Applications of Value of Travel Time to Travel Demand Estimation

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Potential areas of application of the value of time within all the predictive models in the transportation planning process are identified, and basic problems associated with such application and the urban transportation planning package are discussed. Three alternatives are described for determining the function of value of time in predictive models. The major applications of values of travel time are in the conventional travel demand models: trip generation, distribution, mode choice, and route assignment. A formulation that would involve the use of costs and times as major explanatory variables in the various decision processes is discussed. Broad areas in which the generalized cost concept in urban transportation models may be applied are indicated (for possible exploration), and gains that it may provide in terms of realism and accuracy of existing models are considered. The need for considerable research in modeling of trip generation before operational models are produced, incorporation of generalized cost in models of trip distribution and mode choice, use of an algorithm in trip assignment procedures, and model interaction are discussed. The reasons for the lack of a set of modeling tools for interurban travel are noted, and choice situations that should be differentiated are indicated. The value of time should be used specifically in predicting the market for possible new modes of intercity travel.

Conventionally, the major application of the value of travel time has usually been in the evaluation of alternative highway projects as discussed by Stopher in a paper in this Record. Another area of the application of value of time has been the transportation planning process, which includes predictive models. Though similar in their characterization by means of a systems approach, both transportation investment evaluation and travel behavior modeling differ fundamentally in their required properties of the actual values. Transportation investment evaluation is a particular case of social accounting techniques, based on the concepts of macroeconomic theory, as proposed by Reichman in a paper in this Record. The value of time that is used in this case needs to be positive, and, in practice, either a representative or a threshold value is used. Another property of the value of time in investment evaluation is that it is a unidirectional deductive process, whereby values are derived from macroeconomic theory but are not reincorporated into the national accounting system.

The modeling of travel behavior, on the other hand, uses an essentially inductive method, based on concepts of both theories of spatial organization and utility theory. The empirically established results provide a much wider range of values, not necessarily positive. Furthermore, it can be argued that, when values have been obtained, they can be applied as explanatory variables in more than one direction: in formalizing travel behavior as part of the transportation planning process and in considering theories of spatial organization. It is the primary intention of this paper to identify potential areas of application of the value of time within all the predictive models in the transportation planning process.

BASIC PROBLEMS IN APPLICATION OF VALUES OF TRAVEL TIME

Before considering the applications of the value of travel time in transportation planning, one must address several basic problems or at least recognize them as being implicit behind the applications. Most important, one must consider whether the value of travel time represents a valid choice parameter in the individual decision-making process or whether it represents an artifact designed to serve as a useful proxy for a number of travel characteristics that cannot, at present, be operationally quantified. The answer to this will have some considerable impacts on the assumptions surrounding the measurement of values of time and interpretations of these values outside the context of the transportation planning process. We will discuss the way in which this answer is pertinent to the entire development of concepts of the value of time applied to predictive models in the transportation planning process, whether the value of time exists per se or is simply a useful construct. As will be discussed later, one of the principal potential applications of the value of time in the transportation planning process is in the models used to describe travel demand. In this context, the function of value of time in these models must be determined, if it is to be included. Three alternatives are possible.

1. Value of time may be included on the hypothesis that it will add to the predictive power of the models. This would require that the models be constructed in a mathematical form that permits the value of time to

enter the model (perhaps as a coefficient of time in a cost function).

2. Models should be regarded not as using or requiring value of time as an explanatory variable but as a means of inferring time values for use in other applications in transportation planning. This requires a specific formulation of times and costs in the model. The value of time can only be inferred from a behavioral model if the variables of time and cost enter as absolute values or as differences between alternatives.

3. One could hypothesize that the value of time does not necessarily have an application to these models and that the inference of values of time is not of prime importance in such models. Furthermore, the hypothesis would state that the inclusion of the value of time may well reduce the predictive power or realism of the models. Hence, the models should be formulated in whatever way best explains present behavior or conforms with theories of behavior. This is the implicit assumption of models devised with ratios of alternative costs and times, since such models cannot yield inferred values of time and usually do not incorporate any variable that comprises a measure of the value of time (5, 14).

