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Modelling Travel Demand: A Disaggregate Behavioral Approach Issues and Applications

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I. INTRODUCTION

THE PROBLEMS OF PLANNING and decision-making in transportation have been increasing in the recent past because of the now recognized need to understand the effects of decisions and policies on the use of transportation facilities. This has become important largely because of the recent rapid increase in the numbers of opportunities and demands for investment in transportation systems. With new system possibilities and increasing demands for mobility, the desires for spending money on transportation systems have far outrun our ability to pay for them. Thus, the decisions regarding where to make investments in transportation have become much more important, and questions of justifying given transportation investments have become much more critical.

The decision process can be assisted considerably by mathematical models which are able to predict the probable effects of various policy and plan alternatives on the users of the transportation system. The models which can serve this purpose are ones that address the problem of estimating demand for travel in response to different sets of characteristics defining the travel environment. To be responsive to full range of investment problems, such travel demand models must encompass all the situations where investment decisions are made. In particular, they must cover all travel modes, both long and short range planning, and small as well as large investments.

The travel demand models that are presently available have largely been developed for application at the level of the total urban area. These models have numerous problems associated with them, most particularly that they can generally be applied only at the urban area level. They are not suitable for use in small-scale planning decision processes, nor can they be readily extended to the broader questions of interurban and national transportation planning. Another major problem exists in that these models have been developed, to a large extent, in a highway planning context. Even so, they have many shortcomings for the tasks of highway planning while, for mass transport planning, they are generally quite unresponsive and inappropriate at any level. Clearly, then, there is a need for the development of models of travel demand which can be applied at various levels of detail and have equal application to highway and mass transport planning.

This paper proposes a modelling strategy that will yield a set of models

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intended to fill the need identified in the preceding paragraphs. This strategy is able to be applied at all levels of detail of planning decisions and has no bias toward any specific part of the transportation system. In addition, it can solve a number of other problems that have tended to be associated with the present urban transportation planning models. The modelling strategy will be developed initially using the same framework as that of the conventional urban transportation planning models. This is appropriate since this framework has not been found to be deficient. Rather, the shortcomings and problems of the conventional models have arisen from some of the assumptions made and methods used to build these models.

In presenting the proposed modelling approach, this paper is concerned firstly with describing the existing urban transportation planning models, and with identifying the problems and shortcomings which arise in using them. The strategy of the modeling approach is then described and its specific potentials are discussed. Finally, the application of the strategy is illustrated in the specific context of mode choice in urban transportation. In this last section, considerable attention is paid to the versatility of the approach in answering questions at different levels of planning and decision-making.

II. THE URBAN TRANSPORTATION PLANNING MODELS: DESCRIPTION AND SHORTCOMINGS

The Model Set

The estimation of travel demand, as it is customarily done in the metropolitan transportation planning process, involves four steps: trip generation, trip distribution, mode split, and trip assignment. Trip generation models estimate the total numbers of trips starting from and terminating in given areas. Trip distribution models allocate these trips between specific origin-destination pairs of areas. Mode split models allocate the trips among travel modes, and trip assignment models assign trips to specific travel routes.

These models, which are collectively called the Urban Transportation Planning (U.T.P.) Package, are used in one of two possible rigid sequences. The first sequence is trip generation, mode split, trip distribution, and trip assignment. The second sequence is trip generation, trip distribution, mode split, and trip assignment. These two sequences have associated with them two types of mode split models. The first sequence has a model which is termed a trip-end model. A trip-end model uses socio-economic characteristics and, sometimes, a general accessibility index to the region as a whole, to explain choice of mode. The second sequence has a mode split model which is called a trip-interchange model. A trip-interchange model also uses socio-economic characteristics to explain choice of mode. In contrast to trip-end models, however, it uses accessibility measures between specific zonal pairs (1).

In applying these models in sequence, some recycling of the models is possible. The final distribution of traffic on the transportation networks for each mode will affect travel times and costs used in trip distribution and modal split. However, no effects can be observed on trip generation since this model is formulated independently from the transportation system. Using new estimates of costs and times, derived from the first assignment of traffic to the networks, derived trip distribution and modal split estimates can be obtained and a new assignment made of traffic to the networks. This recycling can be continued until, hopefully, some satisfactory convergence has occurred in the estimates, and travel times and costs have stabilized.

Chronologically, trip-end mode split models were developed in the earliest transportation studies, where the principal concern was the prediction of and planning for highway transportation. Later, as it began to be recognized that mass transport plays an important role in urban movement, trip-interchange models began to appear. The change occurred because trip-interchange models are sensitive to characteristics of the transportation system and because the trip-interchange sequence appears to be more realistic. However, despite these changes, the U.T.P. process has remained very highway-oriented and is generally not very appropriate for detailed mass transport planning.

Shortcomings

The U.T.P. pacakge, described above, is based on a series of assumptions about travel demand and the ways in which to model it. In order to be able to more easily identify the shortcomings of the package, the principal assumptions made need to be stated. These are:

1. It is assumed that travel is demanded, not for itself, but to enable other activities to be undertaken. Travel demand is therefore a derived demand and must be modelled as such. Conventional travel demand models incorporate this fact by stratifying trips by purpose.
2. It is assumed that the complex decision process of travel demand can be validly and conveniently considered to be made up of four identifiable decisions which interact mutually. These decisions are: the decision to make a trip; the choice of destination; the choice of mode of travel; and the choice of route. These decisions are currently modelled by the procedures of trip generation, trip distribution, modal split and network assignment, respectively.
3. It is assumed that the models can be built by considering travel and socio-economic characteristics at a spatially aggregated level. Customarily, an area is divided into spatial units, called zones, and these units have associated with them various aggregated measures built up from measures of the people within those units.
4. It is assumed that associations between intensity of travel and aggregate socio-economic characterics form a valid basis for the prediction of future travel demand, given forecasts of future levels of the socio-economic characteristics.

