \alpha\beta_k\gamma_{kl}\delta_{klm}\omega_{klmp} \tag{11}$$

where

V_{klmp} = travel between origin k and destination l by mode m and path p,
α = total (regional) travel,
β_k = split fraction of α from origin k,
γ_{kl} = split fraction of $\alpha\beta_k$ to destination l,
δ_{klm} = split fraction of $\alpha\beta_k\gamma_{kl}$ to mode m, and
ω_{klmp} = split fraction of $\alpha\beta_k\gamma_{kl}\delta_{klm}$ to path p.

Each of the terms on the right side of Eq. 11 is intended to be a function of activity system and transportation system variables in Manheim's model.

In summary, in the calibration of a travel demand model, the separability property of the independence axiom implies that the (marginal) probability distribution of choice of mode can be separately estimated and multiplied by the conditional probability distribution of another travel choice, e.g., P (destination, mode), to give the joint probability distribution of both:

$$P(M,D) = P(M)\,P(D|M) \tag{12}$$

provided the previously estimated strict utilities from the modal-choice model are preserved. This operation requires 2 assumptions: (a) that destination choices are made conditional on mode choices and not the reverse, and (b) that the (dis)utility from the mode choice is additive to the utility from the destination choice. Thus, the mode choice is assumed to be independently made from the destination choice (in this case) but not the reverse. Given the separability and sequence assumptions, the choices can be separately modeled, assuming negligible income effects, and later recombined into one joint probability model by simple multiplication of the separately calibrated probability models, as in Eq. 12. Conversely, the joint distribution, P(M, D), must be estimated directly if the sequence and separability assumptions appear too strong. The possible behavioral bases for sequential and separable choice assumptions are discussed in the next section.

Travel-Choice Behavior

Existing travel demand models are classified as short-run or long-run demand models, according to whether (short-run) travel decisions (choices) are modeled separately from (long-run) activity-location decisions. The additional classification of direct and indirect demand models is used to describe whether the short-run travel decision is modeled as one simultaneous "joint" choice or as a series of separate choices (e.g., mode, destination, frequency, and so on). In this section, certain behavioral assumptions in these choice classifications are discussed.

Activity (Land Use) Location

In travel demand forecasting, activity-location choices are assumed to take place in a much larger market than travel choices. Also, the time periods over which activity-location choices are made is assumed to be much longer. If activities are considered substitutes for each other in one market, this requires long-run demand models where activity locations and intensities are allowed to vary. The recent mixed success in land use modeling (38) testifies to the difficulty of describing the attributes of all the related choices in this larger market (which also includes travel choices). Thus, the present state of the art of travel demand forecasting with a few exceptions allows only amount of travel to vary, i.e., to be the dependent variable. [Some demand models have been formulated and calibrated that forecast (long-run) residential location, car ownership, and modal split in one equation set (1, 30). However, these models do not forecast quantity of travel. Nevertheless, the models provide a direction for further work.]

In modeling travel separately from activity location, the attribute variables describing the choice situation must be limited to those "highly" involved in the decision (i.e., close substitutes and complements). Indeed, a necessary condition for utilities derived from separately modeled travel decisions to be considered additive is that their components must be neither competitive (substitutes) nor complementary (43).

Trip purpose is the first way of describing the restricted set of choices that are said to be available to the traveler as an individual decision-maker. No substitution is assumed among trip purposes because the purpose of the trip corresponds to the activities at the trip destinations. The activities in place are taken as given in the partial equilibrium framework. If activities are taken as substitutes, a long-run demand (land use) model results.

The choice ordering implied by assuming that travel choices are made, conditional on activity locations, is represented in Eq. 13.

$$P(T, A) = P(T|A)\ P(A) \tag{13}$$

where

P(T, A) = joint probability distribution of travel and activity location;

$P(T \mid A)$ = conditional probability distribution of travel, given activity location; and
$P(A)$ = marginal probability distribution of activity location.

Equation 13 implies the sequence assumption that activity-location choices are made first and precede travel choices. The sequence requires that the strict utilities inferred from activity-location behavior be used in the calibration of the travel demand model. This is, of course, not the way travel models are currently calibrated.

It is, of course, possible to assume that travel and activity location are independent. That is,

$$P(T \mid A) = P(T) \tag{14}$$

This is exactly the assumption that is made when one assumes that there is a sequence of travel-choice decisions in which mode and route choice precede destination choice. That is, these choices are assumed to be made solely on the basis of the (dis)utility of the trip itself. Making this particular assumption of travel choice ordering (discussed in the next section) is at least consistent with Eq. 14.

In summary, although the logical conclusion of the theory of travel as a derived demand is to allow both short- and long-run travel activity to vary as complements in a general equilibrium framework (7), the assumption is made that we can eliminate the imposing structure this would require and model travel choices separately as an activity with a set of complements (activities) in place and fixed.

The resulting set of attributes needed to describe the choice environment for input to a travel-choice model is correspondingly (greatly) reduced. Further, the choice ordering implied by this assumption is that travel choices are adjusted much more quickly to a change in travel conditions than in residence and work-place location. Modeling the latter requires a dynamic model where changes are measured over relatively long periods. Thus, if a static travel model is assumed, the effects of changes in travel conditions on travel can be modeled (inferred), it is assumed, separately from their effects on activity location. This assumption and its implications are worthy of considerable research.

Travel Choices

The open question is, What does the traveler perceive in his evaluation of his travel alternatives? Modeling travel directly as a simultaneous decision means including the attributes of every conceivable alternative to a specific choice in any model of that choice. By modeling long-run demand separately from short-run travel, we exclude moving the traveler's residence and work-place location as alternatives to his travel choice. However, such alternative choices remain as traveling to activities at varying locations as an alternative to staying put (destination choice versus no-trip choice); an automobile trip at a different, say, off-peak, time of day as an alternative to a transit trip at the peak hour; and so on.

As noted in the introduction, the conventional breakdown of individual travel choices is to separately model trip frequency, trip destination, time of day, mode choice, and route choice. Such a breakdown involves a stronger set of assumptions than the assumption of simultaneous travel decisions. The trade-off is generally between a stronger set of assumptions but less complex models and weaker assumptions but more complex and difficult-to-calibrate models. The unanswered questions are, How difficult to calibrate are models that combine travel decisions, and how difficult are they to forecast with?

At least 2 of the conventional travel choices might plausibly and relatively easily be combined, at least for purposes of empirical testing. That is, combining trip frequency and trip destination into 1 set of alternative choices appears theoretically plausible and convenient. Zero-trip frequency is the equivalent of no change in traveler location. Other combinations may also be speculated on. However, some appear more difficult than others, not because of the difficulty in assuming that travel-choice behavior is a simultaneous decision, but because of the separability property of most existing travel models. For example, combining mode and route choice into one decision may be difficult because of the similar characteristics of alternative routes within modes and the overly strong separability property in this situation. [The evidence is that "the addition of an alternative to an offered set 'hurts' alternatives that are similar to the added alternative more than those that are dissimilar" (75).]

Because the basis of calibrating travel demand models using the separability property is to constrain some decisions on the basis of attribute (utility) evaluations made in decisions modeled earlier in the chain, a discussion of travel-choice-separation assumptions cannot proceed far without including consideration of the ordering of the separate choice assumptions.

Choice Ordering

The assumed order of the travel decisions, given a separation, determines which choice situation is used to estimate the initial strict utilities. Empirical testing with alternate orderings and breakdowns can provide some evidence as to "natural" orderings, given the underlying assumption of "conditional" choice behavior. Is there a logical or natural ordering of travel choices? If there is any separation at all, hypotheses can be attempted for specific orderings of the choices. The following hypotheses are some that support the assumption that travel choices are separable and proceed in some sequence or order.

1. Sequential choice ordering based on timing. Traveler decision-making proceeds from the latest to the earliest decisions in time. For example, for a particular trip purpose (choice-of-destination activity), the traveler may be hypothesized to have some notion of the conditions on the available modes and routes when choosing his destination. That is, he has already considered the modes and routes that are available to him. He anticipates and makes choices on routes and modes that may then limit or constrain his available destinations and departure times. (Within a mode, he is apt to have anticipated the conditions on the alternative routes within the mode when he makes his mode choice. This suggests that mode-choice decisions are made after path decisions as opposed to both decisions being made simultaneously.) This implies a logical order of travel-choice decisions running counter to their sequence in time.

The possibility of a logical order of decisions running counter to their sequence in time in the case of travel decisions was discussed already by Beckmann et al. in 1955 (3). This reverse order also gets us around the practical difficulties (probably impossibility) of having to compute supply-sensitive system characteristics (travel attributes) on an area-wide basis for input to (disaggregated!) trip-frequency decisions made at a point (or zone), or for input to a modal-split model that precedes trip distribution. Production functions g(x) for, say, travel times, are well known on a link and route within modal basis (28).

2. Sequential choice ordering based on adjustment time. Models that assume some choice ordering in a sequence could rest their plausibility on the time it takes to adjust behavior to a change in policy. Some decisions (e.g., route choice) can be adjusted more quickly by an individual than others (e.g., an origin change involving a house purchase or a mode change involving a car purchase) because they involve less commitment to their former situation. Thus, sequential choice models that involve adapting to changes in supply considerations can be considered in this sense dynamic or stochastic (5). Conversely, simultaneous-choice assumptions result in models that are in this sense static. Unfortunately, only cross-sectional data exist at present to empirically test most travel demand models.

3. Sequential choice ordering based on experience. Traveler decision-making proceeds from those choices on which there is the most experience to those choices on which there is the least experience. Most, if not all, current travel demand models are based on or can be shown to be equivalent to rational "economic man" assumptions. These yield plausible (if normative) descriptions (models) of travel behavior, but they

demand more of man's capabilities than he can generally "deliver." In addition, they assume that the traveler's values, and the choices he confronts, are constant over time. Conversely, there are other descriptions of behavior that assume less (or a bounded set of) knowledge on the part of the individual decision-maker. These provide alternate but as yet largely unexplored bases for modeling travel behavior, and the dynamics of commitment to old and selection of new travel choices as families move spatially and socially over time.

Important theoretical support for separate and sequential choice modeling comes from the theory of decision-making called "satisficing" (46). This theory rejects the notion that there exists a rational economic man who is perfectly knowledgeable and perceptive about all the possible alternatives that confront him and who can compare all possible alternatives with one another to find his optimal choice by manipulating stored criteria describing the alternatives. Satisficing substitutes for this true or complete rationality a hypothesis of bounded rationality. This implies sequential search and limited sets of criteria used for evaluation. That is, in place of simultaneous (or separable and transitive) comparison of all alternatives, alternatives are examined sequentially according to satisficing. And rather than being compared to one another on the basis of a set of (interval scale) operational criteria, the alternatives are compared to a simpler set of minimal criteria until an alternative is found that satisfies the decision-maker. Alternatives are discovered or searched sequentially until a satisfactory alternative is encountered. No attempt is made to exhaust all possible alternatives. Moreover, search for new alternatives will only occur if the traveler perceives a discrepancy between his level of aspiration and his level of reward from the existing behavior.

This "model" in its general formulation can be interpreted as supporting models of sequential travel behavior. Travelers can be considered to evaluate sequentially well-defined travel alternatives in terms of the objects that provide the travel service (modes) and in terms of the benefits from the travel service (destinations). Conversely, the traveler may sequentially apply a limited set of criteria that are used to reject alternatives that do not meet threshold levels of those criteria. (This latter interpretation provides support for choice-abstract sequential models.) In both cases there is support for the hypothesis of choice behavior that involves sequential examination of choices.

We may describe the present trip of a traveler as one path through the tree shown in Figure 2 (assuming he presently makes a trip). If he is dissatisfied with any aspect of his present trip or, if confronted by a new alternative with a promised or expected improved level of service, does he sequentially examine "near" alternatives at only one level of choice? Or does he reconsider many paths involving changes throughout the hierarchy? Or does he simply consider only the new alternative if available and accept it or reject it?

According to the theory of satisficing, there is generally a conservative bias in the system of choice. That is, over time, levels of aspiration tend to adjust to levels of achievement. (It is the difference in the levels that is said to motivate search for new alternatives.) A new alternative may or may not change the traveler's perception of difference between present and possible (future) alternative states if he changes his travel behavior. We clearly need to better understand what those perceptions of difference are, at what level in the hierarchy they occur, in what sequence they occur, and how their relative requirements of adjustment time may operate to eliminate certain choices from the sequence.

The above hypotheses that support sequential travel decision-making are not made as a matter of idle speculation. The current conventional procedure of travel forecasting assumes sequential travel choice and a very particular choice ordering. The choice ordering is allowed to vary only slightly in practice. For example, the place of modal split in the order of trip-choice decisions has been called "the most actively debated issue in modal split" (80). The context of this statement referred to whether modal split should precede or follow trip distribution. The alternatives can be represented by the following 2 model structures (probability statements in this case):

$$P\,(M, D) = P(D|M)\; P(M) \qquad (15)$$

$$P(M, D) = P(M|D)\ P(D) \tag{16}$$

where M = mode, and D = destination. If Eq. 16 were true and Eq. 15 false, destination choice would be independent of the availability of a mode (say, automobile) to reach the destination. This does not seem plausible except possibly in the case of work trips. (In such a case, the car is assumed to be purchased if not available and if necessary for reaching the destination.) In the reverse case (Eq. 15 is true, and Eq. 16 is false), the choice of mode is assumed to be made independently of the choice of destination. For example, the automobile, if available, might be selected for the trip, and the destinations that can be reached by automobile are then considered by the traveler. This appears somewhat plausible (say, for convenience shopping trips), at least more plausible than the reverse sequence. (If this is true, at least for some important trip purposes, it augers badly for transit usage. That is, choice of mode, e.g., transit usage, would be independent of origin-destination transportation system characteristics, including origin-destination pairs in larger cities where transit service may be excellent.)

There is an alternative model structure that poses a way out of the above dilemma if the order of travel behavior is not stable or must be subjected to further empirical testing. Equations 15 and 16 may be rewritten in the following form (17):

$$P(M, D|MEX_D) = P(D|M)\ P(M|MEX_D) \tag{17}$$

$$P(M, D|DEX_M) = P(M|D)\ P(D|DEX_M) \tag{18}$$

where X_D is the set of all decisions made prior to the choice of destination, and $P(M, D|MEX_D)$ is, therefore, the conditional probability that M and D will be chosen if mode choice precedes destination choice. Analogous statements apply to Eq. 18. Because MEX_D and DEX_M are mutually exclusive, Eqs. 17 and 18 can be added together to yield

$$P(M, D) = P(D|M)\ P(M|MEX_D) + P(M|D)\ P(D|DEX_M) \tag{19}$$

This is an exact expression for P(M, D). Equation 19 is equivalent to Eq. 15 or 16 only if mode choice always precedes destination choice or vice versa. It is also possible to expand Eq. 19 to include all aspects of travel decision-making.

The logical place of the time of departure decision in an assumed sequence of decisions is diffucult to establish even in theory. It may, for example, plausibly come before or after the trip-destination decision. The separation of time-of-day utility from destination-place utility and trip (dis)utility, as noted before, may make this the weakest assumed separation, leading to confusion as to its place in a logical order of travel decisions. The choice of time of departure might best be combined with frequency or destination or both, even though this would make travel models more complex.

Unfortunately, a solid case cannot be made for many trip-choice sequence assumptions. Our theory is weak, and we must look at whatever empirical evidence is available. Ben-Akiva (5) showed empirically that mode choice, assumed before or after destination choice, or the 2 travel choices modeled jointly all lead to different valuations (relative marginal utilities) of the trip attributes, (e.g., time and money costs of travel). (But this is insufficient evidence to lead to the conclusion that both sequences are wrong or that the separation assumption is incorrect.) His work on estimating the joint probability of mode and destination choice directly is the first demonstration that disaggregate data can be used for simultaneous travel-choice models, though not all travel choices were included. [The first simultaneous choice model using aggregate (zonal) data was by Kraft in 1963. The trip-generation and mode-choice decisions were combined and modeled simultaneously. Again, not all travel choices were included.] By combining choices and modeling them simultaneously, the need for sequence assumptions, but not separability assumptions (except when applying the model directly), is avoided. That is, the separability property of any formula satisfying Eq. 6 (e.g., multinomial logit) allows travel choices to be separated while still preserving the strict utilities. The separability property allows the conditional and marginal probabilities of the travel choices to be computed from the joint probability distribution estimated from the simultaneous model. Thus, for forecasting purposes, models satisfying Eq. 6 may be separated and applied sequentially (indirectly) or combined for application in a direct model (see later discussion of alternative methods).

When travel-choice models are calibrated separately, the alternatives allowed are determined by the conditional probabilities. That is, in Eq. 15, the only alternatives allowed are the destinations that are available or can be reached by mode $\dot{m}$. The estimated strict utilities from this set of choices are then assumed to be independent of the choices as soon as the separability property of Eq. 6 is used in travel forecasting (see later discussion of definition of alternative choices).

The hypothesis of simultaneous (i.e., not conditional) travel choices can be easily tested by using standard chi-square tests for differences between marginal and conditional distributions of the same random variable. If there are no differences, the hypothesis of no relation between, say, mode and destination could not be rejected. Because it is relatively easy to show a relation by the chi-square test with large sample sizes, an inability to reject no sequence might be considered evidence that the decisions are being made simultaneously. (However, the power of the test is low.)

Theories of choice that consider different choice-abstract aspects of travel attended to at difference times and in some specific order were discussed earlier. Aspects of travel can overlap with the definitions of travel choices because attributes in the definitions of each are often common to both. Some arguments against transitive value (strict-utility) models can be used in part to advance the case for assuming sequential travel choices and thus advantageous use of the separability property to calibrate demand models.

