THEORY AND METHOD IN LAND USE AND TRAVEL FORECASTING

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This paper reviews the theory of demand and its translation into current method in urban transportation planning, namely, the conventional sequence of urban travel-forecasting models. The current models are examined from the perspectives of appropriate structure, usefulness in practice, and relevance to emerging values. The models appear to faithfully reflect the understanding of land use location and travel behavior and of the information requirements of an earlier period in urban transportation planning. A transportation-related general equilibrium land use model is derived, based on a causal theory of travel, namely, the theory of urban person travel as a derived demand. This long-run, activity-distribution, general model is used to examine the new set of (short-run) travel-demand models employing direct and cross relations and then the conventional sequence of traffic models: trip generation, trip distribution, and modal split. The simplifying assumptions required for these models are explicitly examined for their structural (causal) and statistical implications. It is concluded that separate modeling of short-run travel demand from long-run activity location introduces structural and statistical problems whose implications require further research. However, the structural and specification errors revealed in the current conventional models are such that they are of doubtful validity and produce possibly misleading travel forecasts. Such forecasts are in danger of being bypassed in current urban transportation controversies, and consideration of user travel costs may be bypassed with them.

•IN THEORY, demand is a function, not a fixed quantity. Demand models relate quantities of travel demanded to resources expended by travelers. The latter are travel times and costs, broadly defined, incurred on or supplied by the transportation system. How accurately and usefully has this theory of demand been translated into method in urban transportation planning? This paper first examines the current method, namely, the conventional sequence of travel-forecasting models. The current method is examined from the standpoint of appropriate structure and usefulness in current and emerging practice in urban transportation planning.

CURRENT PREDICTIVE MODELS IN URBAN TRANSPORTATION PLANNING

Current practice in predicting quantity of travel on transportation networks is 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 found (such as times and costs) on the loaded network and the travel conditions used as input to the prediction. The current well-known 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

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as a separate step. For each travel choice, the existing pattern of 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 simple description of the trip lengths that prevailed at the equilibrium between supply and demand represented in the base-date data file. The usual trip-generation procedure 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 addition, there are computational and logical difficulties in bringing the predicted travel conditions into line with the conditions (if any) used as input to each of the component travel-choice models. There is no assurance that travel times and costs resulting from traffic assignment will equal travel times and costs explicitly or implicitly input into each sequentially applied model of component travel choice (1)—that is, that an internally consistent network equilibrium will be produced.

One may reflect that the urban transportation studies in the 1950's and 1960's took the easy way out by equating usage (a constant) with demand in calibrating their models. For existing conditions, the models fit well with usage. Not generally recognized was that present usage is merely a fixed quantity of travel demanded at existing levels of supply, accessibility, and benefits from opportunities at existing trip ends. The simple trends or descriptions contained in the conventional models cannot be predicted forward with much confidence in a situation as complex as travel within an urban region.

The shortcomings of the conventional models increase when predictions are made of travel on congested networks (i.e., when small changes in assigned link travel volumes result in large changes in link travel times and delay). Since large-capacity, relatively congestion-free expressways in high-density urban areas are increasingly difficult (if not impossible) to build in the era of urban highway controversies (2), we can look forward to the future equilibrium between supply and demand being quite different from that which existed in the early 1960's when most of our large-scale transportation study data collection took place. Society's changing values introduce new conditions and information requirements in the transportation modeling process.

Operationality in transportation planning today requires demonstrating how smaller transportation systems accommodate smaller amounts of travel and how greater systems accommodate greater amounts of travel. Savings in resources expended by travelers (i.e., user benefits) from transportation improvements must be accurately calculated and vary appropriately with the total resources expended by society to provide those benefits. The latter resources, which are increasingly highly valued by society, include air and noise pollution, safety, community disruption, and many other effects that are external to the calculation of travel demand in a predictive model. Accurate travel forecasts are needed to calculate their magnitudes.

Only by explaining the causal relations underlying travel demand can accurate forecasts be made of future changes in the performance of a transportation system as land uses and transportation facilities change. Emerging values and information requirements of transportation decision-makers require policy-sensitive demand models in transportation planning.

New theory that improves our understanding of travel behavior can help in structuring appropriate travel-demand models. The theory also helps identify the important variables that affect individual travel decisions and that should be included in the models. The derivation of a "new" method in the next section proceeds from a new theory of travel demand.