Values of time can be inferred (see item 2, above) from travel demand models in the following manner: Consider a travel demand model that comprises a dependent variable Y and independent variables of cost and time in the form of

$$Y = \alpha_1 C + \alpha_2 T \qquad (1)$$

The value of time may be inferred by considering the change that would occur in Y for a unit change in either cost C or time T. Consider first the unit change in cost. Such a change will result in a change of α_1 units of Y. The same change in Y could also occur from a change of α_1/α_2 units of time. If, in equation 1, the units in which costs and times are measured are cents and minutes respectively, then it follows that a change in cost of 1 cent is equivalent to a change of α_1/α_2 minutes in equation 1. Therefore, the equivalence between time and cost is such that the value of time is α_2/α_1 cents per minute. This is an inferred value of total travel time if equation 1 is applicable to travel demand. A similar result would follow if, in place of cost and time in equation 1, there were a cost difference and a time difference. In both cases, the value that is inferred is unique for this relationship, i.e., there is one unique value of time that can be inferred from each relationship in the form of equation 1, as Stopher discusses in a paper in this Record.

The other main form in which costs and times enter travel demand equations is as ratios. Consider the following equation:

$$Y = \alpha_3(T_1/T_2) + \alpha_4(C_1/C_2) \qquad (2)$$

Note that the independent variables in equation 2 are dimensionless in that they are ratios of values measured in like dimensions. In the same way that the value of time was inferred in the previous example, a value may be investigated in equation 2 by considering the effects on the dependent variable of the unit change in either one of the cost or time values. Consider a unit change in time T_1. The effect of a unit change in time T_1 on the dependent variable Y will be a change of α_3/T_2 units. The same change in Y could be achieved by a change in C_1 of $\alpha_3 C_2/\alpha_4 T_2$ units. Clearly, in this case, the value of time depends on the values of both C_2 and T_2, and, therefore, there is no unique value of time that can be inferred from this relationship. Furthermore, problems similar to those affecting the differences formulation—in terms of values away from the mean and statistical confidence—also affect values of time inferred from ratios of times and costs.

Therefore, a time-independent and cost-independent value of travel time can only be inferred from a travel demand model that incorporates absolute values or differences in the values of costs and times. Such inferred values must also be treated with considerable caution in terms of departures from the means of costs and times—or cost and time differences—and in terms of the statistical reliability of the result.

If the value of time is to be incorporated in travel demand models as an exogenously valued parameter, a further problem arises. Stopher, in a paper in this Record, states that one of the principal sources of implied values of time is behavioral mode choice models in urban travel. However, the value of time so inferred is a value of a time saving or of an added expenditure of time, derived from a trade-off between two transport alternatives (e.g., two modes or two routes). In choice processes at an urban level concerning two or more alternatives of modes or routes, the value of time savings is an appropriate parameter. The value of total travel time appears to be a more appropriate measure in choice processes concerning whether or not to make a trip, mode and route choice in interurban situations, and, to a lesser extent, trip destination.

At present, it is not possible to state, with any certainty, whether or not the value of time savings will be the same as the value of total travel time. To equate these two values requires the assumption that the value derived from, say, a 10-min time saving is the value to be applied to a 10-min trip. The estimation of the value of total travel times has not yet been undertaken and poses a much greater problem than that of time savings. In broad terms, the estimation of total travel time value requires, if inferred from behavior, an ability to measure trips not made. This knowledge would effectively reduce the problem to the same level as that of mode or route choice, and a value could be inferred. A situation exists that may produce some information on this subject, i.e., the induced travel resulting from the provision of a new facility. This, however, is by no means a simple exercise, and there are many problems associated with it.

