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Value of Travel Time

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Foreword

Thomas E. Lisco, Illinois Department of Transportation

Travel time value is probably the single most important input for determining the extent, nature, and structure of transportation. It is a crucial factor in forecasting the use of transportation facilities and provides the primary means for estimating transportation benefits. Its applications range from determining broad overall levels of investment to evaluating minute questions of facility plan detail. Throughout transportation planning, design, construction, operations, and maintenance, questions of travel time value are critical and pervasive.

Although the importance of travel time value is generally understood, the phenomenon itself is not. Basic theoretical work in travel time value and the derivation of actual values to be used in the different contexts of application have only been seriously considered during the past two decades. Furthermore, only recently has it become apparent that there is a great deal of work to be done before we can confidently apply derived time values to the vast array of transportation analysis questions that confront us. Time value research is needed in time value theory and concept, methods of deriving time values, actual time value derivations, and applications of derived time values to travel demand forecasting and cost benefit analyses.

In response to this need, the Transportation Research Board formed the Task Force on Value of Travel Time, which later became the Committee on Traveler Behavior and Values. The purpose of the task force was to provide a focus for ongoing travel time value research and to prepare a report on the current state of knowledge regarding travel time value.

This RECORD is the result of the activities of the Task Force on Travel Time Value and includes papers covering important areas of travel time value analysis, such as travel time value theory, conceptual problems in travel time value, methods of deriving travel time values, review of empirical travel time value studies, applications to travel demand estimation, and applications to transportation investment analysis. In all of these papers, attempts have been made to describe what is known in each area and to outline areas of future needed research. It is hoped that these papers will help bring together the thinking about travel time value. A considerable amount of disparate work has been done in the field; it is now time for us to proceed from a common base to fill in some of the larger remaining gaps in our knowledge.

Economic Approach to Value of Time and Transportation Choice

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Travel time was recognized to affect the demand for transportation before it was formally incorporated in economic theory. No traveler, producer of transportation services, or transportation-oriented policy maker needs an economist to make this fact known. The major contribution of economics in this context is in formulating the problem and creating a framework that allows one to measure the effect of travel time on the demand for trips. In this framework, the price of the trip includes both the money expenditures and the opportunity cost of time. Thus travel time affects the choice of destination, the choice of mode, and the number of times one travels. In this paper, I shall try to describe the current state of economic theory regarding the value of time, emphasizing some of the difficulties involved in its empirical application.

The first attempts to incorporate the opportunity cost of time in economic theory date back to the early 1960s (7, 8, 9, 10). The most general and far-reaching formulations can be found in Becker's theory of the allocation of time (2), which hypothesizes that the initial source of utility is the activity (or in Becker's terminology the commodity). Each activity involves the combination of goods purchased in the market, the household member's time, and (sometimes) intermediate activities. For example, the activity meal combines the capital services of the dining room and its fittings, the participants' time, and the activities of cooking and serving. The activity visit to another city involves the money expenditures for accommodations and food, the time spent in that city, and the activity trip. The household tries to maximize the utility derived from all the activities engaged in subject to two constraints: the budget constraint, which specifies that total money expenditures cannot exceed income, and the time constraint, which stresses that the time involved in all activities is limited.

Formally, the utility function is as follows:

$$U = U(Z_1, \ldots, Z_n) \qquad (1)$$

where Z_i denotes the ith activity; Z_i in turn depends on the household production function,

$$G(Z_1, \ldots, Z_n, X, T) = 0 \qquad (2)$$

where

X = vector of market goods and services, and
T = vector of time units, since time is not necessarily a homogeneous input.

We may distinguish hours of the day, days in the week, and months in the year. Daytime may be used extensively for work while sleep is produced at night. Summertime may be a prevalent input in the activity going to the beach, and wintertime figures extensively in the production of skiing. Furthermore, equation 2 allows for joint production. For example, a mother may engage simultaneously in cooking and child care, and an air passenger may travel and watch a movie at the same time.