DERIVING A GENERAL LAND USE MODEL

A recent major theoretical paper on the subject of travel-demand forecasting defines passenger travel as a derived demand: "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)." However, the papers of Kraft and his colleagues (3, 4), which contain this and other fundamental contributions to travel-demand theory and behavioral modeling, do not model travel explicitly as a derived-demand commodity. An extension of their modeling into the area of land use or general equilibrium modeling is presented here. In the process, the theory of travel as a derived demand can be incorporated explicitly into the more general model. This is made possible (or at least made easier) because the larger general model permits travel to be modeled as one intermediate (derived) output of the larger urban system.

The land use or general model once derived can be altered by making some simplifying assumptions in a way that produces the earlier behavioral travel forecasting models. In addition, the general model can be simplified still further to produce each of the current conventional travel models, namely, trip generation, trip distribution, and modal split. In the process of this successive alteration of the general model, the simplifying assumptions in (short-run) travel-demand models in general, and in the current conventional models in particular, are clearly illustrated. The implications of these assumptions can then be examined.

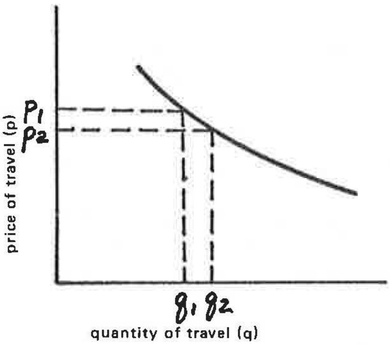
Theory: The General Model

Because travel is a derived demand, as defined above, trips would not be made if the benefits to be derived at their destinations were not greater than the resources expended in getting to and from the destinations. This holds whether we consider one round trip or whether we consider tours, that is, trips involving multiple stops. [There is increasing evidence indicating the importance and prevalence of tours (5). Intermediate legs of such tours are modeled separately as non-home-based trips in the conventional models. Much useful information on preceding mode and the like is lost by not modeling these trips as tours.] The base location can be considered an arbitrary zero or reference point where the benefits from consumption of the output of the activity at that location is less than at most other locations. (The most logical base point is an open question. Home is usually taken as the base. However, everybody may be destined for home because consumption of activities at home is valued most highly. The theory is independent of this problem.)

In the case of urban passenger travel, we can define the resources expended by consumers of travel in the usual way, namely, the traveler's money and time. (Time here is activity specific. Its value, relative to money and to consumption of outputs at trip ends, is dependent on the activity engaged in during travel, i.e., the method of travel and its component parts.) If the output at the trip destination is valued more highly by the traveler than the resources expended in travel, he will make the trip. The difference between the two (if any) is the net benefit of the trip.

The existing universe of travel and activities in a region represents some equilibrium between the preferred activities of residents and the desire to minimize resources in travel. (This is not a static equilibrium in reality, nor are the activities engaged in or the resources expended in travel intended to be described here as optimal or minimal in any way.) If improvements in transportation result in some lowering of the resources that must be expended per unit of travel, we can assume there will be an equal or greater amount of travel consumed by the individual, or output by the transportation system. (Travel must be consumed to be produced: an interesting and known identity.) That is, new opportunities at trip destinations farther away in distance but not in travel cost will come into range, and they will offer an increased net benefit from travel—often, of course, at the "expense" of previous destinations! (Eventually the "quantity" of travel must be operationally defined. Distance is a useful interpretation at this stage because the producer's cost of supplying or outputting travel is logically related to distance.) Thus, improvements in transportation that lower the cost of travel (i.e., money and time resources that must be expended in travel) tend to alter the former equilibrium. Note that only monotonic behavior is assumed; that is, increases in travel do not necessarily result from transportation improvements.

We can draw a monotonic curve that is purely descriptive of this covariation in the price of travel output by the transportation system and the quantity of travel consumed in the region:



As the price of travel (the resources in time and money expended in travel) decreases from p_1 to p_2, the quantity of travel in the region is equal to or greater than its previous amount ($q_2 \geq q_1$, and $dq/dp \leq 0$).