Theoretically, it appears to be possible to derive a value of total travel time by investigating traffic that is induced by a new transportation facility. When a new facility is opened for use by the public, three types of travel basically can be identified as occurring on the new facility: (a) traffic diverted from other modes or routes but between the same origins and destinations; (b) traffic diverted from other possible destinations to new destinations, thereby using the new facility; and (c) induced traffic, that is, traffic that did not occur before the opening of this facility. In the cases of all diverted traffic on such a facility, the appropriate value of time that could be inferred from measurements of this traffic is only the value of time savings. However, the value of time that could be inferred from measurements of the induced traffic would be an absolute value of travel time in that it represents the choice between making a trip and not making a trip. The actual problem of making measurements of this type of travel is in determining the size of the area to be considered and the ways in which the various trips being made can be accurately measured.

Effectively, what is required in such a study is the measurement both before and after of trip making in a large area around the new facility. The measurement of trips that are diverted by mode only does not present a considerable problem of measurement. It is usually possible to determine the approximate area that the new facility will serve and thereby measure the trip making before the facility is open in that entire area. The principal problems develop after the facility is opened. Trips can be induced on the system. Also, trips may be diverted in terms (of any or all) of origin, destination, mode, and route. To determine the induced traffic, one must extract the diverted trips as well as those trips that are unchanged by the new facility from total traffic. Furthermore, both diverted and induced trips are likely to occur on the original facilities and on the new facility. When trip origins or destinations are changed in trip diversion, considerable difficulties arise in determining that the trips are diverted since observation is required before the new facility is opened. Therefore, two successive comprehensive origin-destination surveys covering a wide region within a short period of time must be carried out. Currently, the lack of expertise in survey methods and in identification of trips is such that this procedure does not represent a realistic source for determining the value of total travel time.

URBAN TRANSPORTATION PLANNING PACKAGE

The major application of values of travel time discussed in this paper concerns possible use in the conventional set of travel demand models—trip generation, distribution, mode choice, and route assignment. Although the discussion will focus on this set of four distinct models, it is nevertheless applicable to any other framework for modeling total travel demand. Currently, in total travel demand modeling, two distinct types of travel are identified: urban and interurban. By far, the greater total effort has been devoted to the modeling of the urban travel demand, and only recently has much attention been given to modeling interurban travel demand. Attempts at extending the techniques of modeling urban travel to interurban travel have not been notably successful, and it is apparent that the characteristics of, and demand for, interurban travel are different from those of urban travel demand. If this is the case, then it becomes necessary to develop a meaningful basis for defining when any trip is urban or interurban. Within the context of the large metropolitan areas and corridors that have evolved in North America and elsewhere, definition of the basis of this dichotomy is not a simple geographical exercise.

The U.S. Bureau of the Census (25) defined interurban trips as any trip that is longer than 160 km (100 miles) or that involves an overnight stay. This definition appears to have been adopted in most studies concerned with either urban or interurban travel. However, this definition may not necessarily be the only or the most meaningful and operationally useful definition. In discussions of applications of value of time, the dichotomy of urban and interurban travel has been observed as basic to the discussion; however, the census definition is not necessarily implied here.

The major reason for distinguishing between urban and interurban travel, is that, from a modeling viewpoint, these two forms of travel represent somewhat different phenomena. In each case, the various characteristics of travel are somewhat different. Urban travel has a large repetitive element, and a major proportion of the total number of trips are between home and work [trips between home and work constitute between 40 and 58 percent of all trips in urban areas, such as Chicago, Toronto, and Puget Sound (2).] On the other hand, interurban travel has a much less repetitive nature, and work trips no longer constitute a large proportion of the total number of trips being made [in interurban trips, according to the U.S. Bureau of the Census, about 20 to 27 percent of trips are for business purposes, and less than 4 percent of all trips are for work (9, 25)]. Therefore, there will be no hard dividing line between urban trips as is implied by a rigid definition that interurban trips are longer than 160 km (100 miles) or involve an overnight stay. Instead, there should be a transitional zone in which there is a trip of somewhat indeterminate nature that represents the changeover from basically urban trips to basically interurban trips.

A further distinction between urban and interurban trips is that of a difference in the importance of times and costs in the various identified decisions in travel demand. In urban trips, although system characteristics are certainly partial determinants they are not a major parameter in the decision to make a trip or the choice of a destination. They become much more important as the decision process moves on and are most prominent in the choices of mode and route for a trip. However, in interurban travel, the early decisions (as identified here) are based far more on considerations of the system characteristics.