The standard U.T.P. package has a number of serious shortcomings, which arise in part from the last two assumptions and in part from the actual execution of certain modelling stages. Present experience indicates that both the first and second assumptions are completely valid. However, the second assumption gives rise to problems because of the inadequacy of the interactions between the present models. The separate models have largely been developed and refined in isolation from each other. As a result of this, they are based on dissimilar techniques and rationales, and a vehicle for interaction, in the form of a series of common variables, is largely lacking, or has occurred only fortuitously. This is a particular problem in the execution of trip generation modelling where it is assumed that the generation of trips is independent of the supply of transportation. This leads to serious deficiencies in the modelling process and in the interactions between models. Clearly, no interactions are possible between changes in transportation system characteristics and trip generation. Thus, the process acts as though there is a given total level of demand, irrespective of the transportation system. This also precludes the estimation of induced travel, caused by the building of a new transportation link. The first major shortcoming is, in summary, the general inefficiency, and often total lack, of interactions between the models.

The third and fourth assumptions, which relate to modelling at an aggregate level, are made for some very important reasons but also bring with them some serious problems. In transportation studies, sample data are gathered which are expanded to represent the entire population. Because the expanded data are an aggregation, this necessitates the use of aggregate models. In addition, to handle the entire data for an urban area at a disaggregate level would involve an inordinate expenditure on analysis and forecasting. Consequently, aggregation is necessary for analysis purposes.

However, several problems arise from aggregation as a result of the assumptions implicit in the application of aggregate models in a zone framework for travel demand. These are:

(i) that the zone sample mean is representative of the households in a zone, and that the zone sample mean is a reliable estimate of the population mean;

(ii) that the zones are, to a large extent, homogeneous with respect to characteristics important in travel demand; and

(iii) that valid travel demand relationships can be developed on the basis of zonal aggregates of household trip-making and characteristics.

Investigations (2) of these basic hypotheses have yielded some indications of the following nature:

(a) Zone sampling distributions are skewed, not normal, indicating that zonal means are not the central values around which individual households are grouped. Thus, assumption (i) does not appear to be upheld in current U.T.P. modelling.

(b) The within-zone variances of parameters associated with travel demand are large in relation to between-zone variances. In other words, these parameters exhibit a high degree of heterogeneity within zones. Assumption (ii) is, therefore, also not upheld.

On the basis of these two findings, the third assumption implicit in the development of aggregate U.T.P. models appears to be placed in jeopardy. A further problem that arises in aggregation places even more doubt on that third assumption. This is the problem of "ecological correlation" (2,3). Social scientists have long been aware of the fact that an ecological fallacy arises from attempting to use aggregate data to build models of the behavior of individuals. This means that associations between aggregate variables tend to be misleading because they are so strong, statistically, that they mask the real behavioral associations. Unfortunately, the use of standard statistical modelling techniques, such as multiple regression, leads to models which standard statistical tests determine to be excellent descriptive or "explanatory" models. Descriptiveness is not, however, a sufficient criterion for determining good predictive models.

Since the travel demand process is the same at a regional and a subregional level, it would seem to be desirable to be able to apply the U.T.F. models at finer levels of aggregation than the zonal basis of most transportation studies. However, it can be demonstrated that, although aggregate models can generally be applied at grosser levels of aggregation than that used at calibration, application to finer levels of aggregation is not generally feasible. This severely restricts the usefulness of current models for small-scale planning applications and decision-making.

Finally, the present U.T.P. models must be re-calibrated, and sometimes re-formulated, for every new region to which they are applied. This arises from two processes in the model-building stages. Firstly, the underlying process is usually not well understood and simplifying assumptions are made concerning the mathematical form and variables to be included. This results in the inclusion of proxy variables of unknown make-up which have to be evaluated for each region where the models are applied. Secondly, further simplifications are frequently made in the variables to be used by omitting certain variables because they are inapplicable at a specific time to a particular region. It is not uncommon to find, in past U.T.P. analysis, that all transit patronage is assumed captive and no model is included to deal with competition between auto and transit.

In summary, we can say that the conventional travel demand models used in the U.T.P. process suffer from several important shortcomings. These include a lack of ability of the models to interact fully, model relationships based on ecological fallacy due to spatial aggregation, dubious validity for future predictions, and the lack of geographic transferability. In addition, the lack of flexibility for small-scale planning decisions produces serious restrictions on the use of the models outside the regional U.T.P. process. Because of these basic shortcomings, and a general dissatisfaction with the realism and accuracy of existing models, a number of attempts have been made to devise improved models or systems of models particularly for U.T.P. applications (4,5,6,7). This paper is concerned with formalizing one such approach and relating it to some specific planning problems to illustrate its potential usefulness.

III. A SOLUTION TO THE PROBLEM

Disaggregate Behavioral Models

The types of models proposed in this approach are disaggregate, stochastic models. They are stochastic in that they predict a probability of an individual making a specific choice. This probability is assigned on the basis of the consideration by the individual of the characteristics of the choice environment, modified by relevant characteristics of the individual. This modelling approach is most consistent with modern theories of human discrimination and choice. These theories state that, since there is a minimum variance in discrimination and there are dynamic changes in preference, every human decision is, in essence, probabilistic. In addition to providing a basis in behavior to the concept of stochastic, disaggregate models, these theories lead to two conclusions which are extremely important in formulating models of this type:

(a) that the number of variables required to predict probability of choice is finite and rapidly approaches the limit of human discrimination; and

(b) that as a set of alternative choices becomes equivalent in subjective characteristics, the probability of choice approaches a limit, 1/n, where n is the number of alternatives.