We note here only the most simple linear equation that describes the curve graphed above:

$$q = a + bp$$
$$b \leq 0$$

Inasmuch as we assume that people minimize their costs or resources expended in travel in order to maximize their net benefits from travel, we can assume that people tend to choose their methods of travel (mode, route, and time during the day) to minimize their costs or resources expended in travel. If some alternate method of producing travel (e.g., alternate mode or route) presents itself that involves lower cost to the traveler, we can assume that the traveler will choose that alternative in order to maximize the net benefit from travel. The closer the substitute is, the greater the switch will be from one alternative to the other. Also, the greater the cost savings on the alternate are, the greater the tendency will be to increase the quantity of travel on the substitute (and to increase total travel and thus net benefits from travel). Also, higher cost savings on the alternate will decrease the quantity of travel by the first method.

This behavior can again be described in simple linear travel-method-specific (e.g., mode) equations employing direct and cross relations:

$$q_1 = a_1 + b_1p_1 + c_1p_2$$
$$q_2 = a_2 + b_2p_2 + c_2p_1$$
$$b_i \leq 0$$
$$c_i \geq 0$$

where 1 is the first travel method and 2 is its substitute.

Defining exactly or precisely the commodities and the relevant market so that useful direct and cross relations may be developed is an important problem in demand analysis. High cross relations between commodities are indicative of a well-defined market and help to delimit the market (6). In our case we are fortunate in that there appears to be an identifiable and reasonably well-circumscribed market called urban travel. It remains to appropriately define the commodities making up that market.

The lumpiness of urban transportation technology, composed as it is of generally easily distinguishable (from the supply side and thus of great interest to those who must provide it) modes and links making up routes and networks, helps us (from the supply side) to distinguish among different methods of travel. Also, the value that individuals attach to component times and costs required to be expended on travel by the various available (thusly) defined substitute methods in an urban area appears logically and empirically to vary (4). Thus, the well-defined market, the variation in activity-specific time and money value, and the importance of the different travel methods to planners (from the supply side) suggest that we can profitably search for high cross relations of travel on alternate modes and routes and at alternate times.

In the simple equations presented thus far, there are important missing variables that describe how the system of interest behaves according to our theory. One missing variable is the output obtained from activities at the trip destinations. If the output (opportunities) at trip destinations in the region increases, there will be a tendency to increase the amount of travel in order to increase total net benefits from travel. At the new equilibrium, the increased value of outputs obtained at the trip ends would be equal to or greater than the increased resources expended on travel. This behavior can again be described in simple linear equations that are consistent with previous work (however, the present model, based on the theory of travel as a derived demand, is as yet incomplete):

$$q_1 = a_1 + b_1 p_1 + c_1 p_2 + d_{1k} A$$

$$q_2 = a_2 + b_2 p_2 + c_2 p_1 + d_{2k} A_k$$

$$d \geq 0$$

where A_k = measures of activities (1, . . ., k, ℓ, . . ., K) at the trip ends from which value is obtained.

Because additional travel is being traded off or expended in order to obtain higher valued outputs at the trip ends, we can expect the signs of the d coefficients to be positive. That is, higher valued activities can be expected to occur (covary) with greater amounts of travel.

General Equilibrium Model

We have defined travel as a derived-demand commodity. That is, it is desired not for its own sake, but as something on which resources must be expended in order to obtain the benefits of some output from activity at trip destinations. Therefore, the appropriate way to forecast a derived demand is to forecast the demand for the final good, namely, the trip-end outputs. The resources expended on travel (volume times cost) will be one of the costs of obtaining the final goods and, thus, it will appear in the predictive equations modeling demand for the final outputs (activities).

The equilibrium equations for the final outputs or activities in their simplest form for a region, again with 2 travel methods, are

$$A_k = a_k + b_k p_1 + c_k p_2 + d_{k\ell} A_\ell$$

$$b \leq 0$$

$$c \leq 0$$

For a region with an unspecified number M of alternate travel methods, the more general form of the linear model is

$$A_k = a_k + b_{km} p_m + c_{k,n \neq m} p_{n \neq m} + d_{k\ell} A_\ell$$

where m = method of travel (1, . . ., m, n, . . ., M).