Thus, at least three properties of trips have been identified as a basis for distinguishing between urban and interurban travel: the mix of trip purposes, the repetitiveness of travel, and the importance of system characteristics in the decisions. Any one of these criteria could be used as a basis for determining bounds of total trip length in time or distance, and this, in turn, could be used as a basis for describing urban or interurban trips. As an alternative, the distinction between urban and interurban trips might be based on discriminant analysis, in which the variables that make up the discriminant function would include the three characteristics just identified. This latter approach has some appeal in that it automatically includes a transition area in which it is not specifically possible to identify trips as being either urban or interurban. All of these alternatives appear likely to yield a more operationally useful definition of urban and interurban trips; however, they are put forward here only as concepts without the mechanics of the definitions being fully detailed. In the discussion of applications of value of time in each of urban and interurban travel, some similar operational definition has been made.

DEVELOPMENT OF URBAN TRANSPORTATION PLANNING MODELS

Existing models (12) are generally recognized as doing an inadequate job of predicting travel demands, particularly when changes are expected in system characteristics, relative to each other. Efforts to improve on these models have generally followed two alternative approaches. The first is based on the economic theory of consumer behavior and, because of the way it handles system characteristics, implies that value of time is irrelevant to travel demands (8, 16, 22). In these models, relative trip times by different modes are entered as ratios and thereby extensively complicate the inclusion or inference of a value of travel time. The second is based principally on making incremental improvements or restructuring the existing four-model process. Within this approach, it is possible for the value of travel time to be included, or not, entirely according to the hypotheses put forward. The basic hypothesis relating to the value of time in these models concerns the mathematical form in which costs and times are entered. Various alternative formulations have been put forward within this approach, but this paper focuses on the use of costs and times as major explanatory variables in the various decision processes.

Generalized Cost

The major application of the value of time to urban transportation planning models (27) comes about through the use of the concept of a generalized cost. The generalized cost of a trip is defined as the total effort of making the trip expressed in money terms. In the past, the generalized cost has basically been made up of measures of both money and time costs of a trip. This generalized cost is used in place of a single time or cost function to describe the function of trip making. Because the concept of a generalized cost requires that elements of time and cost are added together, a means must be found by which travel times can be expressed as money equivalents. This means is provided by the value of travel time.

As a potential major application of the generalized cost concept in urban transportation planning models, changes in the existing models can be envisaged whereby the generalized cost becomes a variable in each stage of the modeling process. Research into this possible application has been fragmentary only. Therefore, this paper will attempt to indicate the broad areas in which this application could be explored and the possible gains that it may provide in terms of the realism and accuracy of the existing models. The basic hypothesis is that the generalized cost may appear as a variable in each stage of the model and, thereby, may improve the realism of each separate model and provide a means by which the entire model set may be recycled so that a possible state of system equilibrium may be achieved. Beyond this, the concept of generalized cost does much to improve the apparent realism of each separate model, and these improvements will be outlined briefly later in this section.

The generalized cost has to be related, in the strict economic sense, to the purchase of a commodity. The existing approach (16) has been to consider the purchase of the services of a given transportation mode or the purpose at a given travel destination as such commodities. Alternatively, it could be argued that trips as such are the commodities for which a generalized cost is incurred. This second alternative offers greater flexibility in treating recreational trips that lack a rigorous origin and destination relationship. Different definitions of the commodity that incurs generalized costs seem to affect the ways in which generalized costs can be included in the procedure of travel forecasting. Only when the commodity is defined as trips can generalized cost be used in each step. If the commodity is defined as transportation services by mode, or purpose at a travel destination, then generalized cost may only be used for trip generation in conjunction with one of these two commodities.