These two conclusions are important, since they assist in the model formulation process. Conclusion (a) makes it clear that disaggregate, stochastic models of this type can be formulated with a relatively small number of variables required to achieve good predictions. This is contrary to an initial intuitive reaction that such models might require a prohibitively large number of variables to describe human choice. Conclusion (b) effectively states that people do not have irrational or unquantifiable biases towards specific alternative choices. In the area of mode choice, for example, this conclusion is a justification for the "abstract mode" concept (5).

Placed in the context of travel demand, this approach effectively states that an individual will make the decisions or choices, implicit in making a trip to a specific destination by a specific mode and route, with a probability determined by trip considerations and his own scaling of the effectiveness of alternatives for that trip purpose. This approach has several advantages to offer which may be seen as correcting some of the shortcomings of the present U.T.P. package.

The first of these advantages is that these models have greater predictive validity than conventional models, since they are based on the behavior patterns of individuals rather than on statistically derived correlations in aggregate analysis. Furthermore, if the models are adequately designed, they need not be constrained to including variables which show significant associative relationships at a single point in time, but can be formulated to include all variables which describe the relevant environment for a specific decision. In other words, the inclusion of variables can be reasoned on the basis of specific theory instead of relying on the analysis of correlation alone.

A second advantage of this approach derives from the fact that the models are based on the smallest element of the population: the individual. This eliminates the problems of ecological fallacy, since the basis for modelling is total disaggregation. A third related advantage, stemming from the disaggregate approach, concerns the levels of aggregation for various planning and decision-making requirements. Since the proposed models are disaggregate, they may be applied aggregated to any required level. The process of aggregation need not necessarily be on a spatial basis, but may instead be based upon characteristics of individuals, the transportation system, and the activities. In this case, it should also be possible to determine the trade-off between predictive accuracy and the level of aggregation, particularly if the costs of various levels of error, or inaccuracy, are known. This may be done by determining the sensitivity of the model predictions to various sizes of "errors" in the parameters used in the model. This sensitivity then yields an estimate of the relative accuracy of a model where the population is aggregated into ranges of values of the parameters in the model.

A fourth advantage of stochastic, disaggregate models is that they provide a basis for inferring the values that people put on various characteristics of the transportation system. These values may be derived by examining the size of the effects of the given system characteristics on the travel choices made. The relative sizes of these effects indicate the differential values placed by individuals on each of the characteristics considered. More specifically, these differential values may be derived by selecting any one characteristic as a basis for comparison and expressing each of the other values relative to that one. Thus, if cost is one characteristic, all other characteristics may have their values expressed relative to cost, giving a monetary value to each characteristic. Similarly, travel time or any other variable may be used. It is important to note that the behavioral basis of the models requires by definition that the values obtained are behaviorally consistent. Also, because of the disaggregate nature of the modelling, the values will be susceptible to analysis in relation to the various socio-economic characteristics of the individuals. For these reasons, the models have a considerable potential for assisting in the evaluation process, over and above their direct application in travel prediction.

Finally, there is no reason to suppose that geographical biases exist in the basic individual decision-making process, (although ethnic differences, which can be handled by the models, might very possibly exist). Thus, a model which sets up the parameters which describe the decision-making process should be valid in any city, town, or region within a country and, therefore, represent a major improvement over existing models.

In summary, the stochastic, disaggregate approach appears to have the potential of overcoming each of the major shortcomings identified in conventional travel demand models. However, so far the approach has only been discussed in general terms, and no details of the operation of the approach have been given. The next section attempts to describe the modelling rationale in some detail.

Framework for Development of Stochastic, Disaggregate Models

The initial framework within which these models are formulated is that of a U.T.P. package. More specifically, a model set is proposed which can address the whole problem of travel demand estimation, covering all of the four decision processes identified in conventional U.T.P. travel demand modelling. In the conventional U.T.P. package, the stratification of the travel demand process into four separate models is not successful because of the inadequacy of the between-model interactions. However, there are a number of clear advantages to be gained from building models of these four separate stages of the travel demand process.[1] Among these advantages are:

1 It should not be concluded that there is no place for considering models which combine some, or all, of these separate processes. As understanding of the total travel demand process increases, particularly from modelling in this four-model framework, it should become possible to build composite models covering more than one stratum of the total decision process.

(i) the travel demand process is extremely complex and, as a whole, presents the model-builder with some very difficult problems to resolve. The stratification of the process leads to a much simpler treatment and a greater opportunity to develop meaningful and useful models than modelling the process without stratification.

(ii) the resulting models have greater adaptability to specific problems, particularly in sub-regional analysis and planning. For instance, the journey to work may be considered to comprise mode and route choices only, the generation and distribution decisions being made outside the travel decision itself. Analysis can then be concentrated on the pertinent models of mode choice and route choice.