Some important changes take place in the signs on the coefficients in the general model for the (now causal!) price of travel variables from those in the previous descriptive or covariational travel equations. The b and c coefficients will now both be negative. This is, of course, consistent with classical economic location theory (1). That is, land value (where land value is value in the long run, though presumably closely and directly related to the sum of short-run outputs of value to travelers) increases as transportation improvements are made that lower the price of travel to and from the location of the land.

This is conceptually a general equilibrium model in that its equations describe a set of conditions that when solved satisfy the stated conditions for the system to be in a state of general or static equilbrium. The equations are solved as a simultaneous set. The number of equations equals the number of activities K being forecast. An initial formulation of the activity variables for transportation study modeling involves measures of activities that relate closely to value obtained from travel, for example, employment, value of wages earned, retail sales, residential value (such as lot size), and measures of recreation and social potential.

A one-dimensional formulation of the transportation price variables involves relatively simple one-dimensional travel-method-specific accessibility (price vector) potential functions. In the two-dimensional case, the activity output variables would still be one dimensional (A_{ik}, i = location index), but the transportation price variables put into the model would be origin-destination and travel-method-specific price vectors (i.e., including components of price and service). The number of these variables could get quite large, of course, because travel method can incorporate mode, route, time of day, and other characteristics. Some form of the more general two-dimensional model is recommended for initial testing. Simplifications of the model will fall out as conclusions from model tests.

The theory of derived urban passenger travel demand does not fully circumscribe the entire set of causal relations among all factors in a city and all measures of activity location and intensity. That is, this is not a "complete" urban system model incorporating all possible causal relations operating in a region and influencing urban development patterns. However, such a complete model would probably lack practical usefulness in most applications.

According to modeling theory, we seek to isolate the important variables and their relations in a purposeful way that contributes to the analysis and, in this case, that implements operationality in transportation planning. Thus, transportation as a causal determinant of activity distribution changes is stressed. The general model allows an improved understanding of the simultaneous determination of travel and activity patterns.

EXAMINATION OF TRAVEL FORECASTING TECHNIQUES USING THE GENERAL MODEL

So that conclusions can be drawn from the general model on the appropriateness of the policy-sensitive nature of travel forecasting models, the general model can be dismembered to resemble each of the travel models in turn. The assumptions involved in simplifying and altering the general model can be explicitly examined for their structural (causal) and statistical implications.

(Short-Run) Travel-Demand Models

The first simplification of the general model involves dropping back one step from the activity-location equations to the equations for travel. This requires the simplifying assumption that the distribution of activities in a region is given and fixed and that travel is modeled as a function of the fixed activities.

By omitting the equations for activity location in the general model, we are left with a partial equilibrium model, that is, a model that describes how part of the system behaves in order for it to be in equilibrium with the rest of the system. Thus, we model the behavior of the trip-maker who considers all trip-end opportunities and travel costs fixed. He chooses only his destination and method of travel because he has no control over the distribution of activities in the region or the (unit) transportation prices he must pay to obtain his desired outputs from those activities.

The first simplification of the general model returns us to the travel-demand formulation from which the final extension to the general model was made. The round-trip, two-travel-method model in product form appears as follows:

$$D^{1}_{iji} = a_1 p_{iji}^{1b_{11}} p_{iji}^{2c_{12}} A_{ki}^{d^{i}_{1k}} A_{kj}^{d^{j}_{1k}}$$

$$D^{2}_{iji} = a_2 p_{iji}^{2b_{22}} p_{iji}^{1c_{21}} A_{ki}^{d^{i}_{2k}} A_{kj}^{d^{j}_{2k}}$$

$$b \leq 0$$

$$c \geq 0$$

where

1,2 = method of travel 1 and 2 (such as mode, route, or time period);
D = round trips;
i = origin;
j = destination;
k = activity (output) type; and
p = vector of round-trip times and costs that must be expended on travel by method m between iji.

Or, the more general form,

$$D^{m}_{iji} = f\left(p_{iji}^{mb_{mm}},\ p_{iji}^{n \neq m c_{m,n \neq m}},\ A_{ki}^{d^{i}_{mk}},\ A_{kj}^{d^{j}_{mk}}\right)$$

where m = method of travel (1, . . ., m, n, . . ., M).