Similarly, arguments against a logical ordering of travel-choice decisions argue also for strict-utility travel-choice models because such arguments are consistent with assuming a single monotonic function of the scale variables of the alternatives and the single estimation of joint probability distributions of simultaneous travel choices (i.e., "direct" demand models). Therefore, uncertainties as to whether travel choices can be assumed to be separable and occur in some logical order do not point to abandoning strict-utility models. They may point to combining choices and making less use of the separability property in model calibration.

In summary, there may be some clear-cut travel-choice ordering that can be assumed from the standpoint of travel behavior and, thus, lead to the conclusion that probability models for combined choices should be calibrated directly wherever possible. Fewer sequence assumptions can lead to improved use of the separability property for combining separately modeled choices into a demand model. Because the independence axiom excludes, in any event, alternatives with zero probability of being chosen, the data requirements for estimating strict-utility models of combined travel choices can be greatly reduced. Simultaneous (direct) demand models rather than sequential choice models seem indicated from a behavioral point of view, although the discussion cannot be closed in view of the above hypotheses.

Combining Strict-Utility Sequential Travel-Choice Models

CRA (10) used the separability property of the independence axiom to calibrate a series of shopping-trip travel models in the following assumed sequence: mode choice, destination choice, time-of-day choice, and trip frequency (including whether to make the trip). Data at the individual traveler level were used. The relative marginal utilities of modal attributes revealed (estimated) in the mode-choice decision were preserved in the next choice modeled, namely, trip destination, by weighting the attributes of travel by mode to each destination by the probability that the mode would be chosen, given the selection of the destination. The weighting and aggregation are done with the estimated parameters from the previous (mode-choice) decision. The previously estimated strict utilities or "inclusive prices" are preserved. A proof is given that this method of combining separately calibrated travel-choice models is consistent with the assumption of additive utilities. There is no summation over the estimated number of trips because the choice of mode is assumed to be independent of the number of trips between an interzonal pair. "Tastes about modes are (assumed) independent of tastes about trip frequency" (10).

The method can be schematically portrayed for the 4 sequential shopping-trip decisions as follows:

$$\left.\begin{aligned} P(\text{mode}) &= f_m(p, s) \\ P(\text{time of day}) &= f_t(\hat{p}, s) \\ P(\text{destination}) &= f_d(\hat{\hat{p}}, s) \\ P(\text{frequency}) &= f_f(\hat{\hat{\hat{p}}}, s) \end{aligned}\right\} \tag{20}$$

where

p = vector of travel attributes,
$\hat{p}$ = previously estimated strict utility = "inclusive price,"
$\hat{\hat{p}}, \hat{\hat{\hat{p}}}$ = inclusive prices previously estimated, and
s = vector of socioeconomic variables.

This is the logical conclusion of the assumption of transitive tastes. (Strict utility suggests that "behavioral time values" have a legitimate place in transportation benefit measurement, assuming transitive tastes!

Summary

Figure 3 shows all the travel demand modeling choices considered thus far. The assumption of individuals' evaluating choices such that their probability of choice is expressible as a monotonic function of the choice-specific attributes of all the alternatives (simple scalability or strict utility) has been shown to be the expression of the independence of irrelevant alternatives axiom. This means that the relative probability of choice between 2 alternatives is independent of the attributes of other alternatives in the offered set of alternatives. The transitive nature (strict utility) of the resulting choice behavior results in multinomial, multivariate probability or share models. The separability property of the independence axiom and its resulting multiple-choice share models allow big, complicated travel decisions (e.g., those modeled in direct demand models) to be broken up into smaller, more easily modeled choices. However, these models may be separately calibrated only if separation and sequence assumptions are made. The separately calibrated models can then be linked through their previously estimated parameters into a demand model (i.e., a direct or one stage-pass demand equation). To do so requires use of probabilities (or relative frequencies), not summation of numbers of trips from the prior travel choice in the assumed sequence.

There is, in addition, a set of travel-choice models based on the strong assumption that the choice probabilities are expressible as a function of attributes of subsets of travel choices making up one complete travel decision. This requires the assumption of sequential and completely independent travel choices where the relative valuation of attributes common to 2 or more travel choices, making up one trip decision, is not constant throughout the hierarchy of travel choices (Fig. 2). These models (e.g., the present UTP models) cannot be combined into one direct demand model, but must be applied sequentially in the order in which they have been calibrated, as discussed in the next section.

Figure 1. Incomplete diagram of travel-modeling choices based on alternate travel-behavior assumptions.

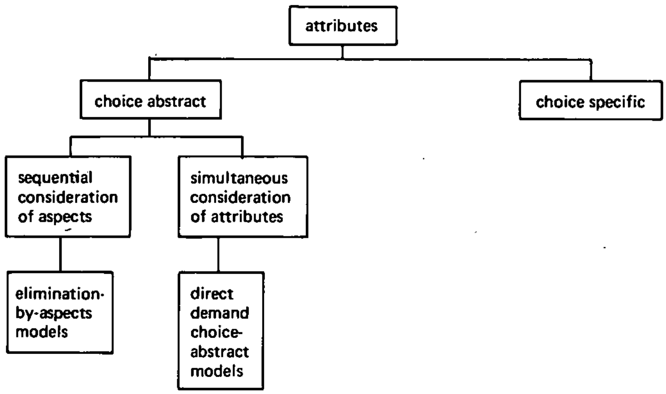


Figure 2. Presumed hierarchy of travel choices.

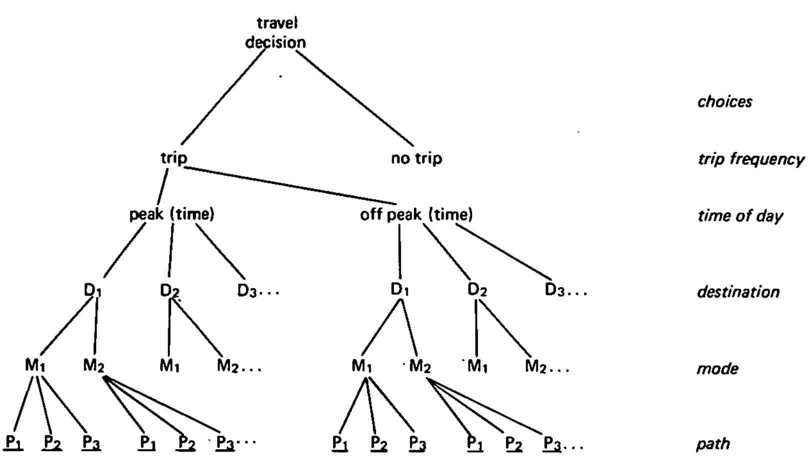
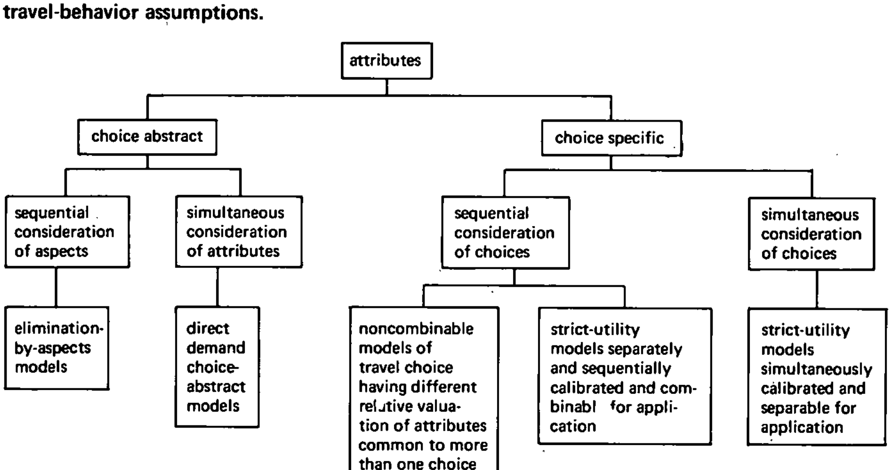


Figure 3. Less incomplete diagram of travel-modeling choices based on alternate travel-behavior assumptions.



APPLYING TRAVEL FORECASTING MODELS

Alternative Methods

The question remains of how to apply travel forecasting models. Five alternative methods are apparent.

1. Apply the models in chains in their usual UTP order (i.e., trip generation, trip distribution, modal split, traffic assignment);
2. Apply the models in chains as travelers are assumed to order their choices;
3. Link sequentially calibrated travel-choice models parametrically and apply them in one stage (i.e., as a direct demand model);
4. Apply simultaneously calibrated travel models in one stage (i.e., as direct-demand models); or
5. Apply sequentially the conditional and marginal probabilities of separate travel choices derived from the joint probability of a simultaneously calibrated model.

In the first (conventional) strategy of chaining independently calibrated travel-choice models with different relative valuations of independent variables common to 2 or more choices, the sequence of application determines the results. In such cases, the separability property of the independence axiom does not apply among choices. For example, in the application of binary-choice modal-split models in a chain, shown in Figure 4 (65), the results (i.e., splits) calculated higher in the chain are preserved lower in the chain. And in conventional UTP, the trips calculated higher in the chain are normally preserved lower in the chain on any pass through the chain.

The critical problem in method 1 is how to input the system characteristics (attributes) of the choices lower in the chain at points higher in the chain. For example, how in trip generation-trip frequency can the system characteristics for the entire region be aggregated to a single point or zone for input to this first step? The choice attributes can either be summed over (weighted by) trips calculated lower in the chain (e.g., potential functions or gravity-model weighted sums) and brought "up" to be input to higher models in the chain. Or the estimated parameters common to all the ordered-choice models can be used to probabilistically aggregate the choice-specific attributes from the lower level choices. The latter method, as noted before, is the only method consistent with the assumption of additive utilities from sequentially calibrated separable multiple-choice travel models.

If sequential models are derived and calibrated consistently with the (implicit or explicit) behavioral assumptions of preservation of strict utilities in separable multiple-choice models, there is no difference among methods 1, 2, and 3 in the resulting computed network-equilibrium travel patterns. That is, the same separable model may be applied sequentially in a series of separate travel-choice forecasts, or the joint probability distributions of choices may be calculated directly by parametrically combining the separately calibrated choice models as per the independence axiom. However, the sequential application of the models in this case can actually be in any order including methods 1 and 2. The estimated strict utilities are independent of the choices, as per the original behavioral assumption implemented by using the separability property of Eq. 6.

Conversely, from a simultaneously calibrated model satisfying the independence axiom, the conditional and marginal probabilities of travel choice may be derived, and the separate submodels of travel choice may be applied sequentially. Submodels so derived may be applied in any order, including methods 1 and 2. Joint estimation of the choice probabilities eliminates the need for the sequence assumption, but not the separation assumption, for models based on or consistent with the independence axiom.

Models based on or consistent with the independence axiom are separable multiple-choice models. Preference for any method of application is a matter of convenience, control, and purpose of the transportation systems analysis. For example, it is often desirable to be able to compute travel in sequential steps (generation, distribution, and so on) in order to be able to check the intermediate results and exert control over the forecasting process in some way. A direct application of the parametrically combined or simultaneous model may be appropriate if the user is confident of his results and wants to save time and money. If the model has been derived in a fashion consistent with its behavioral assumptions, both methods will produce the desired output for calculating the flow volumes on links in a transportation network. The choice of method should be based on the requirements of different planning environments.

Because the aggregate of trips, not the probabilities, are assigned to a network, a complete run through the sequence will be required to produce the joint probability distributions of travel (including trip-frequency probabilities) needed for aggregating over the total number of individual trip-makers to calculate the aggregate demand. Assignment of trips must also be made to update link and path supply functions for computation of an appropriate network equilibrium. Network equilibration can proceed either through incremental (fractional) loading or by iterating.

Defining Alternative Travel Choices

In the application of separable, multiple, choice-specific travel models (models having the separability property of the independence axiom), great care must be taken in choosing alternatives in order that the separability property not be too strong for the application. The strict utilities in these models are estimated in choice-specific situations even though the separability property of Eq. 6 allows travel choices to be separated for forecasting purposes while still preserving the strict utilities. Truly independent and distinct alternatives as perceived by travelers should be chosen in the application of separable multiple-choice share models. A black bus following the same route as a yellow bus, when chosen as an "independent" alternative, has the effect of reducing the use of automobile (the third choice) in order to preserve the relative odds of choosing automobile over either of the bus alternatives taken singly. This is a misapplication of the separability property because the property would appear to be too strong in this application. In model calibration, the color of the bus does not usually specify or identify a choice, so this seems perfectly clear. The black bus running on a different route from that of the yellow bus between the same origin and destination would have the same effect; and again this effect appears too strong, unless the strict utilities are clearly identified as route (choice) specific. If the yellow bus were now changed to yellow rail transit, and if the multiple choice-specific model were calibrated specifically with rail and bus transit parameters, as well as with automobile parameters, the separability property would appear not to be troublesome. Caution, however, is certainly advised.

Alternative destinations are rarely if ever defined in such a way that choice-specific strict (destination place) utilities are estimated for each destination. That is, the use of socioeconomic variables to describe the (static) trip-end activities amounts to the behavioral assumption of choice-abstract destination-place attributes embedded in an otherwise choice-specific travel demand model. Even more troublesome for the use of separable travel models are the implications of changing the destination alternative set from a small set of alternatives used for model calibration, each having nonzero probabilities of choice, to the usual large number of alternatives, among which trips are forecast in order that a high degree of resolution may be obtained for traffic-assignment purposes. In such cases, forecasting should probably be a 2-step process. That is, forecasts of trips should be made to large aggregations of zones, grouped on the basis that they are distinctly different and real (known) alternative destinations to travelers at the origin. Such grouped destinations might be based on a hierarchy of increasingly regionally oriented work or shopping places for the type of worker or shopper in each zone. Destinations not likely to be known to travelers at each origin would be eliminated from consideration. Forecasts to these zonal aggregations would then be allocated in some way to the small component zones for traffic-assignment purposes (e.g., based on employment share). Another possible way of forecasting is simply to truncate to zero trips to low (calculated) probability destinations, just as low or zero probability destinations were excluded from the data used in model calibration, as per the separability property of the independence axiom.

In summary, in an application of a separable multiple-choice share model (Eq. 6) within a hierarchical level (e.g., mode choice), the implication of the independence axiom is that the introduction of an additional transit alternative (mode or submode other than one for which the choice-specific strict utilities were estimated) will change the probability of choice (modal split) for all the existing modes. The relative share of all the existing modes included up to then in the analysis will be preserved because of the independence axiom. This also means that the cross elasticity of the modal fraction for each old mode with respect to an attribute of the new mode is the same for each of the old modes. For example, the cross elasticity of modal fraction on the old modes with respect to fare on a new transit submode will be equal for all automobile and transit alternatives considered thus far. This precludes a pattern of differential substitutability among modes and, in effect, implies a (mode) choice-abstract model with respect to the modal fraction, but not with respect to aggregate demand, however (10, 50).

A number of specific examples, such as the above black and blue bus versus the yellow and red bus, can be and have been used as criticisms of the overly strong separability properties of the independence axiom in many instances. Much practice will be required in defining alternatives before multiple-choice share models are usable in any but the most straightforward mode-choice situations in which they have thus far been applied with apparent success (e.g., by Rassam, Ellis, and Bennett, 60). One set of arguments in certain situations consists of citing examples where the relative odds of choice in a binary-choice situation are unlikely in fact to be preserved when new choices are offered [i.e., the black and yellow bus argument, or a second Beethoven record added to an original Debussy and Beethoven binary choice (12)]. Luce and Suppes (43) state:

> We cannot expect the choice axiom to hold over all decisions that are divided in some manner into two or more intermediate decisions. It appears that such criticisms, although usually directed towards specific models, are really much more sweeping objections to all our current preference theories. They suggest that we cannot hope to be completely successful in dealing with preferences until we include some mathematical structure over the set of outcomes that, for example, permits us to characterize those outcomes that are simply substitutable for one another, and those that are special cases of others. Such functional and logical relations among the outcomes (alternatives) seem to have a sharp control over the preference probabilities, and they cannot long be ignored.

COMBINING MODELING CHOICES: RESEARCH DIRECTIONS

Previous sections have described the major choice-behavior assumptions (stated or unstated) of existing travel forecasting models and discussed some of their implications. This section discusses briefly how those modeling choices might be combined and suggests some further research directions in this area.

Combining Modeling Choices

The choice-specific sequential and the choice-abstract sequential (elimination-by-aspects) models of choice behavior can be combined in their use. That is, when all available (noneliminated) alternatives contain all the remaining aspects (as, for example, if travel time and cost were the entire set of remaining aspects in the scenario in an earlier section), the independence axiom is shown by Tversky (75) to again hold. Thus, the elimination-by-aspects model can be used to select the "independent" alternatives having non-zero-choice probabilities among which choice is allowed. These allowable choices may then be modeled by using forecasting models based on monotonic functions of the remaining important attributes. The remaining attributes may or may not be perceived by the traveler as identified (or modeled) with specific supply-side choices (i.e., as choice-specific attributes). Figure 5 shows these modeling choices (as arrows) added to the previously described set of modeling choices. This "completes" the diagram of modeling choices based on alternate travel-behavior assumptions.

Figure 4. Modal-split chain for commuter travel.