The maximization of utility is subject to two constraints: the budget constraint

$$PX = W(Z_n) + V \qquad (3)$$

and the time constraint

$$T = T_0 \qquad (4)$$

where

P = price vector;
$W(Z_n)$ = earnings that are a function of the activity work, Z_n;
V = other sources of income; and
T_0 = a vector of total units of time available (the components of T_0 may differ since there are, for example, more workday than weekend hours and more day than night hours in summer).

The maximization of the utility function with respect to these two constraints yields the optimum combination of activities, the optimum allocation of time and goods, and the value people place on their time.

To analyze this optimum, let us assume for simplicity that there are no intermediate activities, that there is no joint production, and that the production function is continuous throughout the relevant range. Given these simplifying assumptions, equation 2 can be rewritten as

$$Z_i = F_i(X_i, T_i) \qquad (5)$$

where

X_i = vectors of goods, and
T_i = time inputs involved in the production of activity i.

The budget and time constraints have to be rewritten

$$\sum_{i=1}^{n} P_i X_i = (Z_n) + V \quad \text{and} \quad \sum_{i=1}^{n} T_i = T_0 \tag{6}$$

Defining the Lagrangian,

$$L = U(Z_1, \ldots, Z_n) + \lambda\left[W(Z_n) + V - \sum P_i X_i\right] + \mu\left(T_0 - \sum T_i\right) \tag{7}$$

and maximizing with respect to Z_i yield the necessary conditions for an optimum

$$u_i = \lambda[P_i x_i + (\mu/\lambda)t_i] \qquad (i = 1, \ldots, n - 1) \qquad u_n = \mu t_n - \lambda w \tag{8}$$

where

$u_i = \partial U/\partial Z_i$ $(i = 1, \ldots, n)$ = marginal utility of activity i,
$x_i = \partial X_i/\partial Z_i$ = marginal inputs of goods,
$t_i = \partial T_i/\partial Z_i$ = time in the production of Z_i, and
$w = [\partial W(Z_n)/\partial Z_n] - P_n x_n$ = marginal wage rate.

Differentiating the Lagrangian with respect to X_i and T_i yields the optimum combination of inputs in production,

$$\frac{\partial Z_i}{\partial T_i} \bigg/ \frac{\partial Z_i}{\partial X_i} = \frac{x_i}{t_i} = \frac{\mu/\lambda}{P_i} = \frac{K}{P_i} \qquad (i = 1, \ldots, n) \tag{9}$$

where $K = \mu/\lambda$. The scalar λ is the marginal utility of income. The vector μ denotes the marginal utility of the various time units. $K = \mu/\lambda$ is therefore a vector denoting the (money) value placed by the household on the different units of time. Thus, by equation 9 the marginal rate of substitution in the production of activity i (i.e., the ratio of the marginal products of T and X) equals the input price ratio.

Rewriting equation 8, we have

$$u_i = \lambda(P_i x_i + K t_i) = \lambda \Pi_i \qquad (i = 1, \ldots, n - 1)$$

$$K = \mu/\lambda = [w + (u_n/\lambda)]/t_n \tag{10}$$

The first of these equations states that in equilibrium the marginal utility derived from activity i is proportional to its marginal cost of production Π_i. By the second of these equations, the shadow price of time K depends on the marginal wage rate w; the money equivalent of the utility of work, u_n/λ; and the marginal product of the time unit in the production of the activity work $1/t_n$.

In the past, the value of time was usually identified with the wage rate. Equation 10 indicates that even under our set of simplifying assumptions this equality can be regarded only as a crude approximation. The value of time depends on the marginal wage rate, $w = [\partial W(Z_n)/\partial Z_n] - P_n x_n$, and not on the reported average wage. It has been argued that the marginal productivity of labor and the hourly wage rate change as the daily number of working hours varies (Figure 1). Thus, if the daily number of working hours falls short of t_n^* so that the marginal productivity of labor is still increasing (1), the average wage is an underestimate of the marginal wage rate. If on the other hand the number of working hours exceeds t_n^*, the reverse is true. Furthermore, to obtain an estimate of w, one has to deduct the marginal money cost incurred from the marginal wage rate. It is frequently argued that, at least in the case of married women, these costs (e.g., the cost of babysitters and other forms of child care) are substantial.