The (short-run) travel model states that trips by method m from origin i to destination j (or bundle of destinations j) and then back to i are some function of the activity systems at i and j and the price and service conditions by method m and all substitutable methods n. Trips by travel method are forecast directly in separate equations. Separate equations can be used to model the behavior of various socioeconomic groups. This is the basic model that has been estimated already by using urban travel data from Boston (4).

There are 2 principle consequences of separating the long-run demand or activity-location decision from the short-run travel decision that we can discuss on the basis of this simplification of the general model. The first relates to the logical and statistical problems introduced by omitting causal variables. The second relates to the separation itself.

The first consequence for short-run travel forecasting is that, because travel is a derived-demand quantity, equations such as those given above are incomplete. That is, travel should be modeled as an intermediate output of the larger urban system, as per the general model. The omission of important variables in a general model can cause inappropriate measurements of the effects of other variables (8). The statistical and operational consequences of this omission need thorough empirical and theoretical study.

The second consequence relates to the (modeling) separation itself of long- and short-run demand. In this regard, Lowry (9) notes:

> Since a stock is by definition the integral over time of the corresponding flow, it must also have the same determinants as the flow. [We note that travel by type to and from a point mirrors the amount and type of activity at that point, particularly when the activities are defined as travel-related outputs.] But if the model builder limits his attention to flows which occur over any short span of time, he can afford to take a number of shortcuts. Exogenous variables whose

> effects on stocks are visible only in the long run can be ignored or treated as fixed parameters.... By accepting the initial magnitude of a stock as historically "given," one avoids the necessity of replicating the past and can devote himself to modelling the events of the present and the near future.

However, by avoiding specific attention to the long-term effects contained in the general model, one also avoids structurally modeling those effects. Just as (structural) changes in network equilibrium are not modeled in the current conventional models, there may be and probably are structural long-term changes that are (of course) not modeled in a short-run travel-demand model.

However, this cannot lead us to conclude that the separation of long- and short-run forecasting is itself at fault. It leads us instead to the conclusion that the long-run models themselves must be structural. It also reminds us once again that our short-run models should incorporate relations among travel and its determinants that are expected to remain valid in the future.

Conclusions on the usefulness of short-run demand models in view of the possible consequences of separating short- and long-run models need much future research. This is a central problem in transportation systems analysis. The first problem, that of misspecification (in view of the lack thus far of a good short-run theory of travel demand), is more troublesome than the second. That is, separating long- and short-run travel-demand forecasting is itself not a problem, if a short-run model based on a plausible theory of short-run travel demand can be obtained, which is to say the two problem areas are really one. The general model appears to be a useful vehicle for further research into this question.

Meanwhile, in the absence of an estimated general model, short-run travel-demand models are the only travel-forecasting models available. These include the models presented and discussed in this section and the current conventional models used in the urban transportation studies during the 1960's. The remaining task, therefore, is to examine the general model further to help us evaluate the operationality in transportation planning of the current conventional short-run travel models.

Conventional Models

Trip Generation—Trip generation in the conventional model omits round trips and all costs of travel from the short-run travel model given above, leaving, for trip production,

$$q_i = "G_i^i" = f(A_{ki}) = d_1^i A_1 + d_2^i A_2 + \ldots$$

and for trip attraction,

$$q_i = "A_j^i" = f(A_{kj}) = d_1^j A_1 + d_2^j A_2 + \ldots$$

As noted earlier, the number of trips in the future is assumed in the conventional models to vary only as the activity levels vary. Nothing else influences the amount of travel, whether it be the price of travel (times and costs) by one travel method, the presence of substitute methods of travel, or the level of trip-end opportunities at the opposite trip end. Vis-á-vis the explicit lack of policy sensitivity of conventional trip-generation equations, the same conclusions as before may be drawn. However, collapsing the general model, or even the short-run travel-demand model given above, demonstrates how badly trip-generation equations are misspecified. That is, we can expect widely varying effects of the omitted variables to be attributed to the activity variables. The attribution by regression techniques of the effect of these omitted variables to the remaining variables can be expected to impair the accuracy of the effect of the activity variables on trip generation.