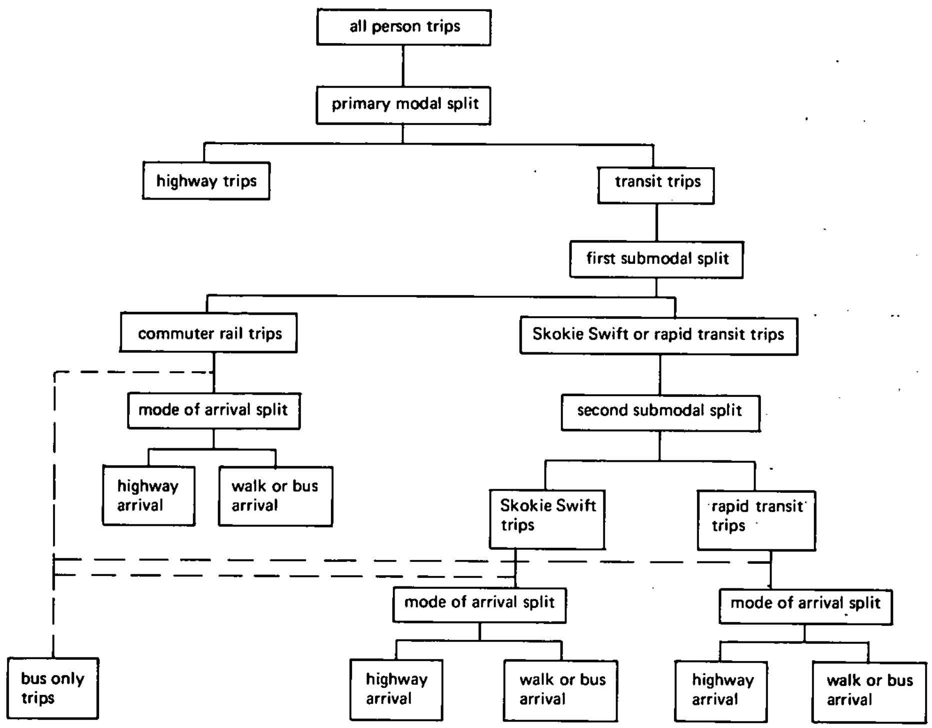
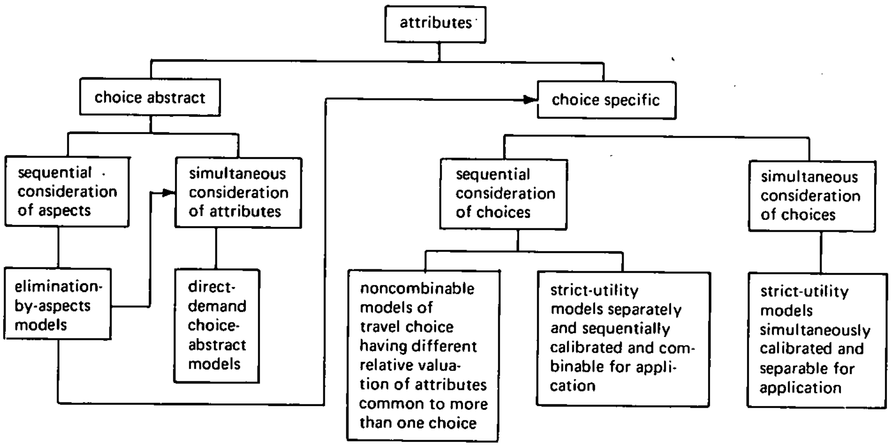


Figure 5. Complete diagram of travel-modeling choices based on alternate travel-behavior assumptions.



It is perhaps also possible that the arrows can be drawn symmetrically from right to left, that is, from choice-specific models to choice-abstract models. For example, this might more accurately describe a travel demand model having choice-specific mode and route attributes (assumed first in the choice ordering) and choice-abstract destination and origin-place attributes. This highlights the difficulty that existing travel demand models have in discriminating among competing activity locations. That is, there are no specific cross relations among place (choice) specific trip destinations in practically any existing travel (forecasting) models. However, the diagram need not be additionally embellished at this writing.

Additional Research Directions

Other decision rules can also be imagined in the sequential choice-abstract case. For example, more than one aspect at a time can be applied to eliminate alternatives. However, this produces the same results as applying aspects one at a time because all alternatives not containing the aspects are eliminated either way. A search of the mathematical psychology literature will no doubt turn up additional possible sequential choice rules.

Is there a remaining possibility that certain travel choices are decided on the basis of different weightings of the attributes than other choices? This would require that trip choices be perceived as fundamentally different, independent, nonhierarchical choices and that alternatives considered for each choice be disjoint (no aspects or attributes contained in common) with the alternatives for another choice. This appears to be the strongest (most heroic) assumption, as discussed earlier. If the assumption can be verified, it would certainly strengthen the basis in behavior of present UTP models. Clearly, some important research questions remain.

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APPENDIX

Utility Analysis

Perhaps the most plausible descriptions and interpretations of travel-choice behavior derive from utility theory. That theory describes the traveler as an individual welfare maximizer, one who maximizes his own personal welfare from travel, subject to constraints, such as not exceeding his total time or resources available. Considerable scholarship in the field of economics has been devoted to developing a "science of rational choice," resulting from the utilitarian foundations of modern economics that people do (or tend to) act rationally (15). That is, that people act to maximize their own utility. Whether or not the reader agrees with utility analysis is inconsequential to the theoretical development in the body of this paper. Certain important travel models that can be analytically derived from consideration of an individual traveler's maximizing personal utility from travel can more simply be derived on the basis of logic from assumptions on consistent choice behavior. However, utility theory derivations highlight certain additional assumptions of these models, which are usefully documented in a state-of-the-art paper.

Principles

Travel forecasting can be based on consideration of the rational individual's maximizing his own welfare or benefit from travel. Travelers are presumed to be rational decision-makers, acting in their own behalf. This constitutes the basic normative statement of behavior of the system that has as its objective adequately describing that behavior. For this property to be used to solve rigorously (analytically) for the state of the system at any time requires that the assumption be made that the system is in static equilibrium. Comparison of alternatives via the comparison of (travel) outcomes of alternatives is made by the method of comparative statics.

The equilibrium solution proceeds from the property that "the conditions of equilibrium are equivalent to the maximization of some magnitude" (61). In utility analysis, personal utility is maximized subject to certain time and resource constraints. "The individual confronted with given prices and confined to a given total expenditure selects that combination of goods which is highest on his preference scale" (61). At equilibrium, the ratio of the marginal utility of 2 choices is equal to the ratio of their "weighted" attributes (i.e., their revealed "prices"). The relative marginal utilities of the attributes of a choice situation can be solved for (inferred from) observed data on the choices made.

In general, therefore, the utility, U, of a trip is related to the attributes of characteristics, Z, of a trip through some constants of proportionality, u_k. For example, in linear form,

$$U = U(Z) = u_o + \sum_k u_k Z_k \tag{21}$$

In equilibrium analysis, this function is maximized, subject to certain constraints (e.g., budget). The attributes are related to the amount of travel, X, and the characteristics of the choices by means of "supply" or production functions,

$$Z_k = g_k(X) \tag{22}$$

where g(X) is specified by the choices (e.g., the transportation "technology" and link characteristics in the case of travel time over a single link in the usually depicted speed and volume supply function). In the general case, the attributes Z_k are outputs of the consumption activity X, travel.

The problem of deriving a demand function then becomes one of specifying the attribute variables, Z_k, that describe the traveler's choice situation, and the form of the utility function, U = U(Z). Utility maximization calculus is then applied to solve for travel, X, at the point at which the marginal costs of travel equal the marginal benefits from travel. (Continuous functions are assumed in the usual formulation, although discrete choice alternatives can be encompassed in programming solutions.) This results in some function of the scale values of the attributes.

$$X = f(Z_k) \tag{23}$$

where X = quantity of travel.

Specifying Utility

The first step in deriving demand models analytically from utility assumptions involves specifying the utility function, $U = U(Z)$. Travel, according to prevailing thought, is a derived-demand commodity (34): "A trip is made because a household member wishes to purchase commodities or services, or obtain other satisfactions such as the purchase of food, a visit to the doctor, or obtaining of income (through work)."

Travel activity can be considered to consist of positively valued time foregone at the trip origin, time and money spent in travel, and positively valued benefits at the trip destinations. The quantity being maximized would therefore be some function of the benefits (utility) from the purpose(s) served by travel and the cost (disutility) of travel. The utility function, $U(Z)$, includes Z variables that describe characteristics of consumption activities, A_i, as well as transportation "activities," Z_k.

$$U = U(A_i, Z_k) \tag{24}$$

Models derived analytically from utility theory must include other than transportation variables, Z. Travel choices that are based on maximization of personal utility and that exclude positive utility from activities at the trip destinations will result in minimum quantities of travel, **X**. Such models omit or set equal to zero the relations between travel and the consumption activities resulting from travel.

CRA (10) includes the characteristics of the trip-making populations, s, in its characterization of utility, $U(Z)$. Some others do not (e.g., Golob and Beckmann, 21). On practical grounds, Stopher and Lavender (71) show that separate choice equations estimated for each population group (or "market segment") gave better fits than choice equations that included separate socioeconomic variables. On the other hand, the inclusion of s, the population characteristics, in the utility function avoids the necessity of stratifying the data by population group and thus allows all the data to be used in estimation when the data are limited. However, the penalty is to increase the number of variables and interaction terms in the utility function.

Analytically Deriving Travel Models from Utility Analysis

Several examples exist in the literature of models of travel demand derived analytically from assumptions of maximizing personal utility from travel. Excellent examples for purposes of illustration and clarity are provided by Golob and Beckmann (21).

Their derivations start out with the statement of the utility functions in the form of Eq. 24. That is, trips, X_k^m, by mode m to destination k, generate utility, Z^p, based on the achievement of purpose, p, equal to the sum of the achievements of p at all destinations, k, visited.

$$A_i = Z^p = \sum_{k,m} \alpha_k^p X_k^m \tag{25}$$

where α_k^p = degree to which purpose p is served at destination k; and the trips generate disutility, y^r, equal to the sum of the traveler's expenditures in terms of attributes, r, incurred on trips to all destinations visited.

$$Z_k = y^r = \sum_{k,m} \beta_k^{mr} X_k^m \tag{26}$$

where β_k^{mr} = perceived expenditure in terms of attribute r on a trip to destination k by mode m.

The utility function, therefore, includes both the utility derived from the trip and the disutility incurred in making the trip.

$$U = U(Z^1, Z^2, \ldots, Z^p, y^1, y^2, \ldots, y^r) \tag{27}$$

The equilibrium solution proceeds from the hypothesis that the traveler maximizes this function with respect to the decision variables (trips), X_k^m. If continuity and other conditions are satisfied, the necessary utility maximization calculus can be applied. The necessary condition for a maximum,

$$dU/dX_k^m = 0 \tag{28}$$

says that trips to destination k by mode m will be pushed to the point where the marginal net utility is zero (i.e., where the combined marginal utilities of the trip purposes equal the costs of the trips), while trip mode combinations that do not occur have a nonpositive initial marginal utility.

This particular approach assumes direct maximization of utility with no money or time expenditure constraints. Golob and Beckmann go on to derive a generalized gravity model that assumes purposes are identical with destinations, power form utility functions, $U = U(X^*)$, and separable (additive) utilities.

$$X_{ik} = \left(\frac{u_k}{C_{ik}}\right)^{\frac{1}{1-w}} \tag{29}$$

where

X = number of trips,
i = origin,
k = destination,
u_k = attraction of a destination,
C_{ik} = generalized trip cost (an empirically derived constant), and
w = constant varying between 0 and 1.

The authors also deduce other demand functions based on other assumed forms of U(z) (e.g., step functions). They conclude, "While a great number of demand functions can be deduced from corresponding utility functions, not necessarily every proposed demand function can be interpreted as the result of utility maximization."

In summary, travelers are assumed in a (static) partial equilibrium mode 1 to behave in such a way that their jointly derived satisfaction from both travel and the activities at the trip end(s) is maximized. Travel is assumed to increase until the marginal (dis)utility of the trip itself is equal to the additional marginal utility of the activity that can be engaged in. Thus, utility-based travel demand models, calibrated at (assumed static) equilibrium, reveal or show marginal rates of substitution among all the separate attributes associated with the travel decision.

Travel Models: A Review

Probability Models

An important accommodation to the practical difficulty (impossibility) of exactly specifying the worth (utility) of a particular travel choice to an individual traveler is to assume that the utilities from these choices are random variables. In these random-utility models, probabilistic behavior is assumed from the randomness of the utility function. Another class of probability models can arise from the assumption of constant utility and a probabilistic decision rule, that is, where the utility function is a fixed numerical function of the attributes of the choice alternatives and the response probabilities are some function of the scale values of the relevant alternatives (43). [According to Beckmann et al. (4), "Trip behavior is held to be rational, albeit with a random component . . . within the decision-maker's own value set. If the random component were greater than the rational component, then any attempt at prediction would have to be abandoned, at least at the individual level."]

CRA (10) derives analytically the multinomial logit model of probabilistic travel choice from considerations of maximizing personal utility from travel. That is, the utility-maximizing individual discussed previously will choose alternative travel choice i if

$$U(Z_i) > U(Z_j) \tag{30}$$

for $i \neq j$, $j = 1, \ldots, J$. The model is derived on the basis of attributing a random element to the worthy (utility) of outcomes. Full information on the outcomes is assumed available, and individuals are assumed to exhibit no bias in the valuation they attach to the worth of choice alternatives.

The utility, $U(Z)$, is taken as randomly varying because the vector of attributes of the choices "does not capture all of the factors influencing the formation of tastes or the perception (measurement of attributes) of alternatives" (10). There is a value of $U(Z)$ for each individual drawn from the population with the same observed characteristics and choice alternatives.

The utility of a travel choice can be written as the sum of a nonstochastic function, $V(Z_i)$, and a stochastic term ξ_i.

$$U(Z_i) = V(Z_i) + \xi_i \tag{31}$$

The deviations ξ_i are assumed to be independently distributed random variables containing the effects on utility of the choice-situation attributes that are unable to be measured.

The choices of individuals are then modeled in a probabilistic manner. That is, the probability of choice of option i is

$$P_i = \text{probability } [V(Z_i) + \xi_i > V(Z_j) + \xi_j] \tag{32}$$

$$P_i = \text{probability } [\xi_j - \xi_i < V(Z_i) - V(Z_j)] \tag{33}$$

for $i \neq j$ and $j = 1, \ldots, J$.

The specification of the probability function, P_i, requires an explicit functional form and probability distribution for each of the terms in the (probability) argument. CRA shows that, if the ξ_j are independently distributed with identical reciprocal exponential distributions,

$$\text{Prob } (\xi_j \leq w) = e^{-e^{-w}} \tag{34}$$

for the 2 (binary) choice case where $i = 1, 2$,

$$P_i = \text{Prob } (\xi_2 - \xi_1 < w) = \frac{1}{1 + e^{-w}} \tag{35}$$

and, from Eq. 33,

$$P_i = \frac{1}{1 + e^{-[V(Z_1) - V(Z_2)]}} \tag{36}$$

This is the logit function for the probability of choice of alternative 1, analytically derived from considerations of maximizing individual (personal) utility.

If the stochastic term $\xi_2 - \xi_1$ is bivariate normally distributed, then the standard binary-choice probit model is derived [assuming $V(Z)$ is linear in parameters]. And if the stochastic term is uniformly distributed over the feasible range (for which P_i varies between 0 and 1), a truncated linear ogive curve is the resulting probability model of binary travel choice.

In the multiple-choice case, the same assumption on the distribution of the random terms results in the multinomial logit formula:

$$P_i = \frac{e^{V(Z_{ki})}}{\sum_{j=1}^{J} e^{V(Z_{kj})}} \tag{37}$$

Equation 37, which is the same as Eq. 7, says that the probability that alternative i will be chosen is directly proportional to its utility, $V(Z_{ki})$ (a function of attributes, k, of the choice situation, i), and that the probabilities of choosing one alternative in the set of available alternatives, each with a nonzero probability of being chosen, must sum to one. This is the same "strict-utility" multinomial, multivariate choice model of Luce (41), which was presented before in Eq. 7. The strict-utility model is shown by Luce and Suppes (43) as being a (independent) random-utility model, but not all random-utility models are strict-utility models, In fact, only independently distributed reciprocal exponential distributions of the random utilities, or monotonic transformations thereof, result in this equivalence. According to Luce and Suppes (43), "It is conjectured that these are the only reasonably well behaved examples, but no proof has yet been devised." CRA also rejects multiple-choice generalizations of other random-utility models (which assume other probability distributions of the utility functions) as being analytically intractable or otherwise computationally impossible to work with. For example, the multivariate normal distribution of the utilities with a known covariance matrix, which would yield a multiple-choice generalization of the binary-choice probit model, is rejected on this basis. Thus, the binary logit model is the only binary probability model for which the multinomial extension is practical.

By a logarithmic transformation of the utilities, we can write Eq. 37 as follows (similar to Eq. 6):

$$P_i = \frac{h(Z_{ki})}{\sum_{j=1}^{J} h(Z_{kj})} \tag{38}$$

for j = 1, ..., i, j, ..., J.

And, if the utility function is in product form,

$$P_i = \frac{\theta_i X_{1i}^{a_{1i}} X_{2i}^{a_{2i}} \cdots}{\sum_{j=1}^{J} \theta_i \prod_k X_{kj}^{a_{kj}}} \tag{39}$$

where X is used instead of Z to represent choice variables.

Equation 39 is the McLynn and Woronka "market share" modal-split model (50). The derivation of this model, which proceeds from aggregate travel-behavior assumptions, is shown in an earlier section on travel behavior. If the parameters of Eq. 39 are not mode specific (i.e., do not contain subscripted j parameters), the equations are the same for all modes in a modal-choice model. This is the Mansod relative shares model (52). This model "approaches mode abstractness" (11) (but not "abstract mode" or complete choice abstractness because the constant term is assumed to capture the effects of the unmeasured attributes of any choice alternative in the context of the choices available.) The model was developed for the Northeast Corridor where the new-mode problem was of great concern, as discussed earlier.