Even if we were able to obtain accurate data about w, we would have to correct the data for the (unknown) value of the marginal utility of work so that an estimate of the value of time could be obtained. The marginal wage rate w is an overestimate of the value of time K when work involves marginal disutility and is an underestimate when work involves positive utility.

Finally, up to this point, it has been implicitly assumed that all units of time are used for work (i.e., $t_n > 0$). This is clearly an inaccurate assumption: A large fraction of the adult population (mainly housewives) is not part of the labor force, and even those participating in the labor force cannot change their working hours freely (e.g., they cannot substitute night for day working hours). In the extreme case, all working hours are determined institutionally and are not subject to the household's decisions in the short run. Whenever units of time are not used for work or cannot be substituted freely for working time (i.e., when the appropriate elements of the time vector satisfy $\partial Z_n/\partial T_n = 0$), the marginal wage rate becomes irrelevant for determining the value of these time units. The value of these units is determined in this case by their scarcity, i.e., by their supply and demand.

How is the value of time affected by changes in wages and other sources of income? An increase in the marginal wage rate directly affects the value of time of those units that are freely substitutable for working hours. This increase may also affect the second component of the value of time by changing the number of working hours, the marginal utility of income, and the money equivalent of the marginal utility of work, u_n/λ. The resulting change in income increases time scarcity and the value of time units that are not freely substitutable for work. The value of these time units need not increase by the same rate, the change being dependent on the income elasticity of the various activities: The value of those time units that figure extensively in the production of income-elastic activities is more sensitive than others to changes in income. Thus, the effect of a change in wage rates on the value of day hours may differ from the effect on night hours, and weekend hours may be affected differently from workday hours.

Similarly, changes in other sources of income, V, may affect the value of time by changing the number of working hours and the marginal wage rate, the value of the marginal utility of work, and the scarcity of time. Note that this change may have opposite effects on the value of time that can be used for work and time that cannot. Thus, although an increase in other sources of income is expected to increase the value of time, which cannot be converted into working time, it may result in a decline of the value of working hours if the reduction in these hours results in a decline in the marginal wage rate.

In conclusion, even under this set of simplified assumptions it cannot be argued that the value of time equals the average wage. There is no unique value of time. The set of values of the various time units may be positively affected by wages and other sources of income but is not equal to the wage rate.

Changes in the value of time, K, affect both the optimum combination of inputs in the production of each activity and the optimum combination of activities. An increase in the value of time results in a substitution of goods for time and a shift from time-intensive activities (whose relative price rises) to goods-intensive activities.

VALUE OF TIME ADAPTED TO TRANSPORTATION

Adapting the value of time to transportation calls for the removal of some of our simplifying assumptions. The demand for trips is usually a derived demand, the utility derived from the trip itself being only a part (and usually a small part) of the benefits accruing to the traveler; most of the benefits originate in the stay at the destination. Thus, a trip can be regarded as an intermediate activity in the production of a visit. First, to analyze the demand for trips, one must therefore introduce intermediate activities into the model. Second, most modes of travel (and in particular public transportation) do not preclude travelers' engaging in other activities (e.g., conversation, reading, and sometimes working). The assumption of no joint production of activities must therefore be removed. Finally, the assumption that the production function of trips is continuous must be released. In general, travelers cannot affect the traveling time and costs of a given mode. Each mode involves spending money and time in fixed proportions, and the production function is discontinuous. I shall remove these restrictive assumptions one by one.