Trip Generation

Current trip generation models do not include any systems characteristics, except car ownership. They are empirical constructs that establish the travel attributes of a given zone or household. This means that it is implicitly assumed that the possible range of variations in system characteristics would not affect the aggregate traffic generation of a given traffic zone. In the application of trip generation models in the standard planning process, this assumption leads to an inability to predict changes in the total amount of travel resulting from changes in the transportation system. At first, this appears to suggest that the appropriate corrective procedure is to build trip generation models that include generalized cost; this will make the models sensitive to the transportation system. Such a procedure conforms with the assumption that a trip per se is the commodity being purchased. However, if modal services or location-specific activities are assumed to be the commodities being purchased by the traveler, then the inclusion of generalized cost in the trip generation model is not appropriate. Instead, this assumption calls for the definition of new models of mode choice and destination choice that estimate the total number of trips by a mode or to a destination rather than the diversion of trips among alternatives. It should be recognized, however, that such changes in trip generation modeling will require considerable research before operational models can be produced.

Trip Distribution and Mode Choice

Trip distribution models already include a system characteristic in the form of either trip time or trip distance. This single system characteristic is intended to serve as a proxy for the function of trip making. It would appear, however, that this function of trip making could be better represented by the use of the generalized cost. Both Wilson (27) and Mansfield (11) have indicated means by which the generalized costs may be incorporated into a model basically of the gravity model type in trip distribution. Wilson has also shown how the generalized cost may be implemented in the formulation of a conventional opportunity model. Exhaustive tests of this method have yet to be undertaken, however, although the indications are that this could prove to be a useful improvement on existing trip distribution models (3, 6). On the other hand, empirical research has progressed so as to provide estimates of values of travel time by trip purpose and trip length (23, 24).

In the area of mode choice models the application of the concept of generalized costs has been researched most extensively. To date, several attempts have been made to construct new models of mode choice that incorporate the use of differences of costs and times among available modes for a specific trip (1, 10, 17, 20, 26). Limited tests of these models appear to indicate that this development is likely to bring an improvement in the realism and the accuracy of these models to predict the existing and possible future use of modes of travel. At present, these mode choice models have been used as the basis for inferring values of travel time. In addition to these specific developments in mode choice models, Wilson (27) also showed that an extension of his theory of distribution models would yield a mode choice model that again would be based on the inclusion of a generalized cost function. He also showed that this function was in accord with that attained by the application of the techniques of discriminant or logit analysis to a mode choice situation. The underlying hypothesis of this general development of mode choice models is that the use of differences in system variables and of the value of travel time improves the realism and predictive powers of the model. In each case, an attempt is being made to make the models more behavioral than the models that have previously been calibrated. However, when values of travel time have been established, these values can become an a priori input to the building of mode choice models, rather than an a posteriori output.

Trip Assignment

Finally, in trip assignment procedures, it seems possible that the use of an algorithm that attempts to minimize the total generalized cost of a trip would be a more realistic basis for assigning trips than that of minimum time, or distance, paths. Given an urban transportation model set that continues to comprise these four-model sets of trip generation, trip distribution, mode choice, and trip assignment, some iteration must be done to approximate the necessary omnidirectional interactions of these four steps. If generalized costs are contained in all four models, a channel is immediately provided for realistic interaction. A series of iterations of the model set, with generalized costs reevaluated after the assignment stage on each iteration, should hopefully tend to an equilibrium state of demand for travel between any two points by any mode and route.

Model Interaction

It should be reemphasized that the derivation of generalized costs depends on the knowledge of the value of time, and, hence, these possible refinements in urban transportation planning models constitute a major application of values of travel time. The use of generalized costs in these urban transportation planning models serves two basic goals. First, it represents a more behaviorally sound inclusion of transportation attributes in the models. These attributes, such as times and monetary costs, are derived from the characteristics of the various transportation modes; however, their perception and evaluation by the traveler represent subjective decision making. In this way, generalized cost is indicative of the person-machine interface that characterizes person trip making. Second, it provides a means whereby the sequential set of models may be used to approximate a simultaneous decision on travel. This mechanism exists if there are variables that are common to all the models in the set, both in terms of inclusion and mathematical form. One of the major problems of the existing, conventional set of urban transportation planning models is their inability to interact because of the lack of common variables. Clearly, to include generalized costs in some of the models of the set and not include it in others will make no gains whatsoever in this direction. Furthermore, it may even further weaken the models because of the severity of resulting incompatibility problems. Hence, improvements to be gained by using generalized costs in the travel demand models result only from the use of generalized costs in all the models of the urban transportation planning package.