The class of separable multiple-choice share models of which Eq. 6 or 33 is the general statement has been shown (and will later be shown) to be derived from many different assumptions. The CRA derivation from consideration of personal utility shows the consistency of utility theory with the independence axiom. More important, it provides an additional basis in behavior for interpreting strict utility and specifying appropriate choice-specific variables (attributes) that determine choice behavior within (assumed) separate choice situations.

For example, depending on the travel choice, revealed marginal utilities from equilibrium analysis will probably vary simply because marginal utilities are generally not constant according to well-known theories of diminishing marginal utility. [In the psychological literature this is expressed as follows: The weight or importance of any attribute will vary with the individual's level of satisfaction with respect to that attribute (27). Also, stated attitudes toward the importance of a particular attribute are a function of both the underlying strength of the human need and its present satisfaction level (8). This appears to reduce considerably the ability to transfer the utilities in a model based on attitude survey results (24) from one surveyed situation to another situation. Also, the direction of change of an attribute is thought to influence the weight attached to that attribute (66). A method for including directionality of effect of a change in the attribute in a travel demand model has been proposed by McLynn in his metric model (51).] Constant marginal utilities need not be assumed in travel choice models based on the independence axiom. However, constant relative marginal utilities must be assumed for the strict-utility function, $V(Z_{kt})$, i.e., constant marginal rates of substitution between travel-related attributes, such as the traveler's willingness to trade off time and money. Functional forms of strict-utility functions should be used that are plausible from the standpoint of prior understanding of travel behavior and not be solely based on goodness-of-fit considerations (i.e., which describe best, or discriminate best among, alternative choice situations within the data set used for model calibration).

Multiple-Choice and Direct Demand Models

Stopher and Lisco (70) propose a multiple-choice probability model as follows:

$$P = P_g P_d P_m P_r \tag{40}$$

where

- P = probability that an individual will make a trip to a specific destination by a given mode and route;
- P_g = probability that an individual will choose to make a trip;
- P_d = probability that an individual will accept a destination, d, given that he will make a trip;
- P_m = probability that an individual will choose a mode, m, given that he will make a trip to a particular destination; and
- P_r = probability that an individual will choose a route, r, given that he will make a trip to a particular destination by a specific mode.

In Manheim's (45) general share model, Eq. 11, the split fractions (shares) are separately modeled and must each sum to one for "internal consistency." This allows a probabilistic interpretation similar to the Stopher-Lisco model, Eq. 40. Both are multiplicative and, thus, assume separability of the travel choices. However, there is no guarantee that Eq. 5 will hold because of strict utilities having been estimated in accordance with an assumption of constant relative valuation of attributes throughout all travel choices in the hierarchy. Stopher and Lisco (70) address themselves to this point as follows: "The objective is to make sure that the behavioral relationships identified in one detailed disaggregate (choice) model still retain their basic identity in the more aggregate general ones. The aim is to see that the summed models are indeed the sum of their parts." And Manheim (44) states, "A desirable property of a sequential implicit system is that it be internally consistent."

The authors thus appear to be leaning heavily toward assuming constant relative valuation of attributes throughout the complete travel decision. In this case, their choice models can be only separately calibrated given the additive utility assumptions as discussed in the earlier section on the separability property.

Manheim's (45) more detailed specification of his general share model, Eq. 11, is as a series of special product models. Each split fraction is in the form of Eq. 6, where the $Z_{k\ell}$ include both activity and transportation system variables. For example, destination share, γ, is a share model in the form of Eq. 10, with A_j being activity system variables instead of trips attracted. Aggregation of costs (travel attributes) is carried out by simple summation. That is, the denominator in the (assumed) previous choice (e.g., trip distribution) is used to weight the (interzonal) travel attributes for input to trip generation. There is no (additional) relative frequency or probability weighting as there must be to preserve the basis in behavior of the additive utility and separability assumptions of the separately calibrated travel-choice models. The separability property can only be used to combine separately calibrated models on the basis of these assumptions.

Manheim (45) states, "Any explicit (direct) demand model can be expressed as a general share model." We note that it must be expressible as a multiplicative choice (share) model to be consistent with the basic travel-behavior assumption. However, none of the existing "1-stage" direct demand models is equivalent to the multiple-choice share model. It may be no accident that attempts to derive the present "standard" direct demand models analytically from considerations of maximizing personal utility have failed despite rather heroic attempts (10, 37). The possible reason the direct demand models cannot be analytically derived is that their causality premise (travel is a derived demand) results in a long-run demand (land use) model (7). Thus, short-run travel demand models, which are monotonic functions of scale variables describing the choice situation, can only be derived by resorting explicitly to the assumption that the (dis)utility of travel is additive to the utility from activities in place. The resulting models are probability share models of short-run travel choice.

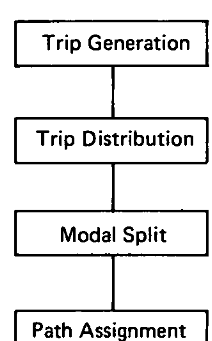
McLynn and Woronka's composite analytic model (50) is a 2-stage (2-choice) aggregate demand model that incorporates the results of his separately estimated modal-choice share model (Eq. 39). The derivation of the model is only in terms of the shares themselves rather than the attributes (derivation is described below in the section on modal split). The method of aggregation of costs is similar to Manheim's method described above. Both models are in concept extensions of the gravity model, discussed in an earlier section; the gravity model is taken specifically as a starting "analogy" (50) in McLynn and Woronka's derivations.

In sum, the travel model that satisfies both the utility-maximizing (rational) travel behavior premise and the independence axiom is the (separable) multinomial probability or share model (Eq. 6). But to use the separability property of the independence axiom to reduce the number of choice alternatives and allow calibration of separate, less complex models that may later be combined requires the assumption of additive utilities from sequentially made travel choices to estimate sequential choice models that may later be combined into 1 multinomial, multivariate probability or share model.

Separate Travel-Choice Models

The conventional series of (aggregate) sequential choice travel forecasting models are usually chained, as shown in Figure 6. Current travel forecasting procedures that predict quantity of travel on transportation networks are based on the theory of equilibrium between supply and demand on the transportation network. That is, there should be an equality between the travel conditions, such as times and cost, on the loaded network and the travel conditions used as input to the prediction. As shown in Figure 6, the current conventional procedure is to model travel behavior as a series of sequential, independent choices of trip generation, trip distribution, modal split, and traffic (route) assignment. Land use forecasting precedes travel forecasting as a separate step. For each travel choice, the existing pattern of

Figure 6. Conventional UTP travel-forecasting chain.



usage in the region at the prevailing equilibrium between supply and demand is related to a small set (often one) of independent variables. The trend or description is then assumed to hold in the future.

For example, trip distribution is modeled as a function of a description of the trip lengths that prevailed at the equilibrium between supply and demand represented in the base-date data file. Trip generation usually relates total trips in and out of a zone only to measures of the activities existing in the zone. The assumption is made that total travel, as measured by trip ends, varies only as development varies, not as conditions on the tested networks change.

In a single pass through the chain shown in Figure 6, the initial number of trips generated is kept constant, regardless of what happens later in the chain. Iteration is the conventional method of feeding back the effects of changes in travel conditions lower in the chain on forecasts made higher or earlier in the chain in order to equilibrate between supply and demand on the transportation network. The difficulties of introducing "lower down" choice attributes higher in the chain is well known, in part because of the incomplete and irregular specification of choice variables (e.g., transportation system attributes) in each step (7, 45). The way to overcome this problem is through parametric aggregation, as already discussed (assuming constant relative valuation of choice attributes throughout a complete travel decision).

The next sections discuss existing models of travel choice. Each is taken individually, except trip generation, which is discussed above and in the introduction. Issues of combining models into one demand model are not discussed.

Trip Distribution

The gravity model was shown earlier to be derivable from a general statement of proportionality to attributes of a constrained-choice situation, i.e., constrained in the sense that these attributes included the constraining (previously calculated and held constant) trips generated and attracted. The attributes can potentially include all the attributes of travel (disutility) between origins and destinations. Solving for the constant of proportionality results in the multinomial share model. This may be the simplest possible statement of the multinomial model as the logical result of assuming rational choice (transitive values) throughout the travel decision.

The gravity model was also shown earlier to be analytically derivable from considerations of maximizing personal utility (21), assuming destinations expressed the utility of the trip (purpose identical with destinations).

Wilson (81) derived the gravity model as the "most probable distribution of trips among zones" given the usual assumptions that the numbers (i.e., frequency) of trips generated from, and attracted to, each zone are fixed (constant) and the total "generalized" cost of travel is held constant. He later attempts to embellish this very interesting result by showing its consistency with maximizing entropy (82).

Loubal and Potts (40) derive a trip-distribution model that is equivalent to the exponential form of the gravity model and assumes that a "trip potential, giving an expected number of trips in the absence of resistance to travel can be combined with a correction term dependent on network constraints." Two of the initial assumptions made are the same as Wilson's (81); namely, trips to and from each zone are constant and known. However, Wilson's assumption that the total generalized cost of travel is constant is dropped. The model is derived on the basis of probability statements whose normalization properties allow the model to be applied with different zone configurations provided that "network parameters are adjusted with appropriate weight factors."

Wilson (81) also derives the intervening-opportunities model (63) by the same methods and from the same assumptions plus one, namely, that intervening opportunities are a proxy for cost. That is, "the number of opportunities passed (so far are) a measure of the cost of getting so far" (81). The total opportunities passed sum to total trip-end destinations, which are assumed fixed, as is total cost. The derivation provides an interesting equivalence statement between opportunities and cost of travel. If we assume that there is some utility derived from the purpose of travel, the statement says that the number of opportunities passed is minimized in order to maximize net benefit from travel. Thus maximizing net benefit from travel means minimizing the number of destinations passed. The L in the opportunity model, which is supposed to be a constant probability of accepting a given destination, can then be interpreted as a parameter, estimated on the basis of minimizing destinations passed, or trip cost, both of which are now considered equivalent. The (constant) parameter suggests that the value attached to trip cost (its "marginal utility") is constant.

Modal Split

There are numerous derivations from different "first principles" of the multiple-choice share model. Wilson (81) derived it (Eq. 7) in its aggregate form (P_i in Eq. 7 equals the split fraction on the ith mode) by using the method and assumptions for deriving the gravity model, adding the restriction that the cost of travel among all zones over all modes is fixed. He notes that the function (Eq. 7) is "identical in form to that derived from a statistical approach to modal split using discriminant analysis" (59). Warner (79) and later others (39, 69, 73) also use the probabilistic formulation (Eq. 7) or its equivalent as fitting functions to estimate the probability of mode choice in the so-called disaggregate probabalistic behavioral models, as noted previously. One of the principal interests of the latter group is to estimate the value of time from a binary-choice probit model or a strict-utility function, rather than to analytically derive a new demand model.

The next attempt to analytically derive the share formulation (Eq. 6) in modal split from some statement of first principles is by McLynn, Goldman, Meyers, and Watkins (49). Their model (Eq. 39) is derived analytically from assumptions only on the split fractions of each mode. The first assumption, or statement of behavior, is quite familiar: "The split fractions which define the share of the market are assumed to be functions of the choice influencing attributes of all the competing products." The split fractions, of course, express the aggregate result of modal-choice behavior. The choice influencing attributes are represented by a vector, X_{kj}, where j is the mode and k is the variables (attributes) describing the choice situation. According to the authors, "X_{11} need not have the same interpretation as X_{12}, and might even refer to some quality of (j = 1) that is meaningless for (j = 2)." The authors next define terms.

$$M_j = w_j M \qquad (41)$$

where

M = total market size,
M_j = size of j's market share, and
w_j = j's fraction of the total market.

They then decompose Eq. 41 by differentiating in the usual fashion to derive the separate (additive) elasticities.

$$E_x(M_j) = E_x(M) + E_x(w_j) \qquad (42)$$

where $E_x(\ )$ = elasticity with respect to the attribute x of the term in the argument ( ).

They then focus separately on the $E_x(w_j)$, the elasticity with respect to the X_{kj} of the market share or split fraction of mode j. The assumption that actually specifies the form of the model is that the elasticities of the split fractions, with respect to the attributes X_j, are a function only of the split fractions themselves. (This appears to be a general result, as well as a possible starting assumption, for multiple-choice share models—a result worth pondering.) That is,

$$E_{x_j}[w_j] = f(w_j) \qquad (43)$$

$$E_{x_{i \neq j}}[w_j] = f(w_i) \tag{44}$$

The latter (Eq. 44) are the cross elasticities that depend only on the split fractions of the competing modes, not on the attributes X_j. This leads to possible nonmode specificity of the cross elasticity of the P_i or w_j (share) as discussed in the section on defining alternative travel choices.

After a lengthy and rigorous mathematical derivation, Eq. 39 results ($P_i = w_j$). The model is calibrated with aggregated data on market shares and mode-specific variables X_{kj}.

The derivation of the model from these simple assumptions is indeed an elegant piece of work. Unfortunately the assumptions offer no particular basis in "behavior" that is helpful in specifying appropriate X_{kj} variables. That is, the traveler is logically confronting situations described by the X_{kj}, not the direct and cross elasticities. One wishes to tie the assumptions back into statements of choice behavior that are more easily interpreted.

There follows a spate of additional derivations of the multiple-choice share model in transportation, and these should be mentioned. The first (48) follows from the Luce (41) independence-of-irrelevant-alternatives axiom. McFadden uses the statement of the independence condition (Eq. 4) to derive Eq. 7 by using the properties that the $h(Z_{ki})$ are proportional to the odds that i will be chosen and the sum over i of the $h(Z_{ki})$ must equal one. This is the same as McLynn's first quite general statement, in the form

$$h(Z_{ki}) = f(X_{kj}) \tag{45}$$

Townsend (74) derives the multiple-choice share model axiomatically from transitivity and continuity statements that are quite independent of, but analogous to, Luce (41). Mayberry (47) claims that Eq. 6 is "equivalent" to a statement that says that an increase in attractiveness of mode m (with other modes unchanged) will cause travel on m to increase and travel on all other modes to decrease. A decrease in attractiveness of mode m would cause the opposite behavior. This is, of course, nothing other than simple scalability. Mayberry worries aloud that his statement has entailed too large an assumption because Goldman pointed out to him the "problem" with Eq. 6: "The ratio of travel by one mode to travel by another depends only on the characteristics of those two modes, and not on the characteristics of any other mode!" (47). However, after worrying about the problem of not always being able to describe independently perceived modes within the abstract mode formulation (is a flying blue bus a bus or an airplane?), Mayberry is apparently satisfied that "homogeneous population groups" will make the distinction and continues his axiomatic development of Eq. 6.

Rassam, Ellis, and Bennett (60) derive independently an exponential-form multinomial logit model (Eq. 7) from 2 assumptions similar to those made before. Their first assumption (similar to that of Mayberry) is that, if the attractiveness of a mode is expressed by a disutility function, which includes transportation variables, "then the share of that mode decreases when any of its transportation variables increase and, ceteris paribus, those of the other modes will increase or remain stationary." The second assumption (similar to that of McLynn et al., 49) "structure(s) the relationship between modal split and the explanatory transportation variables, namely, that the ratio of a small change in modal split of a given mode to that of a given transportation variable is proportional to the modal split of this mode and to a linear function of the modal splits of all modes." This statement is expressed as

$$\frac{\partial w_m}{\partial X_{ij}} = w_m \sum_{k \neq m} \alpha_{ijmk} w_k \tag{46}$$

where X and w are as defined in Eqs. 43 and 44, i and j are origins and destinations, and k and m are modes. [This equation, which is in Rassam, Ellis, and Bennett's Eq. 5 (60), is the linear case of McLynn's et al. Eqs. 1.17 and 1.18 (49).] The usual set of assumptions and restrictions is made (choices are mutually exclusive and define the full alternative set, the sum of the shares, i.e., modal splits, equals one and so on) and the resulting system of differential equations is solvable as a series of exponential-form share equations (Eq. 7). The Z_{ki} in Eq. 7 is a linear function of the attributes X:

$$Z_{ki} = \sum_{i} \alpha_{ik} X_i + \alpha_k \tag{47}$$

The constant term, α_k, is again a mode (choice) specific constant that contains the effects of all attributes or purposes or both not considered or measured. Equation 7 has been used successfully in estimating the split among 4 modes to airports in the Washington, D.C., area.

Because the fundamental assumptions are the same as those of McLynn et al. (49), the same comments apply as to that model—namely, that, although the assumptions can be shown to result in a multinomial share model, they are not grounded in behavior in a way that is helpful in specifying variables. Utility analysis is much more helpful in this regard. However, because the models are the same as those derivable from utility analysis, consideration of personal utility from travel can be used in specifying variables to be used in this share model of modal choice. Specification of appropriate attributes in each choice situation is a critical issue in the aggregation of separately calibrated choice models.

Pratt and Deen (55) fitted a logit function to aggregate sub-modal-split data in Washington, D.C. (In this case, submodal split is intratransit-mode diversion from surface bus to rapid transit.) In that application, they state,

> The final equivalent time diversion curve was formulated by first applying regression analysis and then hand fitting a logistics curve to the data points. The resultant submodal split relationship can be expressed by
>
> $$y = \frac{100}{1 + e^{-0.3X}} \tag{48}$$
>
> where X is the equivalent time saving via rail (equivalence factor—weighting factor for out of vehicle time—of 2.5) and y is the percent using rail. Weighting each data point by the number of observations, the R^2 of the curve is 0.886. This R^2 value is computed by comparing predicted and actual percent submodal split on an interchange basis.