The modelling process described in this paper is, therfore, set in the framework of a stratified modelling strategy, in which the conventional division of the travel demand process is adopted. Thus, the basic framework comprises four models: trip generation, trip distribution, mode choice, and route choice. In order to simulate the simultaneity of these four decisions, considerable attention is paid to interaction and interdependency among the models. To facilitate interactions, it is expected that each model would contain similar variables from the same generic sets. To allow interdependencies to be recognized in the process, the models would be set up in an iterative framework which would use the models in a specific order. This is necessary, since the process would become overly complex and difficult to use if multi-directional interdependencies were introduced. The basic process may be illustrated by a flow diagram as shown in Figure 1.[2]

The models to be constructed are probability models describing the probabilities of various choices being made by an individual in his decision process. Each model is to be designed in such a way that it can be used both in conjunction with the other models (e.g. for regional U.T.P.) and also separately from the other models (e.g. for certain sub-regional planning problems). This is achieved by defining each of the model probabilities as a probability of an outcome given certainty of the preceding choices. This can be illustrated by considering the operation of the models together in the U.T.P. process.

Let p_g = the probability that an individual would choose to make a trip

p_d = the probability that he would accept a destination, d, given that he will make a trip

P_m = the probability that he would choose a mode, m, given that he will make a trip to a particular destination, and

p_r = the probability that he will choose a route, r, given that he will make a trip to a particular destination by a specific mode

Then, the probability, P, that the individual will make a trip to a specific destination by a given mode and route is given by

$$P = p_g p_d p_m p_r$$

Taking each link in a transportation network at a time, the expected number of persons trips on that link will be the sum of the probabilities P for all routes which would use that link.

2 The recycling process could be extended more widely eventually, if models of urban development, land use, and socio-economic changes could be constructed to reflect changes in these parameters resulting from changes in the performance of the transportation system.

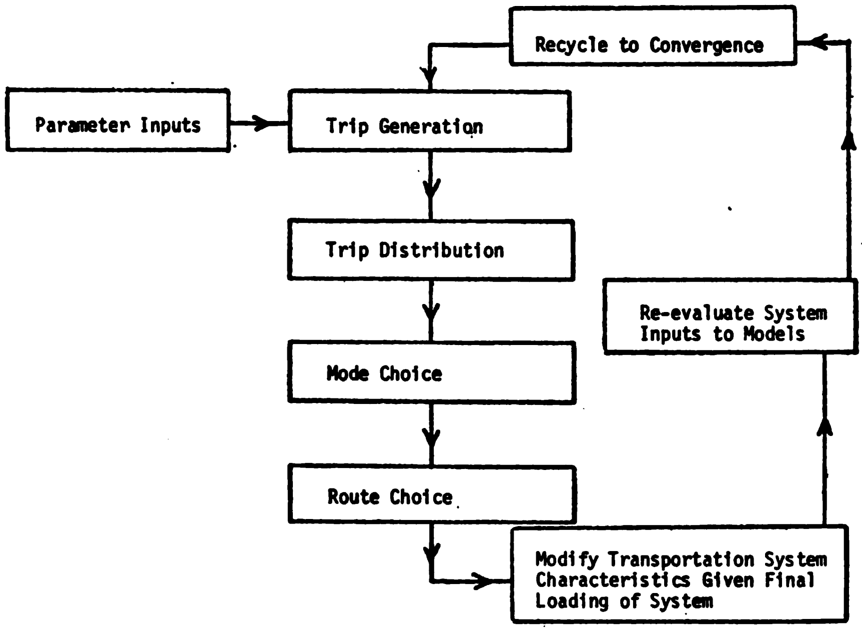


FIGURE 1

Alternatively, suppose the problem at hand concerns the effects on commuters, travelling from a particular suburb to the CBD, of certain possible policy decisions with regard to railroad scheduling. If only one railroad link exists, the question to be answered may simply be one of mode diversion. The required answers can be derived just from the mode choice model applied to the existing commuters from that suburb.

The Form of the Models

Each of the models will be formulated in a similar way, based on perceptions of the mechanism of individual choice. A ready representation of the choice mechanism is a symmetrical sigmoid curve representing the pattern of changes of probability of a decision with a changing stimulus. Various investigations at an aggregate level have tended to produce similar forms of curves as well. Several statistical techniques are available for building models to yield this sigmoid relationship. The simplest of these is the fitting of the logistic curve by "logit" analysis. This will be assumed to be the technique used in the remainder of this paper, but this assumption does not impose restrictions on the validity of the models. The logit relationship may be generalized as:

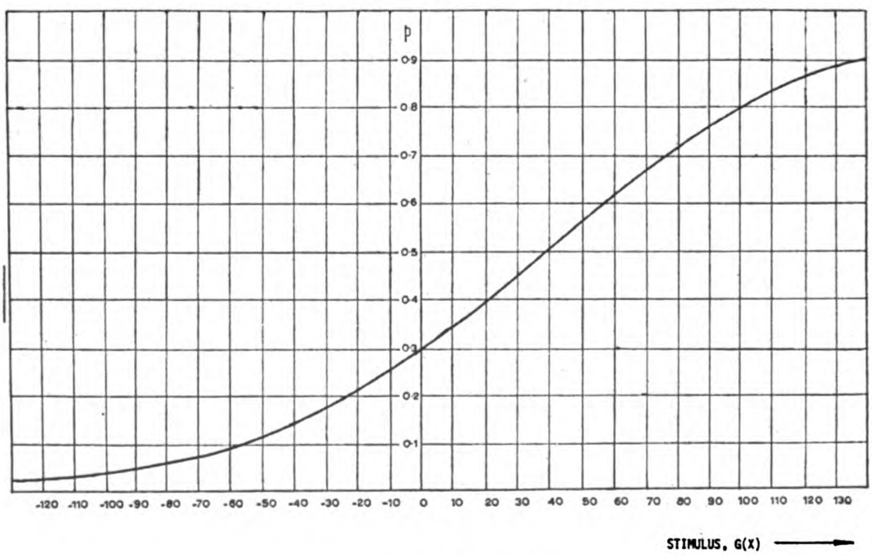
$$p = \frac{e^{G(x)}}{1+e^{G(x)}}$$

where G(x) represents some function describing, in this case, the environment which stimulates a decision, see Figure 2. In discussing the form of the model, the purpose of this paper is to briefly introduce certain ideas about the form that the function G(x) would be expected to take, and the meaning of the probability, p, in each model.