INTERURBAN TRANSPORTATION PLANNING

Unlike its urban counterpart, interurban transportation planning does not comprise an established set of modeling tools. It is only recently that attempts have been made to model interurban travel, and, for the most part, these attempts have been based on economic theories of consumer behavior (7, 15). These models have not been overly successful, at least in part because of the serious error propagation properties, and this area of modeling is still wide open to research. Basically, interurban travel has a different composition and rationale than urban travel. The lack of a set of modeling tools for interurban travel can be seen as due to the following properties of interurban travel as opposed to urban travel.

1. The recurrence, or periodicity, of trips is much less pronounced in the interurban context, and it is the repetitiveness of urban travel that makes it amenable to mathematical modeling. The much less repetitive form of interurban travel therefore requires the inclusion of considerably more random factors in any mathematical models of interurban trip making.

2. The number of choices are extended, beyond just whether or not to make a trip, to include a choice of whether or not a trip should be satisfied within the urban area. The number of interurban trips originating in any given urban area is usually a relatively small portion of the total number of trips being made within that urban area; therefore, it has been possible for successful urban models to be devised that ignore the choices of interurban versus urban trips. However, in interurban travel, urban trips form a much larger total number of trips than interurban trips, and, as a result, the choice between making a trip within the urban area or to another urban area must now be included. In addition to these problems, variances from aggregation and with the use of central measures become considerably larger. The number of origins and destinations that are possible for trips in the interurban context is immense, and the central measures, e.g., the use of centroids, have much larger variance than in the urban context. In addition, trip generation cannot be disaggregated by land uses since the total area for each zone at an interurban level will comprise far too many and diverse land uses for this to be a meaningful operation.

3. Given the constraints of social and spatial organization of human activity patterns, interurban travel will probably have to be viewed in terms of the joint product of travel time and activity time at the origin or destination (4). This raises the question of the validity of the use of trip generation models, per se, for interurban trips, since the commodity purchased is more likely to be transportation services by a given mode or the activity at either trip end.

In interurban travel, time and the value of time become considerably more important than in urban travel. In the typical consumer choice situation, time characteristics of a trip will be a major determinant of whether a trip will be made and whether that trip is urban or interurban. Currently, time and value of time are used primarily in the areas of mode choice and new technology acceptance at the interurban level. It is clear, however, that both time and the value of time are important parameters for inclusion in any models of total travel demand by mode and route by destination from any urban area at an interurban level. To incorporate such terms, one must find a basis on which to estimate the value of travel time and of travel time savings at the interurban level. Such estimation is complicated by the fact that assumptions of correct perception of system characteristics and degree of knowledge of the alternatives available are not valid at the interurban level (13, 18, 19).

Even if one assumes that the derivation of revealed values of time may be feasible and representative, the possible applications in interurban travel should be considerably more discriminating. Ideally, the following choice situations should be differentiated:

1. Interurban trips with or without an alternative of air transport. It may well be that small time savings do not have the same value in trips without as in trips with the air alternative (21).

2. Trips that start at different times of the day. Early morning trips are probably those where applications of value of time might prove to be particularly important.

3. Trips with different increments of time saved, either because of varying distances or speeds or be-

cause of varying schedules, change of mode, or other delays. In this case, a distinction between average and marginal values would be critical in the application of this choice parameter.

Because of the current lack of good interurban transportation planning models, the major problem within this context does not appear to be directly that of incorporating value of time and time measurements within the models. Therefore, the value of time cannot provide the same coalescing influence as it was demonstrated to do in the urban transportation planning package. Rather, it should be used more specifically for interurban mode choice models, wherein it would have a primary application in predicting the market for possible new modes of intercity travel. Any further application must await the development of basic hypotheses and modeling rationales for interurban travel.

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