The aggregate "conventional" modal-split models familiar to us from the UTP process are excellently summarized by Fertal et al. (19) and Weiner (80). These models, whether or not they are post- or pre-distribution, fit the dependent variable (e.g., percentage of transit use) to some function of a set of variables describing the choice environment. The fitting is usually either eyeball smoothing of curves to plotted data (26) or linear regression fitting, necessitating the additional assumption that the effects of the independent variables on modal-split fractions in a linear regression equation are additive (20).

S-shaped hand-fitted modal-split curves often bear some resemblance to ogives (e.g., cumulative normal or logit curves), and the possible translation in concept to a probability model (e.g., logit) is clear. The linear regression equation can also be interpreted as a linear approximation to an ogive as long as it is appropriately bounded such that the dependent share, or probability of choice, is allowed only to vary between 0 and 1 (where probability is defined as the limit of the ratio of the number of outcomes of a given choice to all possible choices in a large number of trials, i.e., observations on individuals, in which the attributes of the choice situation are held constant).

Pratt (56) proposed a binary aggregate primary modal-choice model that was applied in Minneapolis-St. Paul (67). A disutility function is postulated for each modal alternative that transforms time, convenience, and dollar cost into a common unit of equivalent time (i.e., disutility). The differential weighting of various components of travel time was frequently used previously in coding transfer links in network analysis by Alan M. Voorhees and Associates (78) and probably by other organizations. Table 1 (67) gives the procedure. The weighting factors are drawn from a variety of previous modal-split and value-of-time studies. The disutility difference between automobile and transit is calculated for each interzonal pair, and the percentage of trips (between zones) using one mode, plotted as a function of this disutility, is assumed to follow the cumulative normal (probit) probability distribution. The resultant predictive curve is said to have its point of inflection at 50 percent probability on the y axis and zero-measured disutility difference on the x axis. This assumes, of course, that the choices are completely described by the disutility measures.

The problem with the model (i.e., the published versions) is that its analytic development appears to have stopped with the earlier Pratt and Deen (55) work. That is, the later work represents a conceptual, but not an analytic, translation in the concept of ogive resembling aggregate modal-split curves (26) to a probability model. Unfortunately, once the translation is made in concept, no effort is made to use the properties of the asserted normally distributed probability behavior in the calibration of a (probit) mathematical model, that is, a model with analytically estimated parameters (including a constant term that includes the effects of the left-out choice attributes) and significance tests on the variables and so on. The model continues to resemble the older hand-fitted diversion curves, but has the additional assumptions of additive and constant marginal rates of substitution of times and costs making up modal disutility.

Table 1. Variables and weighting factors in Twin-Cities marginal utility modal-choice model.

Variable	Symbol	Factor
Walk time to and from transit	T_a	2.5
Wait time for transit	T_w	2.5
Transit running time	T_r	1.0
Transit fare	F	1.0
Automobile terminal time	A_t	2.5
Automobile running time	A_r	1.0
Parking cost	P	0.5
Highway distance	D	4.0, 5.7[a]
Marginal utility[b]	U	—
Cost of time[c]	C	—

[a]Cost-per-mile factors rather than weights. For trips attracted to CBD, 5.7 cents/mile was used; for other trips, 4.0 cents/mile was used.
[b]Computation equation for marginal utility of automobile over transit for non-CBD trips: $U = 2.5(T_a + T_w - A_t) + (T_r - A_r) + (F - 0.5p - 4.0D)/C$.
[c]Computed as 25 percent of income: {[Annual income (cents/year)]/[(2,080 hours/year)(60 min/hour)]} x 0.25 = C.

Traffic Assignment

The first application of a multiple-choice share model in travel forecasting (aside from the gravity model, 77) appears to be by Traffic Research Corporation in route choice (traffic assignment). This route-choice model (29) was developed and applied in Toronto in the late 1950s.

$$(AF)_i = \frac{\left(\frac{1}{T_i}\right)^a}{\sum\limits_i \left(\frac{1}{T_i}\right)^a} \tag{49}$$

where

AF_i = proportion of interzonal trips by mode assigned to route i, and
T_i = interzonal travel time on route i.

Time, T, only is used as the measure of route impedence (cost). The formula is in the form of Eq. 6, where the "assignment factor" for route i (AF_i) equals P_i in Eq. 6, and $h(Z_{ki}) = T_i^a$. The subscript k is dropped in Eq. 49 because there is only one (highway) mode being considered. T_i is the route (path) travel time for the i th route from the network. The parameter, α, was held constant over all paths. In effect, this is an "abstract-route" model, consistent with Eq. 39, where α_{ki} varies over modes k, and system variables (costs) i, both of which (k and i) equal 1 in this case. The value of the parameter was not mathematically fitted, but was selected on the basis of a reasonably proportional assignment to paths with Traffic Research Corporation's multipath capacity-restrained iterative assignment technique (29). Rapid settlement of volumes over (equilibration) iterations through trip generation, distribution, and so on was another fitting criterion.

The direct traffic-estimation method (64) is also a probability formulation. That is, the probability of a vehicle on a link finding a destination in the valid domain or set of destinations defined by the tree on which the link is located is inversely proportional to the further travel time (or impedance) to that destination. The derivation is similar to the previous gravity model derivation (Eqs. 8, 9, and 10). The resulting probability of accepting any destination, or destinations within a particular valid domain, is its fraction of the total domain integral. The domain integral, I_D, is defined as

$$I_D = \int_D F dV \tag{50}$$

where

I_D = domain integral;
F = some impedance function, e.g., $F = e^{-kt}$, where k = constant and t = travel time; and
V = set of destinations clustered around a point at which the function F has a definite value.

The probability of having a destination in a subregion R within the valid domain, n (e.g., north of the point on the link), is

$$P\text{ (destination in R)} = \frac{I_R}{I_n} \tag{51}$$

Only destinations within the valid domain have nonzero probabilities of being accepted, and the probabilities of accepting all destinations in the valid domain sum to one.

The probability expression, Eq. 51, is in the form of Eq. 6. The direct assignment technique calculates the appropriate domains for each point on each link of interest on the basis of shortest time (impedance) paths on the network and assigns traffic to links on the basis of Eq. 51 corrected for normalization and symmetry conditions. The direct traffic-estimation method uses practically the same inputs as conventional UTP models, namely, trip ends, an impedance function, and coded networks. It is advantageous in assigning travel to individual links. However, the method assumes complete symmetry in destination volumes and link and path loadings throughout the system, and capacity-constrained loadings are unavailable (22).

Dial (13) has developed a probabilistic multipath traffic-assignment model that uses Eq. 7 to calculate the probability of paths between origins and destinations. The model makes use of a 2-pass procedure that generates all "efficient" paths between origins and destinations and loads them simultaneously. Incremental loading in a capacity-restrained mode is allowed. Efficient paths are generally those that allow the traveler to make apparent progress toward his destination at every branch point (on the network). That is, that reduce the impedance between the traveler and his final destination.

The parallel with the Luce choice axiom is clear. Backtracking on the network in order to "come out ahead" is not ordinarily allowed. Such backtracking can be considered equivalent to decisions that are really "two or more intermediate decisions." These violate the necessary separability assumptions in the independence axiom because such decisions are not simple substitutes for other alternatives at that branch point (node). Such backtracking alternatives must somehow be combined in order that all relevant alternatives may be considered as substitutes for one another with nonzero probabilities of being chosen.

Dial's method appears to be completely general in the sense that any utility function may be used to calculate the probability of using any path (Eq. 7).

The model is a Markov model. At each node, the fraction (probability) of trips assigned to each alternate link (on an efficient path) is calculated based on the path impedance and the number of efficient paths through the link. The separability property of the multinomial formula (Eq. 6) is used (assumed) at every branch point. The use of Dial's method to apply multinomial, multivariate logit models to calculate the probability of any path through complete travel decision trees (e.g., Fig. 2) appears to have considerable promise. That is, the method could be used (applied as described earlier) to calculate the (path) probability of any (relevant) alternative combination of frequency, destination, mode, time of day, and route (having a nonzero probability of choice).

TRAVEL DEMAND FORECASTING: ACHIEVEMENTS AND PROBLEMS

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This paper represents a personal account of some British and European achievements in travel demand forecasting during the past 10 years in the context of a discussion of ongoing issues. The account is likely to be substantially incomplete, especially in relation to continental European countries because of language and information-availability difficulties. It should also be noted at the outset that the emphases and the judgments about the importance of innovations and of the ongoing issues are personal. Some of the bias will result, again, from lack of information rather than the making of explicit judgments.

The paper is structured into 9 sections that describe the organizational content, with emphasis on features peculiar to the British side of the Atlantic; the main innovations in summary and in more detail, but still only in outline, under the fairly traditional headings of trip generation, distribution, modal split and generalized cost, assignment, urban activity models, and transport and related models; and ongoing issues in research and development.

BRITISH AND EUROPEAN EXPERIENCE: ORGANIZATIONAL CONTENT

The first major transportation studies in Britain were launched in the early 1960s. The first one, the London Study, was authorized in 1960, and the actual survey was carried out in 1962. There were 3 phases of analysis and planning associated with this study (1, 2, 3, 4, 5), and phase 3 reports were published in 1969. Since then, the Greater London Council (GLC) has embarked on a new transportation study, for which the survey was carried out in 1971-72. This brief history of the London developments shows 2 things: that the traditional survey and analysis methods have proved time-consuming, but that, nonetheless, at least in the largest city, model-based transportation planning has taken its place as an ongoing continual activity.

A whole series of conurbation transportation studies was launched and completed during the 1960s. They were usually carried out by consortia of local authorities and partly financed by the Ministry of Transport. In turn, there were studies of the West Midlands (7), Merseyside (8), South East Lancashire and North East Cheshire (9, 10), West Yorkshire (11), Teeside (12), and Glasgow (13). There was considerable development in both objectives and methods between earlier and later studies (or between earlier and later phases in the case of London). In the early days, the models were the American models, usually applied by American consultants. Later, as we shall see in the next section, the objectives were amended to take more account of public transport and to allow for the availability of stronger land use planning controls in Britain. There were corresponding developments in the models; modal split was taken more seriously, and the corresponding submodel was made more sensitive.

During this period, and especially toward its end, more and more local authorities carried out their own model-based transportation studies, some using consultants, some relying on their own staff. It is estimated that more than 60 such studies have now been carried out in Britain.

As noted, this effort built on American experience. However, work at the scale described above has generated much expertise within Britain.

The major local authorities usually have their own staff for continuing studies; the GLC is the most striking example of this. Some continuing work is still being carried out by consortia of local authorities, as in the South East Lancashire and North East Cheshire (SELNEC) region, centered on Manchester. Considerable expertise has been built up in central government also, in both Ministry of Transport headquarters, Department of Environment, and the Transport and Road Research Laboratory. Yet more work is carried out in universities, mostly in departments of transport studies (which are usually associated with civil engineering departments).

The work described so far is in almost all cases specifically concerned with transport (except that in some of the larger studies the transport impacts of alternative land use plans were also examined). In the middle-to-late 1960s and the early 1970s, there have been attempts to integrate this activity with the broader aspects of urban and regional planning. An early straw in the wind was the publication in 1963 of the Buchanan report (77), which spelled out the physical consequences of serving the motor car. In 1968, a new planning act required local authorities to produce new kinds of plans—a structure plan for the broader strategic scale, limited to district and local plans, the latter often for shorter action. Structure plans have much more stringent analytical requirements (14), and urban and regional activity and land use models, in addition to the transport model, can be a considerable help in this context. In parallel with this legislative activity, many planners had begun to use urban activity and land use models following the publication of Lowry's Model of Metropolis in 1964 (17). As Goldner (18) pointed out in a recent paper, more development effort was put into models of this type in the United Kingdom than in the United States. This kind of model-building effort has proceeded on a broad front in Britain and has been reviewed by several authors (19, 20, 21). These urban modeling techniques were used by a number of authorities in a structure planning context.

In 1965, the Regional Economic Planning Councils were created (10 in all), and their staffs have produced plans that have a broad content (i.e., not restricted to economics), have often used models, and usually include sections on regional transport needs (22, 23). Other important studies, which because of the demands of structure planning cross local authority boundaries, have been carried out on a subregional planning basis (24, 25, 26, 27). Further, local government reorganization will begin to take effect from April 1974. The new authorities will be of subregional size, and a further impetus for model-based integrated urban-transport planning can be expected at that time.

It is also perhaps worth mentioning that a number of ad hoc studies utilizing transport models have led to important central government reports. Though their subject matter is not strictly urban, they have considerable urban impacts. In 1966 the Ministry of Transport published a paper (28) on the modeling of flows of goods to ports, and in 1969 the ministry published a green paper (29) on national road planning, particularly with respect to the motorway system, which was also model-based. Another ad hoc model-using study was that of the Roskill Commission (30) on the location of the third London airport. All this again reflects the building up of in-house expertise in government.

For continental Europe, it is much more difficult to give a systematic account. Many cities have carried out transportation studies, some using American or British consultants, some using indigenous ones (such as Seiler and Barbe in Zurich).

MAIN INNOVATIONS: INTRODUCTION AND SUMMARY

The main innovations are summarized here; the typical U.S. model of the early 1960s is taken as a starting point. The types of innovation that have been forced by differences between American and European cities are outlined, a number of important theoretical innovations are noted, and some new ways in which the models have been used in a planning context are noted.

When the various studies were initiated, British and European cities were less highway-car dominated than American cities. This has led to a greater concern with the analysis of modal split and with the explorations of a greater range of public transport options. Car ownership, however, has been and still is increasing rapidly, and this has led to another kind of peculiarly European problem: serious highway congestion and a road-building budget that, from the earliest times, was less able to cope with demands than in the corresponding American situation. This has colored the British view of assignment within the model as well as generated, from another aspect, the need to look at broader sets of public transport plans. This leads to attempts to formulate "balanced" transport plans. Also, at least in Britain, physical planning controls are potentially stronger than in the United States, and that has reinforced the desire to integrate transport planning with the broader aspects of urban planning and to integrate urban models and transport models. The British experience in this field has not been quite so unhappy as some American experiences (31), possibly because of lower expectations.

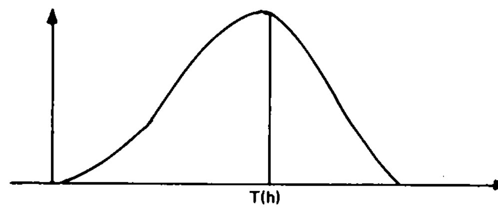
A range of notable theoretical innovations is described below in relation to different model components. For the trip generation submodel, there has been the development of category analysis; for distribution and modal split, there have been the development of entropy-maximizing methods, a set of theorems on balancing factors and connections to mathematical programming, the development of the concept of generalized cost, some innovations with model calibration, and some developments on aggregation issues. These last-named developments could lead to further significant steps forward. Assignment models have been developed to take more account of congestion (and there has been a greater tendency to iterate the full model in conjunction with this) and also to cope effectively with public transport. More generally, there have been interesting work on continuous variable models and a lot of work on urban activity and land use models. The category-analysis form of trip generation has facilitated the connection of these to the transport model. With the transport model as a whole, there has been an emphasis on seeking quick ways of running the model.

In the way the models have been used, there have been attempts to improve evaluation theory and associated techniques such as cost-benefit analysis. This has been associated with attempts to use the model to evaluate a more extensive range of alternative plans. More recently, there have been attempts to examine transportation impacts on particular groups of people and to use the model system to evaluate what now often seem to be more feasible plans that are concerned with traffic management, parking control, pricing, precincts, bus priorities, and so on rather than the building of new facilities.

It is difficult, for the reasons mentioned earlier, to discuss fully other European innovations. Metra/SEMA, for example, developed a different kind of distribution model, which was used in Lisbon and other cities. Much of this work has been reviewed more broadly elsewhere (32, 33, 34). A general description of some Swedish work is given in the report by Bexelius, Nimmerfjord, Nordquist, and Read (35). Other Swedes have produced interesting entropy-maximizing work (36, 37). A different approach altogether to entropy maximizing has been used in Belgium (38). There are French models based on analyses of motivation (39). These innovations are discussed in following sections.

TRIP GENERATION

The basic ideas of category analysis were first reported by Wootton and Pick in 1967 (142) and have been used in many studies since, including London, West Midlands, and SELNEC. The main idea is a simple one: Households are divided into h, and T(h) is defined as the mean number of trips of the same purpose for this category. Suppose the actual frequency distribution of trips for households in this category is as shown in the sketch. Then, the art of category analysis is to define the categories such that the distributions are all as narrow as possible. It is then assumed that T(h) is relatively stable over time, and the forecasting burden becomes that of predicting $a_i(h)$, the number of households of type h in zone i.



The trip generation equation itself can be obtained as follows. We are usually interested in person trips by type n (say car owner/non-car owner). Let H(n) be the set of households containing persons of type n. Then,

$$O_i^n = \sum_{h \epsilon H^{(n)}} a_i(h)T(h) \tag{1}$$

is the number of trip productions in zone i by persons of type n.

Wootton and Pick used 108 categories made up of 3 car-ownership levels, 6 income levels, and 6 types of household structure (defined in relation to both size and number of workers); many other teams in Britain have used the same categories because they relate well to British census data (40). Thus, if h is the set (n, I, p), where n, I, and p are indexes related to car ownership (n = 0, 1, 2, or more), income group, (I = 1, ..., 6), and household structure (p = 1, ..., 6), then (dropping the zone subscript for the present),

$$a(h) = a(n, I, p) = Hf(p) \int_{a_I}^{a_{I+1}} P(n|x)\phi(x)dx \tag{2}$$

where H is the total number of households, f(p) is the probability of household structure p, (a_I, a_{I+1}) are the limits of the Ith income group, x is income, $P(n|x)$ is the conditional probability of being in the nth car-ownership group given income x, and $\phi(x)$ is the probability of having income x.