The basic hypothesis of this approach suggests that the function will comprise characteristics of the individual, of the transportation system, and of the available activity sites. Since travel demand is a derived demand, i.e. it is demanded jointly with the demand to participate in some other activity, the probability of undertaking a trip will be related both to the "value" to be derived from the end activity and to the "costs" to be incurred in undertaking it. Since the value to be derived from an activity is not currently quantifiable, the proxy of trip purpose will be used, and separate models will be calibrated for each trip purpose.

In general, it is assumed that the characteristics of the individual will operate in a choice model by modifying the weights attributed in the decision process, to various system and activity descriptors. Characteristics of the individual will, therefore, be present in each model in this capacity. In mathematical terms, if G(x) is a linear function of system and activity characteristics, then the coefficient of each of these characteristics will be functions of the characteristics of the individual.

The last three paragraphs have outlined the general form of the models. In considering the specific form of each of the four models, the construction of each model can be outlined. The decision to make a trip (trip generation)



Typical Logit Curve of the Form $p = \frac{e^{G(X)}}{1+e^{G(X)}}$

FIGURE 2

is a choice between making or not making a trip. If the trip is not made then, either a substitute activity which does not involve travel would be undertaken, or no activity would be undertaken for this purpose. Therefore, the trip generation model will need to compare the satisfaction of a particular trip purpose which can be obtained by travelling to a new activity site to that obtained from a substitute activity that does not require travel. It would appear that the G(x) will be a function of relative activity characteristics and of transportation system characteristics, where the latter describe the disutility of travelling as against not travelling.

Effectively, trip generation is a special case of trip distribution. The choice of a trip destination would be based on a comparison of all activity sites, which would permit the desired trip purpose to be accomplished, modified by the travel "costs" of reaching each site. Clearly, trip generation, as described in the preceding paragraph, is trip distribution where activities not involving travel are considered as alternatives, and also where the decision not to indulge in the activity is an alternative. However, trip generation would also operate at a much grosser level than trip distribution, since all activity sites would have to be considered together in this model, while trip distribution would be a multiple choice problem between all activity sites.

Given that a trip is to be made to a specific location, mode choices and route choices are processes of comparative assessment of available system alternatives for reaching a particular destination. There are probably strong arguments for eventually combining the two processes but initially it will be assumed that they would be simulated as two distinct models. Mode choice models would use relative values of system attributes between alternative travel modes, probably on the basis of the "best" route on each mode. Route-choice would then be based on relative values on a mode between alternative routes. In both cases, the coefficient, or weights, of each system attribute would be expected to be a function of the individual's characteristics.

Since all four models are based on common parameters, interaction between the models can be accomplished readily. Measures of the activity sites and of the transportation system are both likely to be sensitive to patronage. In the urban transportation planning process, a first estimate of network loadings could be obtained using some initial estimates (such as base year) of these activity and system attributes. Revisions of these values would be made at the end of the first cycle, and these revised values would be used for the next run through the models. This process would continue until satisfactory convergence of network loading estimates was achieved. Strategies for the Development and Use of the Models.

At the present time, the only one of the models, described in this paper, that has been developed is a sub-regional mode choice model (8,9,10,11). This has occurred for several reasons. First, many of the immediate sub-regional problems requiring analysis are principally mode choice problems. Second, mode choice is one of the only travel decisions made on the work journey and the data collection problem for work trips is considerably less than for other trip purposes. Therefore, data on work trip mode choices are generally more readily available than for any other travel demand situations. Last, travel mode choice involves a decision within a clearly defined set of alternatives, which is strictly limited. In general, commuter choices in the larger urban areas do not involve more than three or four main modes. Therefore, definitional and complexity problems are generally less for mode choice than for any of the other models.

In developing the type of model packages described in this paper, two general strategies can be adopted. The separate models can continue to be developed, in the context of sub-regional problems, as the need arises to be able to answer specific questions. In this context, it appears that mode choice models will continue to receive the greatest attention for some time. At the level of the total U.T.P. process, an incremental development of the models appears to have many advantages. Much insight will be gained into the general modelling problems by developing mode choice models to a high degree of refinement. Also, the successful development of mode choice models augurs well for the feasibility of extending this rationale to trip generation, trip distribution and route choice.

IV. AN AREA OF APPLICATIONS: MODELLING MODE CHOICE IN THE DEMAND FOR COMMUTER TRANSPORTATION SERVICES

Framework Objectives

A consideration of the travel mode choice question in the demand for commuter trips between suburban areas and city centers, can well illustrate how disaggregate behavioral modelling can be applied to problems at a number of levels of planning scale in the overall transportation planning process.

At a most detailed level of analysis, rail and auto trips can be considered in their component parts. For rail trips this means conducting analyses of suburban station access and downtown terminal egress behavior, that are separate from analysis that treats the rail trip as a whole from origin to final destination. For auto trips, it correspondingly means conducting analysis of downtown parking behavior separate from analysis that treats the auto trip as a complete door-to-door movement.