Trip Distribution—By dropping round trips and omitting all travel-method-specific equations but one, and by dropping out the terms for the substitutable travel methods from the one remaining (total) travel equation, the short-run travel model can be made to look like the gravity model. That is, omitting terms from the product-form model yields

$$D_{ij} = ap_{ij}^{b}A_iA_j$$

Because the b coefficient is ≤ 0,

$$D_{ij} = \frac{aA_iA_j}{p_{ij}^{b}}$$

Replacing the activities by the G_i and A_j, obtained in trip generation, and solving in the usual manner for the constant a yield the functional form of the gravity model:

$$D_{ij} = \frac{G_i \frac{A_j}{p_{ij}^{b}}}{\sum_j \frac{A_j}{p_{ij}^{b}}}$$

Normal application of the gravity model omits consideration of the effects of substitute modes and omits a full set of travel times and costs expended in travel p. If an application did use some measure (or vector) of price on more than one mode, the proper signs of the b and c coefficients in each of their respective short-run travel-method-specific equations would have to be adhered to and the equations somehow added to preserve internal, albeit only partial, logic (11).

However, the important problem with conventional gravity-model trip distribution, however doctored as per the previous paragraph (and aside from its short-run nature), is again the problem of specification error. That is, the relations among travel methods and the activity variables are omitted from the equation. In their places are inserted fixed numbers of trips (generated and attracted) that must be adhered to (i.e., "balanced"). The travel-cost distribution (the purely descriptive, not causal trip-length frequency distribution) is also fixed. There is no chance to model the travel cost and trip-end benefit trade-off. In short, there is no calculation of a network equilibrium between cost of travel and benefit derived from engaging in various activities at trip destinations. The user is locked into 2 simple descriptions of the conditions that existed at the prevailing network equilibrium for the time and place the gravity model was calibrated.

Modal Split—Current post-distribution, modal-split models normally incorporate the largest set of price variables of any of the conventional models. However, the models operate on (split) the independently derived fixed trip distribution discussed above. Two major problems can be seen.

The first problem is the misspecification problem. That is, dropping out measures of activities at trip destinations causes inappropriate attribution of the effects of these variables on the included times and costs. The effects of the omitted destination variables, for example, can be expected to appear in the price variables in ways that serve to make (again) the partial effects of these variables inappropriate. For example, a simple case of this may cause the usual difficulty that modal-split models have in modeling CBD-oriented and non-CBD-oriented trips with the same model. This is because the influence of different price and service characteristics of trips can be expected to vary depending on the nature of the final goods and services consumed or employment obtained. Simple stratification of trips by trip purpose does not normally even ensure a good fit.

The second problem with conventional modal-split models arises from the lack of travel-method-specific (e.g., mode) travel prices. That is, travel times and costs are treated equally in modal-split models regardless of the travel mode on which they are incurred. This results in a unit change in travel time or cost having the same effect on relative usage of automobile or transit regardless of which is improved (or which is subject to increased congestion or travel cost).

Resources expended on travel should be modeled as mode (method) specific until it can be shown that easily measured resources (components of travel time and cost) can be treated independently of mode. There is evidence that they cannot. That is, elasticities of demand with respect to mode-specific times and costs differed substantially in the already estimated short-run travel-mode-specific demand models of the form given above (4).

It is quite likely that the models one works with for a long time constrain one from thinking freely in terms of how travelers make travel decisions. Modal split (for example) has no behavioral significance to the traveler. For evaluation (if desired), its arithmetic calculation may be made after mode-specific (method) travel-demand forecasts have been made.

Conclusion—The urban transportation studies of the 1950's and 1960's, using the current conventional models, were focused on providing information primarily on a single criterion of building to accommodate some fixed anticipated travel "demand." The studies were mainly content to publish long-range (as indeed required by section 134 of the 1962 Federal-Aid Highway Act) travel projections on the proposed transportation system as the primary justification for the recommended plan; that is, the facilities proposed were big enough to accommodate the anticipated traffic. Operationality in urban transportation planning today requires structural models that allow calculation of new network equilibrium levels of usage and congestion. This requires demand models that incorporate the individual traveler trade-offs caused by changing congestion levels inherent in facilities provided and not provided.

The examination in the previous section of the conventional travel models has been based on an explicit examination of some of the simplifying assumptions necessitated by dismemberment of the general model to look like them. The examination has shown something more alarming, however, than the shortcomings observed prior to the development of the general model in this paper. The alarming problem is that not only are the conventional models not policy sensitive (as concluded earlier) but also the specification errors (omitted variables, variable types, and whole equations) repeatedly raise the strong possibility of impaired accuracy of attribution and estimation of the effect of the policy variables that are included. Thus, misleading "policy" forecasts are possible (if not probable).