Distributions are postulated for f(p), $P(n|x)$, and $\phi(x)$, and then parameters are estimated from current data. Then, forecasts can be made by predicting new means (usually the new mean income distribution suffices) and the new distribution of population, H. Typically, $\phi(x)$ is taken as a gamma distribution, $P(n|x)$ as another form of gamma distribution, and f(p) as a product of distribution relating to mean household size and mean number of workers, which are taken as binomial and Poisson respectively.

Trip attractions can be dealt with by a similar procedure. Wootton and Pick classified urban activities into 8 categories (7 are aggregates of SIC categories, and 1 is population). Then, if $t(\ell)$ is the rate at which trips are attracted to category ℓ, trip attractions D_j are given by

$$D_j = \sum_{\ell} b_j(\ell)\, t(\ell) \tag{3}$$

where $b_j(\ell)$ is the number of units (usually employment) of ℓ activity in zone j. $b_j(\ell)$ can be obtained directly from the census on corresponding (possibly model-based) forecasting procedures. There is no complicated procedure in this case for postulating individual distribution functions to be combined to make up the same cross classification.

It may well be that category analysis does not have any fundamental theoretical advantage over multiple regression analysis (and, indeed, it has been agreed that category analysis is equivalent to regression analysis with dummy variables, 41, 42), but there are considerable practical advantages. The problem of multicollinearity among independent variables is less overt, if not nonexistent. (The corresponding disadvantage is that, unless the dummy variable regression form can be used, there is no correponding measure of error.)

A second advantage relates to the way in which trip-rate variables are separated from variables representing the distribution of population and economic-activity variables by category. This facilitates separate research work on each and the connection of the transport model to urban-activity models. Further, the method of multiplying together calibrated single-variable or conditional distributions to obtain joint-probability distributions is almost certainly a method that will have to be commonly used to overcome data deficiencies, particularly when large surveys cannot be attempted.

A third advantage is that, because the categories used tend to be common among several studies, interurban comparisons are possible, and results from a large survey in one study area can be used to "support" another study area with a small or nonexistent survey.

Experience with the model in Britain has suggested that the results are encouraging. If there is any doubt, it is in the calculation of trip attractions rather than trip productions, and some interesting work is being carried out on trip attraction by special facilities (44, 45, 46).

DISTRIBUTION, MODAL SPLIT, AND GENERALIZED COST

This bundle of topics can be treated together because in summation they form a unified model. We begin, however, by discussing the distribution model alone. Typically, the model has been used as a doubly constrained model:

$$T_{ij} = A_i B_j O_i D_j f(c_{ij}) \tag{4}$$

where T_{ij} is the number of trips from i to j for some purpose, c_{ij} is interzonal trip cost (or time or distance), f is some decreasing function, O_i is trip production in i, D_j is trip attraction in j, and A_i and B_j are the so-called balancing factors calculated to ensure that

$$\sum_j T_{ij} = O_i \tag{5}$$

$$\sum_i T_{ij} = D_j \tag{6}$$

That is,

$$A_i = 1 \Big/ \sum_j B_j D_j f(c_{ij}) \tag{7}$$

$$B_j = 1 \Big/ \sum_i A_i O_i f(c_{ij}) \tag{8}$$

Equations 7 and 8 are solved iteratively.

This model is usually viewed as a gravity model based on the hypotheses

$$\left.\begin{array}{l} T_{ij} \propto O_i \\ T_{ij} \propto D_j \\ T_{ij} \propto f(c_{ij}) \end{array}\right\} \tag{9}$$

with A_i and B_j added to achieve internal consistency. O_i and D_j are interpreted as "masses," and a Newtonian-law-of-gravity analogy is invoked.

Entropy-Maximizing Method

The entropy-maximizing method changes the basis of the analogy. Essentially, it is a statistical average of the behavior of individuals making trips (47). The entropy of a distribution is defined as

$$S = \frac{T!}{\prod_{ij} T_{ij}!} \tag{10}$$

where T is the total number of trips, and if S is maximized subject to Eqs. 5 and 6 and a constraint on total travel cost

$$\sum_i \sum_j T_{ij} c_{ij} = C \tag{11}$$

then we get

$$T_{ij} = A_i B_j O_i D_j e^{-\beta c_{ij}} \tag{12}$$

with

$$A_i = 1 \Big/ \sum_j B_j D_j e^{-\beta c_{ij}} \tag{13}$$

and

$$B_j = 1 \Big/ \sum_i A_i O_i e^{-\beta c_{ij}} \tag{14}$$

This is the gravity model mentioned earlier with $e^{-\beta c_{ij}}$ replacing $f(c_{ij})$. However, even this is not too restrictive; for example, replacing c_{ij} by log c_{ij} transforms $e^{-\beta c_{ij}}$ into $c_{ij}^{-\beta}$.

The entropy-maximizing method can be viewed in at least 4 ways (44, 45, 46).

1. S can be interpreted as the probability that the distribution T_{ij} will occur, and so the model maximizes probability subject to known constraining information. This makes entropy maximizing a useful theoretical tool because a basic research task is to improve the constraining information, and that leads to new models.

2. T_{ij}/T can be taken as p_{ij}, the probability that an individual is assigned to the (i-j) state, and then S can be identified with the information-theory measure of entropy,

$$S = -\sum_i \sum_j p_{ij} \log p_{ij} \tag{15}$$

and the procedure then produces a best estimate, again constrained by known information. Jaynes (48) has developed this argument in relation to the use of entropy in statistical mechanics, and Tribus (49), among others, has developed it more generally.

3. S in Eq. 15 can be identified with the negative of the log-likelihood function for a statistical analysis of our problem. Thus, when we choose the form of the probability function that maximizes entropy, we minimize the likelihood function. This is another way of stating that the probability distribution that maximizes entropy makes the weakest assumption consistent with what is known.

4. If we take S in Eq. 10 as $W\{T_{ij}\}$, the probability that T_{ij} occurs, then an alternative to maximizing probability is to average, to find $\overline{T_{ij}}$ as

$$\overline{T_{ij}} = \frac{\sum W\{T_{ij}\} \cdot T_{ij}}{\sum W\{T_{ij}\}} \tag{16}$$

The mathematical procedure for making the calculation is the Darwin-Fowler method, and, again, the same answer is obtained.

These 4 views of entropy maximizing are, of course, all mutually consistent. It is nice to consider them as a statistical averaging procedure for the population making trips for a particular purpose, for that does preserve the connection with individuals and, as we shall see later, helps with a discussion of aggregation issues.

Perhaps the most important advantage of the entropy-maximizing method is that it generates models that are internally consistent with respect to the constraining information so that, as long as that is consistent, the model is consistent. It facilitates model building in a wide variety of situations. In the transport field, it facilitated the construction of a model that recognized differential availability of modes among person types (in particular, car owner/non-car owner). This led to a model of the form

$$T_{ij}^{*n} = A_i^n B_j O_i^n D_j e^{-\beta^n c_{ij}^n} \tag{17}$$

$$\frac{T_{ij}^{kn}}{T_{ij}^{*n}} = \frac{e^{-\lambda^n c_{ij}^k}}{\sum_{k \epsilon \gamma(n)} e^{-\lambda^n c_{ij}^k}} \tag{18}$$

T_{ij}^{kn} is the number of trips from zone i to zone j by persons of type n by mode k; the asterisk denotes summation over the index it replaces; $\gamma(n)$ is the subset of modes available to persons of type n. Note also that in this model trip productions were characterized by person type while trip attractions were not, which seems realistic. A_i^n and B_j are sets of balancing factors that ensure

$$\sum_j T_{ij}^{*n} = O_i^n \tag{19}$$

$$\sum_i \sum_n T_{ij}^{*n} = D_j \tag{20}$$

so that

$$A_i^n = 1 \Big/ \sum_j B_j D_j e^{-\beta^n c_{ij}^n} \tag{21}$$

and

$$B_j = 1 \Big/ \sum_i \sum_n A_i^n O_i^n e^{-\beta^n c_{ij}^n} \tag{22}$$

c_{ij}^n is interpreted as a composite of modal-interchange costs, c_{ij}^k, which represents the i-j impedance as perceived by type n people. The suggested aggregation is

$$e^{-\beta^n c_{ij}^n} = \sum_{k \epsilon \gamma(n)} e^{-\beta^n c_{ij}^n} \tag{23}$$

We shall later see that this is a first-principles method for producing an internally consistent model, which is one of the set defined by Manheim (50). Other aggregation methods are possible, however (47). β^n and λ^n are parameters that relate to the average behavior of type n people with respect to trip length and sensitivity to modal costs respectively. This was essentially the form of model used in the SELNEC study (51). The model was found to fit reasonably well and to be policy sensitive.

Generalized Cost

It is useful to digress at this point to the concept of generalized cost by mode, c_{ij}^k, which has been implicitly introduced above. British work in the development of this concept was initiated in the work of Quarmby (52) reported in 1967. It is of interest that the modal-split function in Eq. 18 turns up in a variety of approaches to modal split, including the discriminant-analysis approach of Quarmby. In effect, he took c_{ij}^k as a discriminant function and estimated the weights of the components of his linear function, which gave maximum discrimination. This work can be connected to other work on the value of time (55), which usually expresses value of time as a proportion of income. The way in which such concepts have been used in British studies is again illustrated by the SELNEC study. The initial weights used were essentially Quarmby's, but adjusted slightly as part of the model-calibration procedure. The model, for example, predicts car-owner/non-car-owner mix at destination zones, and terminal costs were adjusted to get this as nearly correct as possible. Further calibration adjustments produced one particularly interesting result: Different weightings were appropriate for the distribution and modal-choice parts of the model. These can be written $c_{ij}^k(d)$—which is then used in Eq. 23 to give c_{ij}^n—and $c_{ij}^k(m)$ respectively. The forms used were

$$c_{ij}^k(d) = a_1 t_{ij}^k + a_2 e_{ij}^k + a_3 d_{ij}^k \tag{24}$$

and

$$c_{ij}^k(m) = a_1 t_{ij}^k + a_2 e_{ij}^k + a_3 d_{ij}^k + p_j^k + \delta^k \tag{25}$$

The detailed definition and results are given in the paper already cited (51); t_{ij}^k is travel time, e_{ij}^k is excess time, and d_{ij}^k is distance, used for estimating operating costs. p_j^k is the terminal cost, essentially car-parking time and cost, and δ^k is a term used to represent "intrinsic" preference for car. Thus, the result mentioned earlier was that parking costs, p_j^k, and the public transport handicap, δ^k, were not relevant in distribution to the decision as to where to go, but were relevant in modal choice. The model as a whole was appropriately sensitive, but it is interesting to recall that, when Eq. 23 was used with travel time only, the fit was bad, but, when used with generalized cost, it was quite good.

Intervening-Opportunities Model

It is perhaps worth mentioning briefly that the entropy-maximizing method offers an interesting insight into the intervening-opportunities model (47), which seems to have been relatively little used in Britain. This model can be derived if the following assumption is made: Intervening opportunities between i and j provide a proxy for travel cost, but are counted again each time an opportunity is passed. That is, if $j_\mu(i)$ is the nth zone in rank order away from i and $D_{j_\mu(i)}$ is the number of opportunities at $j_\mu(i)$, then the "equivalent" cost function is

$$c_{ij_\mu(i)} = (\mu - 1)\, D_{j_1(i)} + (\mu - 2)\, D_{j_2(i)} + D_{j_{\mu-1}(i)} \tag{26}$$

and this seems a rather odd function.

Balancing Factors and Connection to Transportation Problem of Linear Programming

Particular attention has been paid in Britain to the properties of the balancing factors, A_i, B_j (in Eqs. 4, 7, and 8, say). Murchland (57) used a maximization foundation of the problem, following Samuelson (58), and some theorems in mathematical programming to establish the uniqueness and existence of the balancing factors. Evans (59) has shown that the iteration procedure that is usually used to calculate A_i and B_j does indeed converge to the desired unique solution. An interesting corollary of his analysis is that, if a matrix F_{ij} is being adjusted by balancing factors A_iB_j to give

$$\hat{F}_{ij} = A_iB_jF_{ij} \tag{27}$$

such that, say,

$$\sum_j \hat{F}_{ij} = O_i \tag{28}$$

and

$$\sum_i \hat{F}_{ij} = D_j \tag{29}$$

then, if F_{ij} is replaced by any matrix of the form $a_ib_jF_{ij}$ (i.e., with multiplicative terms with i-dependence and j-dependence only) and the new matrix is balanced in relation to constraints in Eqs. 28 and 29 to give $\hat{\hat{F}}_{ij}$, $\hat{\hat{F}}_{ij} = \hat{F}_{ij}$. Thus, if we are balancing to given trip end totals, only terms in the model that depend on i and j simultaneously will affect the answer!

It is interesting also to note that these kinds of matrix-adjustment procedures are used in some methods of estimating input-output matrices (60), and similar theorems to those of Evans have been proved in this context, independently, by Bacharach (61), who reported that Denning and Stephan (62) made the first investigation of biproportional matrices. He calls F_{ij} proportional matrices.

More recently, Evans (63) has proved formally a result that has been believed at the level of conjecture for some time. In a model of the form given by Eqs. 12, 13, and 14, for example, as $\beta \rightarrow \infty$, T_{ij} tends to the solution of the corresponding linear programming problem.

Model Calibration

One of the inherent problems in trip-distribution models of the doubly constrained type is that they can eat up computer time because of the iterative calibration for A_i and B_j. Two pieces of work can be mentioned that attempt to alleviate this problem. Kirby (64) has defined an approximate noniterative formula for the balancing factors, and in the calibration procedures for the SELNEC model (65), which involve a large number of runs of the model, one doubly constrained run was carried out, and the value of B_jD_j thus obtained substituted for D_j in singly (noniterative) constrained runs for other parameter values. Final results are checked with other doubly constrained runs.

This is a convenient point to mention other recent work on calibration methods. Hyman (66) has explored distribution-model calibration by constructing an evidence test (based on Bayes' theorem), which also connects closely, as might be expected, to the entropy-maximizing view of the model, and he gives an iterative method for parameter estimation that has since been used by other authors. One consequence of this analysis is that, if a power function is used as an impedance function instead of the experimental function, then the mean of log c_{ij} is the best goodness-of-fit statistic for β rather than the mean of c_{ij}. Hyman's method and other search methods of calibration have been tested by Batty and associates (67, 68, 69). The mathematical processes involved have been further explored by Evans (70), and the statistical processes by Kirby (71).

Continuous-Variable Models

Another theoretical task in the development of distribution and modal-split models that may prove useful in the longer run is the development of continuous-variable models, mainly represented in Britain by the work of Angel and Hyman. Their work will be mentioned only briefly here, and the reader is referred to the original papers for the details.

There are 2 ways in which we might seek to introduce continuous variables into the distribution model: First, take a subscript, such as the type of person index n in Eq. 17, and make a continuous variable such as income or, second, make the spatial variables continuous. The introduction of a continuous-income variable was explored by Hyman (72). One possible development of such models is to try to introduce a hypothesized, known income distribution explicitly into the model so that the parameters of such a distribution become part of the set of parameters of the trip-distribution model. Continuous spatial variables were first used by Angel and Hyman (73) in their analysis of urban velocity fields and associated geodesics—minimum time paths in these fields. They then formulated a continuous distribution model and calibrated it by using SELNEC data (74). It is interesting to note that "assignment" in such a model is the calculation of flow densities along geodesics. The network is not, of course, explicitly represented.

Aggregation, Utility, Elastic Trip Generation, Dynamics, and Other Current Issues

The model whose principal equations are Eqs. 17 and 18 can be taken as a reasonable example of the current state of the art in Britain. The equations are repeated here for convenience.

$$T_{ij}^{*n} = A_i^n B_j O_i^n D_j e^{-\beta^n C_{ij}^n} \tag{17}$$

$$\frac{T_{ij}^{kn}}{T_{ij}^{*n}} = \frac{C^{-\lambda^n c_{ij}^k}}{\sum\limits_{k \in \gamma(n)} e^{-\lambda^n c_{ij}^k}} \tag{18}$$

A_i^n and B_j are balancing factors calculated in the usual way. O_i^n and D_j are obtained from category analysis. C_{ij}^n is related to c_{ij}^k by an equation of the form of Eq. 23, and c_{ij}^k is given by equations of the form of Eqs. 24 and 25 for use in the distribution and modal-split equations respectively. Such a model was used in the most recently published report of the SELNEC study (9).

A number of criticisms can be made of models of this form: They are insufficiently connected to, and perhaps even inconsistent with, microeconomic theory; trip generation is inelastic; it does not respond to accessibility levels; the model is essentially static; and so on. As a response to these criticisms, a number of new approaches have been suggested from both sides of the Atlantic. In this section, we attempt to confront the criticisms of the model in its present form and to compare the resulting suggestions with those made by others. The argument presented summarizes one that is given in more detail in another paper (75).

It is essential to begin with a discussion of the aggregation problems involved in proceeding from a microtheory of individual or household travel demand to a model of aggregate travel demand between zones. An adequate connection between the models at the (useful) level of aggregation we use and microeconomic models can only be made if this problem is solved.