At an intermediate level of generality, the mode choices can then be modeled with travel considered as complete trips. The models previously developed for trip portions then become either directly, or in simplified form, parts of models for the whole. In particular, knowledge about the behavior and values associated with rail access, rail egress, and downtown parking behavior is combined with information on the characteristics of linehaul portions of the rail and auto trips. Together with information on actual mode choices made, this information creates the basis for models that can adequately represent the entire relationship between rail and auto trips in the context of overall commuter travel demand.

Finally, at the most general level, commuter trip mode choices can be considered as one subset of the larger group of travel mode choices that must be taken in combination in necessary aggregate modelling for predicting metropolitan areawide auto and mass transport modal shares. As before, information and models built from choices between commuter rail and automobile provide the modelling input—in original or simplified form—for the portion of metropolitan area travel that offers that particular travel mode choice. Similar information on other choices between auto and mass transport—and also between mass transport modes—comes from the analysis of behavior in other existing choice situations. The combined model inputs provide the basis for the general overall model.

In all of these analyses, from the most detailed to the most general, the intent is to understand how people behave, so as to be able to answer prediction and evaluation questions. For prediction, the objective is to accurately simulate people's actual behavior in given existing situations, so as to be able to predict with reasonable certainty what their behavior could be expected to be in given hypothesized future situations. For evaluation, the necessity is to know what values people place on different alternatives so as to be able to compare the benefits of possible plans with their costs.

As the models go from more detailed to more general, the objective is to make sure that the behavioral relationships identified in the detailed disaggregate models still retain their basic identity in the more aggregate general ones. The aim is to see that the summed models are, indeed, the sums of their parts.

The above provides a general framework for the behavioral analysis of mode choice in the demand for commuter transport services. In the following sections the analysis areas identified above are discussed in more detail. Particular attention is paid to some of the specific problems to be addressed with such analysis, and to how the analysis goes about addressing them. As in the analysis procedure itself, more detailed questions are taken up before more general ones.

Access to Suburban Commuter Railroad Stations

A critical question of suburban station access concerns the relative amounts of different sorts of access mode use that should be provided for. This is basically a mode choice problem, and its answer depends largely on mode choice behavior.

Typically, there are four modes of transportation used to get to the station: walk, drive and park, driven, and bus. The question is, given total demand, how much of each of these modes should be planned for, and at what price?

Reasonably accurate modelling of access behavior at suburban commuter rail stations does not appear to be a particularly difficult task. People travel to commuter stations in many places with different levels of accessibility, and it would seem reasonable to believe that overall the behavior patterns of commuters are much the same given the options facing them. The job facing the analyst is to gather data on behavior in situations with suitably different access availablities, and then to see how commuter behavior differs from one situation to another. The patterns of behavior then provide the necessary information both for predictive models, and for inferring the values that commuters put on different access availabilities.

To do this modelling in its simplest form (access to a given station) two initial analyses would appear to be reasonable. The first is an analysis of the amount that people will pay for parking at given distances from the station, and how much their use of the drive and park mode is influenced by the availability and price of parking. Situations do exist with different availabilities and prices of parking, and commuter behavior should be seen to differ accordingly. In particular, situations frequently exist where parking with lower price can be found further from the station.

The second initial type of analysis in the station access question is an analysis of the service, fare, and socio-economic status elasticities of demand for feeder bus service. Again, there are in existence many different availabilities of feeder bus services with different fares and in neighborhoods with widely different socio-economic characteristics. To obtain the necessary information for building appropriate behavioral models the analyst has merely to gather data from some of these different situations, and to then observe the differences in behavior from one situation and one person to the next.

After simple analysis has been conducted of the parking and bus problems, each considered separately, then a reasonable procedure would appear to be to consider each in terms of the other, and both in terms of the walk and driven options. Presumably, use of drive and park should vary with availability of bus service, with walking distance from the station, and in some way relative to driven. Similarly, use of bus service should depend on the other options, The same, of course, would apply to driven and to walk. Again, it is simple enough matter for the analyst to observe the patterns of behavior and from them both design predictive models, and infer commuter values. It would seem unlikely that more than a few variables are important in access decisions, and thus the modelling process should be relatively straight-forward.

Such analysis immediately leads to the answering of a number of types of questions. If, for instance, a new development is being planned in the commutershed of a given station, a relatively simple model application will tell how much use will be made of different modes of access to the station, given their relative availabilities, and total expected demand. In another situation, there may be a choice between building a higher priced parking facility close to the station and building a lower priced one farther away. Given knowledge of the value that commuters put on saving walking time, an immediate calculation may be made of the relative benefits to commuters of the alternative facilities. A third application is where it is desired to establish a feeder bus service. If it is known to what degree the various attributes of bus service influence its use, then it is a simple matter to predict the use of such service and to assess its relative benefits in the overall station access situation.

Three other questions may be mentioned that are direct applications of values associated with access. The first is that of station spacing. What is optimal station spacing? As station spacing becomes greater, at what point are the time gains of faster schedules to passengers on trains, and saved station and other costs to the railroad, compensated by the access losses to passengers getting to stations? The answer to this question depends directly on the values to commuters of the different availabilities of access.

A directly related question is that of station closings. The calculation is the same. The question is that of determining when the increased access costs to passengers forced to change to more inaccessable stations are greater than the sum of the schedule savings to other passengers, and the operational cost savings to the railroad.