GENERAL CONCLUSIONS

Structural travel-demand models are required to implement operationality in transportation planning. Models are required that can be estimated with confidence that the effects attributed to policy variables are appropriately measured. Appropriate calculations are required of user and social costs reflecting true network equilibrium performance on the widely varying alternative transportation networks now being proposed in cities [and that may soon include innovative transportation alternatives as well (11)].

Travel-demand models must be based on a plausible and well-understood theory of travel behavior. The finely tuned descriptions of existing travel contained in the current conventional models have little relation to a plausible theory of travel and land use location. Of theory and method, more theory and less method are needed.

For practical reasons, also, short-run, policy-sensitive, travel-demand models of the type described earlier and already documented in the literature (3) are needed. Such models predict interzonal travel demand by travel method (e.g., mode) directly and employ relations only slightly more complex than those appearing in each of the separate conventional sequences of models. In ease of application, there appears to be little comparison. On the one hand, solutions are required of one equation directly for trips between a zonal pair (with resulting ease in disaggregating forecasts, a pressing need because of current concern with the distribution of costs and benefits as well as their aggregate values). On the other hand, manipulation of regional data files several times to achieve the same result is required. Errors are decreased with the new models, and introduction of the supply side is greatly facilitated. [This, of course, requires appropriate supply functions and appropriate interaction with the demand functions discussed here (3, 12).]

Further research is needed to evaluate whether in the long run other structural changes may make inappropriate our present separation of short-run travel forecasting from long-run land use forecasting. It may be that not incorporating certain long-run structural relations leads to inappropriate calculation of the long-run equilibrium between land use and travel. That is, not solving as one simultaneous set the relations between the demand for travel and the demand for goods and services output at the trip ends may lead to biased forecasts of either or both. However, the separation of long- and short-run demand seems now to be appropriate for at least practical reasons. Nevertheless, short-run travel forecasting with current conventional models appears inappropriate for both practical and structural reasons.

An approach to travel forecasting needed is one that reflects current societal values and not one that is grounded in past transportation planning values and practice. Rapid changes in values are taking place in our society. If policy-sensitive models are not rapidly implemented, travel forecasting stands in danger of being bypassed in transportation decision-making, and consideration of travel user benefits from transportation improvements will be bypassed with it.

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REFERENCES

1. Manheim, M. L. Practical Implications of Some Fundamental Properties of Travel Demand Models. Paper presented at the 51st Annual Meeting and published in this Record.
2. Public Attitudes Towards Urban Expressway Construction. Charles River Associates, Inc., Cambridge, Mass., April 1970.
3. Kraft, G., and Wohl, M. New Directions for Passenger Demand Analysis and Forecasting. Transportation Research, Vol. 1, 1967, p. 211.
4. Domencich, T., Kraft, G., and Valette, J. Estimation of Urban Passenger Travel Behavior: An Economic Demand Model. Highway Research Record 238, 1968, pp. 64-78.
5. Ginn, J. R. Transportation Considerations in an Individual's Activity System. Northwestern Univ., dissertation, 1969.
6. Watson, D. Price Theory and Its Uses. Houghton Mifflin, Boston, 1963, Ch. 7.
7. Alonso, W. Location and Land Use. Harvard Univ. Press, Cambridge, Mass., 1964.
8. Hanushek, E. A., Jackson, J. E., and Kain, J. F. The Fallacy of the Ecological Correlation Fallacy. Program in Regional and Urban Economics, Harvard Univ., Cambridge, Mass., Paper 70, 1972, Appendix.
9. Lowry, I. A Short Course in Model Design. Jour. of American Institute of Planners, 1965, p. 162.
10. Brand, D. Evaluation of Transportation Planning Methodology. Center of Urban Studies, Wayne State Univ., Detroit, Feb. 1971.
11. Brand, D., ed. Urban Transportation Innovation. ASCE, New York, 1970.
12. Ruiter E., and Manheim, M. DODOTRANS, A Decision-Oriented Data Organizer. Department of Civil Eng., M.I.T., Cambridge, 1968-1970.