In such a discussion, we must first characterize transport as a good. Usually, we can speak of quantity x_i of good i purchased at price p_i. But for transport, 2 variables are needed to describe quantity: frequency of trips in the same time period and length of trip (perhaps measured as expenditure). Then, for an individual resident r in zone i, say, we can describe his trip-making at different levels of aggregation as follows:

1. Amount of travel consumed $\quad C_i^r, O_i^r$
2. Distribution among trip purposes $\quad C_i^{pr}, O_i^{pr}$

3. Distribution among destinations for each purpose c_{ij}^{pr}, T_{ij}^{pr}

4. Distribution among modes c_{ij}^{pkr}, T_{ij}^{pkr}

C_i^r and O_i^r represent total expenditure on travel and number of trips made. C_i^{pr} and O_i^{pr} are similar quantities split by purpose. T_{ij}^{pr} is O_i^{pr} split by destination, and c_{ij}^{pr}—in accord with our usual convention—is the cost of a single trip from i to j. When these quantities are split by mode, they become c_{ij}^{pkr} and T_{ij}^{pkr} for mode k. These variables provide descriptions of the individual's travel behavior at the 4 levels shown.

The usual entropy-maximizing model is obtained by aggregating individuals r into groups of type n, denoted by $r \epsilon R(n)$, say, and assuming that

$$\sum_i \sum_{r \epsilon R(n)} C_i^{pr}$$

and

$$\sum_{r \epsilon R(n)} O_i^{pr}$$

are given. We usually also assume that totals of trip destinations, D_j, are given.

The usual utility-maximizing model is obtained by taking variables at level 4 for individual r and finding their values by maximizing his individual utility function, probably subject to a budget constraint (76). The problem is then the usual one of how to obtain aggregate demand. For a population with arbitrary utility functions, aggregation is virtually impossible. Beckmann and Golob have indicated the range-of-utility function that makes aggregation feasible (76). There is a further difficulty: At level 4, each utility function is a function of a large number of variables. The suggestion made is that it may be much more reasonable to define individual utility function at a higher aggregation level for the individual, say, level 2, and then, having determined values of C_i^{pr} and O_i^{pr} and aggregated these over r, to use something like an entropy-maximizing method to obtain T_{ij}^{pkn} for persons of type n. The paper cited earlier (75) outlines a model based on such a scheme. At first sight, this may simply appear to defend the status quo for the entropy maximizer, but in fact a number of radical changes are suggested for the model given by Eqs. 17 and 18. They are summarized below; full details are available in the paper cited earlier (75).

1. In the aggregation scheme, we never wish to aggregate to groups larger than individuals within a zone and then to assume that we can have a model to estimate C_i^{pn} and O_i^{pn} for a person of type n. This means that the distribution-model parameter β^n should be replaced by β_i^n and calculated for each zone i.

2. C_i^{pn} can be modeled in the same way as O_i^{pn}. We have suggested that, ideally, a full economic model could be developed. However, in the way in which various techniques that are familiar to us are used to estimate O_i^{pn}, similar techniques could be used to estimate C_i^{pn}, for example, category analysis. If this is done, then β_i^n (or β_i^{pn} if we distinguish purpose explicitly) ceases to be a parameters; it is directly calculable as a function of C_i^{pn}. Further, we have now shifted the problem of predicting the change in β_i^{pn} over time to that of predicting C_i^{pn}, which task, although hard, is more feasible.

3. In aggregating to the resident's zones only, we no longer feel it necessary to use fixed-attraction constraints unless capacity constraints are definitely known to exist. Otherwise, attractiveness factors should be used, as in the shopping model (78).

4. In such a scheme, there is no reason why O_i^{pn} should not be a function of accessibility and the availability of opportunities. Thus, it seems that the best way to introduce elastic trip generation is to seek to make the estimating equation for O_i^{pn}—whether regression analysis or category analysis—elastic. The variation of C_i^{pn} over time, and the corresponding variation in β_i^{pn}, could be said to produce an elastic trip-length model.

5. One of the weakest parts of the entropy-maximizing derivation of Eqs. 17 and 18 has been that which produces the modal split. In the new scheme, this derivation is

improved. Alternatively, it could be replaced by a utility-maximizing derivation of a "market-share" type.

6. If C_i^{pn}, c_{ij}^k, and O_i^{pn} can be modeled as functions of variables whose time behavior can be predicted, then we have the basis for a fully dynamic model.

The model that results from applying these recommendations can be summarized as follows (75):

1. Calculate the spatial distribution of activities that generate transport flows, capacity constraints at destination trip ends, and modal and person-perceived interzonal travel costs. All these quantities are inputs to the travel demand forecasting model, but some of them, such as the interzonal costs, can only be finally obtained within an iterative scheme that involves running the travel model with preliminary estimates of their values.
2. Calculate C_i^{pn} and O_i^{pn} as functions of the variables listed above.
3. Divide destination zones into sets Z_1 and Z_2, where Z_1 is the set of zones in which destination capacity constraints "bite," and Z_2 is the set in which they do not. [This technique of building a hybrid model by dividing zones into sets of different characteristics was first introduced in a residential location context by Wilson (79).] Then, for trips from i to j by person of type n for person p,

$$T_{ij}^{pn} = A_i^{pn} B_j^p O_i^{pn} D_j^p e^{-\beta_i^{pn} c_{ij}^{pn}} \tag{30}$$

for $j \epsilon Z_1$ and

$$T_{ij}^{pn} = A_i^{pn} O_i^{pn} X_j^p e^{-\beta_i^{pn} c_{ij}^{pn}} \tag{31}$$

for $j \epsilon Z_2$, where D_j^p is the destination capacity, and X_j^p is the destination attractiveness when a constraint is inoperative. (The makeup of the sets Z_1 and Z_2 can only be discovered after a preliminary run through the model.) The balancing factors A_i^{pn} and B_j^p are determined in the usual way (though the resulting equations are slightly unusual because of the sets Z_1 and Z_2), and β_i^{pn} is directly calculable from C_i^{pn}.
4. Modal split is given by

$$M_{ij}^{pkn} = \frac{e^{-\lambda_i^{pn} c_{ij}^k}}{\sum_{k \epsilon \gamma(n)} e^{-\lambda_i^{pn} c_{ij}^k}} \tag{32}$$

so that

$$T_{ij}^{pkn} = M_{ij}^{pkn} T_{ij}^{pn} \tag{33}$$

λ_i^{pn} may well be taken as independent of i.
5. Assignment can then take place in the usual way as part of an outer interative loop.

It is argued, then, that the revised model presented here represents a framework within which many of the outstanding problems in travel demand forecasting can be solved. The research needed to implement such a scheme is clear from the above description, and much of it can be carried out with data and methods that are already available or well known.

We can now explore how this approach relates to others that have been suggested, beginning with utility-maximizing approaches. It should be clear that a utility-maximizing approach can only be adopted if the aggregation problem is solved. It will not do to call the entropy function utility. [Beckmann and Golob (76) come quite close to this at times, but do also attack the more general problem that was first explored by Neidercorn and Bechdolt (80).] What has been suggested here is that there is an aggregation level at which economic theory and utility maximizing should be helpful (and best) and another, finer level at which entropy maximizing remains the most useful procedure.

Another new approach is represented by Manheim's class of general share models (50). We need only remark here that the model presented above is one such model. Manheim's approach is an alternative to entropy maximizing for the task of producing internally consistent models. The proposals in this paper attempt to add a certain amount of flesh to the bones.

One word of caution should be added about another alternative approach, entropy-maximizing models based on a certain kind of market share variable (81), that uses

$$x_{ij} = T_{ij}\, c_{ij} \tag{34}$$

or

$$x_{ij} = \frac{T_{ij}\, c_{ij}}{C} \tag{35}$$

where C is total expenditure. It is argued in an appendix to the earlier paper (75) that there are fundamental reasons why such models are unrealistic.

The whole range of alternative models is reviewed by Brand (82). It is a useful exercise to relate the conclusions of this paper to the issues raised by Brand in relation to the general classes of models that he discusses.

The classifications of models used in Brand's paper are based on his interpretation of the assumptions that are made about an individual traveler's choice within different kinds of models. Thus, the traditional model, in the sequence of trip generation, distribution, modal split, and assignment, connects to notions of the traveler making a sequence of choices about frequency, destination, mode, and route. Such models are called indirect demand models in contrast to direct demand models, which connect to multiple and simultaneous choice notions. The rather loose words "connect to" have been used above because the nature of the connections cannot be made clear unless the aggregation problem (how to get from a micromodel of individual choice behavior to an aggregative model) is solved for the particular models under discussion.

There is one general issue that is useful to tackle at the outset: Some aggregative models (which are used and are useful) do not necessarily imply the microassumptions that have been assigned to them by commentators. Thus, the traditional model does not necessarily imply a certain sequence of decisions on the part of the individual traveler, but only a certain conceptualization of the model-building process that leads to some final model that then stands or falls on its own. Further, it is often considered a difficulty in such models that "late-stage" information, e.g., on link flows and speeds, is needed at an earlier stage and that, therefore, an iterative solution to the model equations is the only possible one. There is sometimes a confusion between this kind of iteration or a mathematical technique for solving equations (which is all it is in this case) and microinterpretations of what the model represents.

In summary, then, 2 main issues run through Brand's review: multiple choice (direct demand) versus sequential choice, with or without iteration (indirect demand), on the one hand and degree of disaggregation with respect to individuals on the other.

It is clearly useful (and has been attempted in a different way in the main discussion of this subsection) to investigate the nature of rational choice at an individual level, and Brand's discussion of such topics as rational choice behavior and utility maximization is most useful. However, again, care must be taken because it is possible for microassumptions to be unnecessarily and even unreasonably attached to aggregative models that are then criticized because of these assumptions. There is little doubt that large-scale empirical investigation (if this were possible) of individual behavior would reveal behavior that could be explained by using either decision theory or utility theory. The likeliest outcome of such research, however, would be that the population as a whole exhibited a wide variety of choice mechanisms or a wide variety of utility functions. It could then be argued that a procedure such as entropy maximizing could be taken as a statistical average across this wide variety of individual behavior. Further, the aggregation explorations in the main part of this paper simply examine alternative levels of resolution (83) at which different kinds of analysis can be carried out, e.g., the $\{O_i^{pn}, C_i^{pn}\}$ level for utility maximizing and the $\{T_{ij}^{pkn}\}$ level for entropy maximizing. It does not make any assumption about choice-ordering on the part of the individual traveler.

Thus, the main point to be made here is that, although it is most interesting to explore the possibility of building new models by finding ways of aggregating alternative micromodels of choice behavior or utility maximization, other aggregative models should not necessarily be criticized for microassumptions that their builders do not subscribe to! Further, because of the difficulties of solving the aggregation problem (84), we should note that the models that can be built are likely to have very restrictive assumptions built into them that certainly do not reflect the hybrid-varied nature of the real-world situation.

It seems that many of the criticisms of the traditional model are, in effect, directed at the BPR form of the model, largely because of (a) its internal inconsistency and (b) its inadequate connection with microtheory. What we have tried to show in this section is that a model of this type can be made internally consistent and is compatible with a wider range of microassumptions than most alternative models. By making an appropriate judgment about the level of resolution at which to apply microeconomic theory, the model can be extended and the advantages of a utility-maximizing model of transport consumption incorporated.

This is a convenient place to raise 2 additional points that arise in relation to topics discussed in Brand's paper. First, one of the elements of choice is the time of day at which the trip is made. Although this has not been modeled explicitly in British studies, it is perhaps worth commenting that it has been more often the case in British studies that peak-hour trips have been modeled explicitly rather than 24-hour trips. The second and final point is a somewhat disconnected one and relates to the work of Lancaster (85). Brand points out how this work has been used, for example, by Quandt and Baumol (141) and by Blackburn (87) to produce certain kinds of direct demand models. Mathur (88) and Allen (89) have also discussed the possibility of applying Lancaster's theory to spatial interaction models in the context of Neidercorn and Bechdolt's work. In Britain, Lancaster's ideas have been used in a different way by Evans (90) to investigate the time constraints that relate the consumption of different bundles of characterization and, hence, to say something about the value of time that results from the relaxation of these constraints. This has an obvious relevance to issues of importance in transport studies. Following Evans, this author has explored other ideas, particularly the notion of opportunity gaps. An alternative and interesting approach to time-constraint problems is through-time budget analysis, following partly from Swedish work, and investigated in Britain by groups in London and Cambridge, the latter using entropy-maximizing methods (92, 93, 94).

ASSIGNMENT

It is clear from the length of the preceding discussion that distribution and modal split are considered in this paper to be at the heart of the travel demand forecasting process. Assignment is seen then as having 2 main roles: First, network loadings are useful for engineering purposes; second, the assignment procedure must constrain interzonal travel costs to be related to link loadings and link travel times. There is always the problem that this can only be accomplished in an outer iterative loop in the model because c_{ij} is needed in the distribution and modal-split model, which must precede assignment. This outer iteration is now an accepted part of most British assignment procedures, for example, in London and SELNEC. In essence, this balancing of travel cost against link loads is the so-called capacity-restraint procedure. A variety of such procedures have been used in British studies.

A particular problem mentioned earlier that has occurred in the British context is that no amount of capacity-restraining adjustment will remove link congestion. A special linear programming procedure was developed in phase 3 of the London Transportation Study (5, 143) to overcome this. The problem is that the method has no behavioral basis: What is really necessary is an elastic-trip-generation model.

Assignment takes place on separate modal networks, and most experience, of course, is with highway networks. One British contribution to the public transport side is the Freeman, Fox, Wilbur Smith TRANSITNET assignment program, which calculates minimum paths for a network on which public transport routes and service levels are specified (144). Another approach to assignment by a team at the Transport and Road Research Laboratory has relevance to this (and other) problems. Wigan and Bamford use an iterative perturbation method for assignment to congested and overloaded networks, and the same model has also been used to study the impact of road pricing schemes (95, 96).

Finally, a theoretical comment: It is tempting as computer capacity expands to think of assigning on multimodal networks—in effect, possibly directly to routes on an abstract modal basis. It has been shown that, except under rather special conditions, such a procedure would lead to a model that has unrealistic features: That is, inconsistencies arise because the axiom of independence of irrelevant alternatives (as discussed by Brand) is not satisfied. This is another example of a class of mathematical aggregation problems (47, 84).

Finally, we note that relatively little empirical work has been carried out on route choice, though there is one recent European contribution (97).

URBAN-ACTIVITY MODELS

Predictions of travel demand using the kinds of models that have been discussed can only be as good as the inputs to those models. In particular, travel demand in a city region is a function of the spatial distribution and intensities of population and organizational activities. Predictions of such quantities are, of course, needed for general planning purposes that extend far beyond transport planning. If such predictions are to be at least informed by models, if not completely made by models, then at least the following models are required: demographic models for the study area as a whole and probably operating for a multiregion system; economic models for the study area as a whole; models of the location of population activities—residential and workplace location and the utilization of a whole range of services; and models of the location of economic activities. Travel demand models can then be connected to such a model system. The future pattern of travel demand will be determined more by the spatial distribution and intensity of these activities, and associated parameters such as car ownership and overall income levels, than by specifically transport-system parameters.

Because each of the urban subsystems interacts more or less with one another, this model set should be combined into a general urban model in which these interactions, and the relative time rates in which the different processes involved take place, are explicit. First, however, we comment on British and European work on each of the 4 models listed above and then discuss the task of building a general model. So as not to overload the paper (for this section could be much larger than the rest of the paper put together), the discussion will be inadequately brief, but reference will be made to other review papers and to the appropriate literature where particular innovations are cited.

Demographic Models

The population forecasts associated with transportation studies are usually particularly simple (98), perhaps dangerously so. The set of models developed by Rogers (99, 100) can be used for this purpose, but there has been some reluctance to do so in Britain, possibly because it is relatively difficult to match the data requirements of the model. Recent work in Leeds (101, 102) has aimed at simultaneously improving the model's base and confronting the data problems, and the results appear to be very promising.

Economic Models

More intensive theoretical work has been carried out on the task of building input-output models for urban areas, but again the difficulty is one of finding data that will enable an input-output table to be constructed. Thus, effort has been concentrated on a small number of studies for which such data are directly collected (103, 104) and a larger number (105) that attempt to construct small area tables from national tables plus, say, local row and column information.

It is appropriate under this heading to add a note on car ownership, which is likely to be very much a function of the level of economic development. Much work has been carried out on building submodels of this (106, 107), and this determines the population in the main subdivisions of person types required for the transport model. The next stage of this kind of work is to estimate the car availability for different types of people, but relatively little progress has been made with this as yet (108).

Population-Location Models

Considerable progress has been made on both sides of the Atlantic with models of the utilization of the more obvious services, such as retail services (109, 110). The use of such models is relatively commonplace, and little more need be said [though there are needs for obvious refinements such as making the models mode sensitive (111)].

A much more complicated problem is that of building models of residential and workplace choice. The traditional models are simple gravity models. These have been extensively used, but, although they can give some useful guidance (79, 112), they obviously underrepresent the richness of the real-world situation—different types of people who have different incomes and jobs and live in different types of housing that vary in price. Models are now being built that attempt to reflect this richness (113, 114, 115) and there is some indication of success. As with transport models themselves, this particular model-building problem can be tackled from the viewpoint of microeconomic theory, and, although relatively little operational work in this field has been achieved on the British side of the Atlantic, more can be expected in the future. Some attempts have been made, which again give indications of success, to integrate the 2 styles of approach (117, 118, 119, 120).