A final application has to do with the possibility of providing large parking facilities and stops not at suburban centers of economic activity as is presently usually done, but in between them. Whether this would be worthwhile is a clear case of relative costs of access. Land costs, parking lot construction costs, and driving costs, are largely a matter of record. Other costs of access, including time costs to drivers, must be inferred from the analysis of behavior. With all these costs properly assessed, both the use and the value of such non-centrally located stops and lots can be predicted and assessed.

Egress From Downtown Commuter Railroad Terminals

The only differences between the analysis of downtown terminal egress and that of suburban station access is in simplicity. While four travel modes are generally used to reach suburban stations, typically only three are used to go from downtown terminals to final destinations. They walk, bus, and under certain circumstances elevated or subway rapid transit.

Thus, the analysis of downtown egress consists essentially of determining the circumstances under which people will take the bus or rapid transit from the downtown terminal to their final destination, and those under which they will walk.

As before, it seems quite likely that the important input variables should be relatively few in number and straight-forward. It seems reasonable to expect that the variables of importance in the walk-mass transport egress decision should include total distance, speed of the mass transport service, distances of the station or bus stops from the rail terminal and final destination, frequency of the mass transport service, and the fare. Presumably, socio-economic variables should influence this decision as well as trip purpose.

The chore of the analyst here is again to find egress situations that differ appropriately with respect to the variables. Then the task is to find out how commuters differentially choose their egress modes depending upon different values of the relative egress variables. From the analysis of behavior then comes the inference of commuter egress values.

In egress, there are a number of applications that can be made directly from the models. From the overall distance and mass transport speed variables, an immediate indication may be gained of the minimum likely distance for which a commuter will actually desire to have available mass transport egress services of a given variety. The speed variable alone will indicate to a considerable degree the relative advantages of faster grade separated rapid transit distributor service as opposed to street level bus. Similarly, the values of walking times at the two ends of the distributor trip will give an indication of the values of rapid transit or bus line egress. They will also indicate the effects of proximity, of stations and stops to the commuter rail stations and final destination locations, on the use of such facilities. Finally, information on the effects of frequency of service and of fares has similar applications. Knowledge of the value of frequency of service can lead to providing service at optimal frequencies with optimal size vehicles. Similarly, knowledge of the effect of fares on the use of distributor services gives a direct input to appropriate pricing policies.

Two specific further applications to the downtown egress question should be mentioned. The first is commuter terminal relocation. In a number of places there are plans being made to relocate, to greater or lesser degree, the locations of terminals for commuter services. A simple application of values associated with downtown egress mode availability can tell immediately the degree to which the proposed move represents a net increase in egress availability to commuters, or alternatively, the degree to which it represents a decrease. Similarly, it can indicate how provision of appropriate distribution mass transport services from a relocated station can improve the situation.

The second application is in moving sidewalks, and other similar "people movers". In a number of situations such investments have been made, and in others they have been proposed. Simple knowledge of commuter egress behavior and values can make cost-benefit analysis a relatively simple matter for any such proposed investment.

Downtown Parking Behavior

Perhaps the single most important variable influencing the travel mode choice between driving and mass transportation is parking cost. This causes a tremendous problem for designing modal split models based on zonal averages of independent variables, because the parking charge variable can vary by a couple of dollars—or over half its total range of variation—within the boundaries of one zone. The way this is usually handled in aggregate analysis is to take some sort of averaged parking cost value and to hope for the best.

Obviously there are important dynamics of parking behavior variation active in zones where there are differences of two dollars in parking charges. These dynamics must in turn be very important both in determining where people park, and in influencing overall mode choices between highways and mass transportation.

Thus the disaggregate analysis of parking behavior in central business districts is very important, both for policy issues relating to the provision of parking places in downtown areas, and for understanding the behavior and values operating in determining travel mode choices.

The analysis of parking behavior is in essence little different from that of analyzing rail access or egress. It is a matter of collecting data on the parking choices confronting people and observing how they choose among them. In general, a given individual will have a whole range of parking prices that face him. He can park right at his destination for a certain price, or alternatively, he can save varying amounts of money by parking greater distances away in an appropriate direction from his destination. The question is, with specific prices at the destination, and different possible savings at different distances, what do individuals do? How much will people walk to save a given amount of money? How does this vary according to whether the at-destination cost is large or small? These questions are easily amenable to analysis, and the behavioral relationships should probably be relatively simple. They can then be used in developing parking behavior models and in inferring commuter values.

The immediate applications of parking behavior analysis (considered separately from the effect of parking on mode choice, which is taken up in the next stage of modelling), are in the planning and evaluation of various schemes of locating downtown parking. Some cities, for instance, are contemplating policies of restricting parking in certain areas and establishing peripheral parking elsewhere. Other cities have policies requiring certain minimal amounts of parking to be included with the building of new structures. With knowledge of land values and the expected benefits to non-parking uses of downtown land, the results of parking analysis can be important inputs in the evaluation process for these and other parking policies.

Travel Mode Choice Between Commuter Railroad and Driving

With completion of the three trip-segment models: suburban station access, downtown egress, and downtown parking behavior; the analyst is ready to embark on an analysis of the overall relative mode characteristics that cause persons alternatively to use automobiles or commuter railroad services.

The method of the analysis is to identify the relevant characteristics of the two modes, and then to measure the extent to which the individual characteristics affect travel mode choice. For the rail trip, the analysis of access and egress should already have supplied the basic information for determining access and egress variables. Presumably, for a given individual, the variables describing his possible access and egress opportunities would be a weighted average of the variables describing his access and egress modes. The weighting would be determined by his likelihood of using the given modes. This, in turn, would be determined from the access and egress models.