Economic-Activity-Location Models

It has proved even more difficult to build models of economic-activity location. This can also be seen as a 2-stage operation: first, to model the distribution of economic activities by sector and, second, to collect where necessary what may be called the population-perceived distributions of housing, jobs, and services. One of the main reasons why these sectors have proved more difficult to model is that a relatively small number of decision-makers (relative, say, to the population as a whole vis-à-vis population activities) may be involved in the determination of a spatial pattern, especially when government is involved. In the latter case especially, this can be a saving grace for the modeler because he can take a range of possible decisions as input to other (e.g., population activity) submodels rather than model them directly. The relatively modest achievements in this field will, in fact, be reported in the next section because they were made in a "general" model context.

General Models

Perhaps the most obvious way to build a general model is to take the best available submodels from the wide range of work described above, to investigate the submodel interactions in some detail, and then to build the appropriate general model. However, this is harder then it sounds, if only because the best submodel work probably involves people whose main expertise is in relation to the corresponding subsystem, and it is difficult to assemble the best subsystem expertise plus corresponding general model-building expertise in one team. At present, however, some progress has been made theoretically with this strategy (121).

It is more tempting for people who wish to build a general model to start from some such existing model and to try to apply and to improve it. In Britain, the favorite starting point has been the Lowry model. Much interesting work has been carried out in this way, and the results are well documented (18, 21, 122, 123, 124, 125). Of course, the point could be reached, and perhaps has been reached, where the final improved model looks very unlike the original. Another approach has been to use econometric models based on EMPIRIC (121, 126, 127), and it is in this context that some models of the location of economic activities have been developed. It is particularly important to build explicitly dynamic models, and a start has been made on this (128, 129, 130).

USE OF TRAVEL DEMAND FORECASTING MODELS

It has been argued, in more or less similar terms by several authors (19), that planning processes contain 3 kinds of activity concerned with analysis (understanding, tracing impacts, problem diagnosis), design (generation of alternative plans in relation to the full range of possible policy instruments, including land use and spatial organization), and policy (methods and criteria for choice among alternatives). Travel demand and associated models offer different kinds of aid to these different aspects of planning processes. This is not the place to spell them out in detail or to give case histories, but a number of general comments are appropriate.

Perhaps the most important development in the past 20 years has been our changing view of the transport problem. In the beginning, the transport planner's task was conceived of as building highway facilities that would carry the traffic loads generated at saturation car-ownership levels 20 or 30 years hence. Now, and especially in a European context, we see that such simple objectives are not compatible with the structure of our cities, or we cannot afford the facilities—they are simply infeasible. So we now look at many modes, at impacts on different groups of people in different parts of the city (because we are more socially conscious), and at several time horizons (short, medium, and long term); and then we try to set the plans in the context of the structure of the city as a whole (19). In Alexander's (131) terms, we are becoming more fully self-conscious with respect to all aspects of our planning options.

In Britain, some progress has been made along this line: The full variety of modes is now taken seriously in the model; a greater range of network alternatives is examined; some disaggregation has been achieved in the evaluation indicators, whether in a cost-benefit analysis framework or structure; some progress has been made in testing the transport impacts of alternative land use plans. These trends have affected the travel demand models in the manner described in earlier sections, and they raise ongoing issues to be discussed in the next one.

ONGOING ISSUES IN RESEARCH AND DEVELOPMENT

Comments about ongoing issues can be made in relation to 3 statements:

1. In relation to the travel demand model itself, we must be getting very near to the point of diminishing returns in attempting to improve the model as we know it (though we should leave open the possibility of new kinds of models emerging).

2. The main variables that determine the changing patterns of transport demand, and the associated planning problems, probably mostly lie outside the travel demand model—in particular, economic development and car ownership, population growth, and urban spatial organization. Thus, the travel demand model should be connected to a more general urban model.

3. The model system that is developed must be able to play its part in a responsive, adaptive overall planning system. There will be new issues and problems to be faced on a continuing basis.

The consequences of these statements are explored in turn.

Travel Demand Model

For given inputs, the travel demand forecasting model as we know it is a reasonably good tool. It is unlikely that a refined assignment technique, for example, will fundamentally change its character and its present degree of fit. However, in terms of possible future research projects, a number of points can be made.

1. A formal "drawing-together" operation may be useful, repeated every 5 to 10 years, to make the "best possible" model—or more realistically a range of such models—generally available.
2. A modest program of funded research on the model as we know it will remain worthwhile (earlier sections raise a number of good research problems).
3. It will always be worthwhile to investigate new kinds of models, such as utility-based models, general share models, and so on, though the practical need is not so great that more than modest funds should be associated with such projects. (Some of the problems in such fields involve fundamental theoretical problems of the mathematics of aggregation, which have not yet been fully understood as problems, and caution should be exercised before new approaches are accepted as much better than, or even very different from, older ones.)
4. Another modest research program that systematically compares different types of models, with respect to their prediction of elasticities, for example, might be useful.
5. It would be valuable, for reasons that have been partly discussed and that rise again below, to investigate ways of making the travel demand model quick and cheap to run, for example, by using census data so that special surveys are not required.

Connecting Travel Demand Model to General Urban Model

We argued in earlier sections that work on general model building continued in Britain long after it slowed down in the United States. The British work has been less ambitious, in the first instance, and so has generated fewer traumata than corresponding American work. It has been modestly useful to planners. In Britain, we are perhaps now poised to become significantly more ambitious and, in the end, to be correspondingly more useful to planners. The conclusion seems inescapable that there should be considerable research investment in this field, whether it be called research on general model building or, more simply, on urban structure and dynamics.

Response to New Planning Problems

Planning problems can arise at very general levels or in relation to very specific issues. At the general level, given the models discussed in the sections immediately above, we need an exploration of the range of possible futures as we could now visualize them. This is rarely, if ever, attempted in a whole system kind of way. We have to decide whether to go on accepting low densities and processes of decentralization or, if we find aspects of these that we dislike, whether there are feasible alternatives. We have to match an exploration of alternative future transport systems against broad investigations of that kind.

At more specialized levels, as we saw earlier, we have to confront new issues. We seem to be moving into an era, at least for British cities, in which large highway building programs are recognized as infeasible. The alternatives before us are more likely to be stated in terms of public transport options (in relation to urban structure and densities), pedestrianization of city centers, the scale of out-of-town shopping facilities, traffic management, road pricing, parking control and bus-priority schemes, new schemes of compensation for those affected by development, and so on.

Relatively little research has been carried out on the methods of generating alternatives for testing and optimizing the program of implementation (133, 134, 135, 136, 138, 145). The short-run objective is perhaps simply to ensure that a wide range of possible futures are explored. In the longer run, we should investigate ways of being more systematic (139, 140).

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GLOSSARY

activity system. All nontransportation aspects, including land use and socioeconomic variables, of an area that affect the demand and nonuser impacts of the available transportation alternatives.

aggregate demand model. Model obtained by combining travel observations for individuals into geographic zones. These combined observations are used to estimate new flows when service attributes or zone sizes change. (See also disaggregate demand model.)

alternative. For travel demand modeling purposes, a unique combination of number or frequency of trips, time of travel, mode of travel, trip destination, and travel route. Relevant alternatives for a given potential traveler are those combinations that have some positive probability of being chosen.

analytical structure. Form of the travel demand forecasting function, whether it be a closed mathematical expression or an algorithm.

assignment. Process by which trips described by mode, origin, destination, and time of day are distributed among the various available paths or routes in a network (q.v.) according to one of a number of flow distribution rules (q.v.).

attitudinal. Describing techniques for travel demand forecasting based on data collected from potential and actual travelers concerning their attitudes toward existing and proposed services rather than their behavior in response to these services. (See also behavioral.)

behavioral. Describing the way individuals and groups of individuals react when faced with a set of transportation alternatives. Behavioral modeling, which can be differentiated from attitudinal modeling (q.v.), has as its goal the representation of observed behavior patterns in a mathematical model in order to improve forecast accuracy.

binary choice model. Travel demand model that is based on the assumption that travelers always make 1 or 2 possible choices, e.g., no trip or 1 trip in trip-frequency models and by automobile or by transit in modal-split models. (See also multiple choice model.)

choice. Same as alternative (q.v.).

choice abstract. Assumption that it is not necessary to identify travel choice variables by the name of their mode, destination, time of day, or other characteristic but only by their attributes, e.g., level-of-service variables (q.v.). This assumption requires, for example, that out-of-pocket costs be evaluated similarly by toll road users and by commuter railroad users. (See also choice specific.)

choice specific. Assumption that it is necessary to identify travel choice variables by the name of their mode, destination, time of day, or other characteristic. This assumption may require, for example, that in a demand model travel time by automobile be evaluated differently from travel time by rail transit. (See also choice abstract.)

conditional probability. Probability of A, conditional on B, is the probability that A will occur when it is known that B occurs; normally expressed as $P(A|B)$.

consistency. Condition of sequential (q.v.) travel demand forecasting processes that state that the values of each level-of-service (q.v.) variable should be the same at each stage of the forecasting process.

cross section. Development of models based on data collected by observing a number of instances of a phenomenon at one point in time. (See time series.)

demand. Used in an economic sense and based on the theory and methodology of consumer demand, a schedule of the quantities of travel consumed at various levels of price or levels of service offered by the transportation system. Demand is not a fixed amount of travel, but a function of level of service. Nearly all urban travel forecasting methods are based on the concepts of travel demand and transportation facility supply interacting in a transportation network as the market to produce an equilibrium flow pattern.

destination. Location to which trips are made, variously identified as a zone of specified area (in aggregate travel forecasting) or a location with a specified "attraction power," measured by things such as employees (for work trips) or square feet of sales area (for shopping trips).

deterministic model. Model that provides the "best" estimate of a predicted event, e.g., in demand modeling the best estimate of number of travelers (in aggregate models, q.v.) or alternative selected (in disaggregate models, q.v.). (See also probabilistic model.)

direct demand model. Model that simultaneously (in a single equation) predicts all travel choices for aggregate groups of individuals.

disaggregate demand model. Model that is obtained by using the observations of the travel choice behavior of individuals directly for model calibration and that is usually probabilistic. (See also aggregate demand model.)

distribution. Process by which trips defined by origin are distributed among the various available destinations. Common trip distribution models are the gravity model and the opportunity model.

equilibrium. Condition, which is assumed to exist in the actual transportation system, in which the volume of transportation services supplied and the volume demanded are both equal and occur at equal levels of service. Because of the complexities of the problem with link supply functions, origin-destination demand functions, vector of level-of-service variables, and network of facilities, accurate modeling of the equilibrium condition is very difficult.

elasticity. Value that indicates the percentage change in demand that will result from a 1 percent change in any independent variable appearing in a travel demand model.

frequency. As a travel choice (q.v.) in disaggregate models, a measure of the number of trips made per specified time period and analogous to trip generation, an aggregate modeling term; as a characteristic of transportation facilities (usually for transit modes), an indicator of the number of departures per specified time period and usually directly related to waiting time.

flow distribution rule. Rules used to determine the assignment (q.v.) of trips to routes or paths. Some common rules are (a) travelers use a minimum time or generalized "cost" path; (b) travelers use each available path according to a path choice function based on relative times or generalized costs (proportional assignment); (c) travelers use only the path that has minimum time or generalized cost based on initial time or cost estimates (all-or-nothing assignment); and (d) travelers use the paths that will minimize total system time or generalized cost.

forecasting systems. Sets of computer programs that incorporate all models necessary to forecast travel flows on a network. Existing systems are those developed and maintained by the Federal Highway Administration and the Urban Mass Transportation Administration and are based on the following components of a sequential, aggregate, deterministic (q.v.) forecasting process: generation (q.v.), distribution (q.v.), modal split (q.v.), and assignment (q.v.).

generation. Step in the sequential, aggregate forecasting process in which trips defined by origin or destination (but not both) are predicted based on the characteristics of the activity system and, in some applications, some measure of transportation service to or from the zone. The output of generation is a 1-dimensional array of trips into or out of a zone for input to trip distribution (q.v.) models.

general share model. General structural framework for aggregate demand forecasting models (q.v.) that can be expressed in either a simultaneous or a sequential (q.v.) form. This implies that existing aggregate models have equivalent simultaneous or sequential forms and that the form used for model calibration need not be the only form used for model predictions.

joint probability. Joint probability of A and B is the probability that both A and B will occur; normally expressed as P(A, B).

level of service. Multidimensional characteristics of the transportation service provided that are usually identified specifically by the location of the origin and destination of trip and that are divided into those that are quantifiable (travel time, travel cost, number of transfers) and those that are difficult to quantify (comfort, modal image).

logit model. Analytical form for demand modeling that is suited to modeling of multiple travel choice situations.

long-run demand. Forecast of how transportation system changes affect the redistribution of the location of urban activity. (See also short-run demand.)

low-capital alternatives. Transportation alternatives that can be implemented relatively rapidly at low initial or capital costs, e.g., changes in operating policies (fares, frequencies, traffic signal systems, and bus routes) and changes in regulations (automobile-exclusion areas, parking time limits, reserved bus lanes). Low-capital alternatives have often been neglected in the past in favor of alternatives involving investments in major new fixed facilities (expressways and rapid transit lines).

marginal probability. Total probability that A will occur, regardless of what else occurs. The marginal probability that A occurs is P(A) = P(A, B) + P(A, C) if the possible events (where B and C are mutually exclusive events) are A occurs and B occurs (A, B), A occurs and C occurs (A, C), A does not occur and B occurs (not A, B), and A does not occur and C occurs (not A, C).

market research. Methods of behavioral analysis that were originally developed and applied in the fields of advertising and marketing and that can be used to identify the service attributes (q.v.) that most strongly influence travel decisions.

market segment. Segment of the population that has similar socioeconomic and other transportation-related characteristics and potentially similar travel behavior. For example, an important market segment might be all households in an area that do not have automobiles available during the daytime and whose annual incomes are in the range of $9,000 to $12,000.

modal split. Process of forecasting how many travelers will use each of the available or proposed transportation modes. Normally, modal-split models are either pre- or post-distributional models, depending on whether they are applied to total trips from an origin or total trips between an origin and destination.

multiple choice model. Model that relaxes the assumption of only 2 possible choices and allows any number of possible choices, which can be within a given type or level of travel choice, such as mode, route, or time period, or be between any or all of these trip characteristics. (See also binary choice model.)

network. Set of nodes and connecting links that represent transportation facilities in an area. Normally associated with links are modal names, distances, levels of service, capacities, and level-of-service and volume relations.

new options. Transportation alternatives that involve the use of new technology (tracked air-cushion vehicles, automated guideways), new operating policies (time-of-day fare differentials on transit), new regulations (vehicle exclusion zones, bus priority lanes), or new institutional arrangements (incorporation of taxi service into public transit authorities).

pivot-point procedures. Travel demand forecasting procedures that simplify the prediction of changes from a known or previously predicted flow pattern because of changes in the transportation or activity system or both. Various approximations and assumptions underlie the simplifications made in the equilibration process, for example, the use of constant elasticities (q.v.). (See also sensitivity analyses.)

probabilistic model. Model that provides the probability of a predicted event, e.g., in disaggregate demand models, the probability of the selection of an alternative. (See also deterministic model.)

sensitivity analysis. Process of determining the relative sensitivity of demand model forecasts to the assumptions about the levels of independent variables, such as future-year population by income group or future-year transportation system characteristics, and about the values of model parameters. Relative sensitivities help to indicate the policy implications of changes in values of independent variables and the criticality of the various assumptions underlying a study.

sequential model. Demand model based on the assumption that the traveler makes travel decisions in a sequence of steps such as the following sequence, which underlies the UMTS (q.v.): whether or how often to travel (trip generation, q.v.), what destination to choose (trip distribution, q.v.), what mode to choose (modal split, q.v.), and what route to choose (traffic assignment, q.v.). (See also simultaneous model.)

service attributes. Aspects of a transportation alternative that affect travel decisions concerning the use of the alternative. The set of all relevant service attributes for a given alternative is termed the level-of-service (q.v.) vector for the alternative.

share model. Any travel demand forecasting model that divides a trip-making total (such as total trips from an origin) into its various components (such as trips from the origin to each of the destinations). Share models can be used in both the aggregate and disaggregate modeling of each step of the forecasting process (generation-frequency, time-of-day choice, distribution-destination choice, modal split-modal choice, assignment-path choice).

short-run demand. Forecasting that assumes a fixed set of locations of urban activities on which (conditional) travel forecasts are based. (See also long-run demand.)

simultaneous model. Demand forecasting model based on the assumption that travelers choose a level of trip frequency, time of day, destination, mode, and path as a single "joint" choice and consider in making that choice the alternatives for each of these choices simultaneously. (See also sequential model.)

sketch planning. Transportation analysis procedures that are simpler, faster, and cheaper than using forecasting systems in their entirety and that typically require less input detail and provide fewer output measures with more variability.

structure. (See analytical structure.)

subarea, subregion. Normally, an analysis area that is significantly smaller than the usual metropolitan region and is important because many alternatives influence only subareas.

time series. Development of models based on data collected by observing the same phenomenon at a number of points in time. (See cross section.)

transportation disadvantaged. People whose range of transportation alternatives is limited, especially in the availability of relatively easy-to-use and inexpensive alternatives for trip-making.

transportation system. All aspects of the available or proposed transportation alternatives that affect the demand, profitability, and nonuser impacts of these services and that can be classified as technology, network, link, and operating policy variables.

utility. As used in economics, characteristic of any good or service that makes it desirable to the potential consumer and, therefore, a general quantity that must incorporate in a positive way quality and other user benefits and in a negative way all prices and costs. Travel demand can be forecast as a function of utility based on travel behavior.

UTMS. Urban transportation modeling system, a set of sequential, aggregate travel forecasting models and procedures developed since the 1950s and used in every major metropolitan area of the United States and in many foreign cities. The goal of the research plan described in this reports is to provide improvements to the UTMS.

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