The characteristics of the linehaul portion of the rail trip have not yet been identified. It would seem likely, however, that they would include some or all of the following: overall distance, speed of the vehicle, comfort, degree of crowding, number of necessary transfers, fares. All of these variables in linehaul characteristics could be expected to influence the overall travel mode choices.

For the auto trip, the variables would include a measure of parking availability derived from the parking analysis, plus variables of the auto linehaul. Presumably here some measure of trip distance and speed would be relevant.

The train-auto model, then, should contain variables relevant to rail access, rail egress, downtown parking and availability, and auto and rail linehaul characteristics. Because all the component models included have been designed to be internally consistent with behavior, the combined model should be as well.

With the fitting of the train-auto model, a whole range of predictive and evaluative questions may be attacked. For prediction, the model now shows both in sum and in components what it is that determines commuter choices of travel modes and how important the individual variables are in those choices. In a given hypothesized situation it can now be predicted what the split of trips will be. Also the mode choice effects of different changes in the system can be predicted. In particular, since the model reflects the relative importance of access, egress, parking availability, and auto and rail linehaul characteristics on mode choices, it can be used to predict the effects of changes in these characteristics on mode choice decisions.

With respect to specific applications, all of the system changes that could previously be handled only in a component model context, can now be considered in the context of overall modal split. In the suburban access question this means that changes in access availability such as station closings or openings, parking facility construction, and establishment of feeder bus service, can be looked at now not only from the point of view of changing the mix of modal use to the station, but also in the context of the split between highway and commuter railroad. Similarly, downtown changes such as locational movements of terminals, construction of distributor subways, and changes in bus service, can now be looked at in terms of their mode choice effects. Changes in downtown parking availability and price can be looked at in the same way. Restricting downtown parking or raising its price will have definite effect on the modal split between commuter rails and highways. The model will tell what that effect is.

System change effects that could not be considered in the component models, those of changes in linehaul characteristics, can now also be considered. For every linehaul characteristic in the model, there is a corresponding system change whose mode choice effect can be predicted through use of the model. With use of the cost variable, the mode choice effect of a fare change on the train or a toll imposition on the competing highway can be measured. Similarly, the effect of opening up a new highway and thus speeding up highway travel times can be measured through use of the appropriate travel time variable. Finally, through rail service variables in the model, the effects of service changes corresponding to the variables may be predicted.

The possibilities for evaluation that arise from the mode choice model between highways and commuter railroads correspond exactly to those for prediction. In effect, what the overall model does is establish a behaviorally consistent basis for evaluating investments that will improve commuter transportation opportunities. The basis is the effect of the given investments on modal split. Because the choice model will have a cost term in it, a direct translation from mode choice effect to money value can be made. This in turn gives the basic value information—in terms of value to the commuter—for cost-benefit analysis.

As before, the applications range over all possible investments to improve commuter transportation, whether they be in access, egress, downtown parking or rail or auto linehaul. In the case of any proposed investment its cost can be measured and compared with its benefits as determined by its effect on mode choice.

Some specific applications of this type of analysis to linehaul commuter railroad problems may serve to illustrate. The standard dilemma of commuter railroads has been that of revenue insufficient to cover expenses. The reactive policy of the railroads has frequently been to cut service and to hold fares down as much as possible. This policy has usually been adhered to, however, with no knowledge of whether commuters would prefer higher fares and better service to lower fares and lower level of service. Through good behavioral mode choice modelling, these questions can be answered. What is the worth to a commuter of being able to have a seated ride? What is the worth to him of air conditioning? How does he differentially value improvements in linehaul as compared with improvements in his access and egress opportunities? Behavioral mode choice analysis can give the answers and, with the answers known, priority analysis for capital improvements becomes a much more manageable task.

The General Mode Choice Model

The most general model for predicting travel mode shares between automobiles and mass transport in a metropolitan area must in effect be a composite of a number of mode choice models, all of which are similar in general form to the model described above for the auto-commuter rail choice. These models must cover two basic types of choice situations. The first type is choice situations existing in the metropolitan area where mass transportation services compete directly with automobiles. In addition to auto-commuter railroad type choices, typical large metropolitan areas may have a number of mass transport services, all of which compete directly with the automobile. An incomplete list of such services would include local buses, express buses, rail rapid transit, airport service, and service to special travel generators. To the extent that such services exist in a metropolitan area, a truly responsive area-wide modal split model must recognize them and be built in sum upon the behavioral relationships that determine their use.

The second type of situation that must be modelled in building a generalized composite modal split model is any existing modal choice situation where mass transport modes compete with one-another. Typical examples of this are the competition between commuter railroads and express bus, and between express bus and rapid transit. In these situations mass transport modes frequently in large measure share traffic diverted from automobiles rather than diverting it independently of one another. Thus, in order to build a complete composite mode choice model that is the sum of all the travel mode choices being made in a metropolitan area, all of the within-mass transport competive situations must be included as well as the purely auto-mass transport ones. In the resulting final model, then, mass transport use will be expressed not only as a total, but also as sub-totals for the various individual types of mass transport services available in the region.

In closing, it is appropriate to note that for every component model contributing to the composite regional mode choice model—whether it be a within-mass transport choice or an auto-mass transport choice—the same predictive and evaluative opportunities exist from the modelling as were illustrated in the auto-commuter railroad example. This can be of particular value when new mass transport investments are planned that will compete to some degree with other existing mass transport investments. In these cases, it may be desired to plan the investment to divert the fewest possible passengers, or, at least, to do a good job of predicting what the diversion will be. In these situations, good behavioral choice models may be of invaluable assistance in resolving conflicts and in advancing planning.

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