Let it be assumed (4) that there are only four activities: a visit to some city, Z_V; a trip by mode A to that city, Z_A; a trip to it by mode B, Z_B; and all other activities, including work, $\overline{Z}$. The production functions of Z_A, Z_B, and $\overline{Z}$ are a function of market inputs and time (equation 5) and are continuous, and there is no joint production. The fourth production function, that of the visit Z_V, is somewhat different since it involves the intermediate activities Z_A and Z_B:

$$Z_V = F_V(X_V, T_V, Z_A, Z_B) \tag{11}$$

Maximizing the utility function

$$U = U(Z_V, Z_A, Z_B, \overline{Z}) \tag{12}$$

subject to the time and budget constraints yields the optimum combination of the trips by the two modes:

$$\frac{\partial Z_V/\partial Z_A}{\partial Z_V/\partial Z_B} = \frac{z_B}{z_A} = \frac{\Pi_A'}{\Pi_B'} = \frac{P_A x_A + Kt_A - (u_A/\lambda)}{P_B x_B + Kt_B - (u_B/\lambda)} \tag{13}$$

Since both modes are equally efficient in conveying passengers to their destinations they can be regarded as perfect substitutes in the production of a visit $z_B/z_A = 1$. The choice of mode therefore depends on the relative price, Π_A'/Π_B'. This in turn depends on the money expenditures, the opportunity cost of time, and the money equivalent of the marginal utility derived from the trip (u_i/λ for i = A, B). If the marginal utilities derived from the trip (u_A and u_B) are sufficiently small [i.e., if $u_i < \lambda(P_i x_i + Kt_i)$ for i = A, B], the price line in the relevant range slopes downward. Moreover, if the marginal utilities decline with the number of trips, the price line is concave to the origin (Figure 2).

Travelers who go Z_V° times split their trips: They go Z_A° times by mode A and Z_B° times by mode B. If $\Pi_A = P_A x_A + Kt_A$ is sufficiently different from $\Pi_B = P_B x_B + Kt_B$, or if u_i (for i = A or B) is sufficiently large (in the extreme case u_i may be large enough for the slope of the price line to become positive), the travelers may specialize, taking all their trips by one mode. In this case, mode A is preferred if

$$(1/\lambda)(u_A - u_B) + (P_B x_B - P_A x_A) + K(t_B - t_A) > 0 \tag{14}$$

where $Z_V^\circ = Z_A^\circ$ and $Z_B^\circ = 0$. Note that, in this inequality so often used in predicting modal choice and in estimating the value of time, there is nothing to ensure that the first term, $(1/\lambda)(u_A - u_B)$, is the same for different individuals and is uncorrelated with other terms of the equation. It may vary with income (resulting in differences in λ), with the total number of trips taken Z_V°, and with the length of the trip t_i.

The second assumption to be released is the assumption that there is no joint production of activities (6). Thus, let it be assumed that there are only three activities

$$U = U(Z_1, Z_2, \overline{Z}) \tag{15}$$

where Z_1 is the activity trip, Z_2 is reading, and $\overline{Z}$ are all other activities. Let

$$Z_1 = F_1(X_1, T_1) \qquad Z_2 = F(T_1) \tag{16}$$

where market inputs used in the production of reading are ignored. Maximizing the utility function subject to the constraint inplies that the optimum time spent in traveling is attained when

$$[(u_1/\lambda)/t_1] + [(u_2/\lambda)/t_2] = K \tag{17}$$

i.e., when the value of the marginal product of time in travel and reading equals the value of time. Thus, as long as the marginal unit of time yields utility in addition to the utility of the trip, travelers will be ready to pay less than K for any unit of time saved.

Finally, the assumption of continuity must be removed. The combination of time and money expenditure associated with any given mode is usually (in particular, in the case of public carriers) given to travelers and is not affected by their decisions. Put differently, a trip by a given mode is produced with fixed proportions of time and market goods. Travelers can change the proportions of time and goods only by switching to a different mode. Thus, if one ignores the direct utility derived from the trip and differences in the joint outputs of different modes, then all modes can be regarded as perfect substitutes. The combination of time and money expenditure associated with each mode can be regarded as a point on the isoquant of the activity trip. Let P_i denote the money expenditures (i.e., the units of market inputs are defined so that $x_i = 1$) and let T_i be the time involved in traveling by mode i. Let there be five modes, of which A is the fastest and most expensive and E the slowest and cheapest. In this case, the isoquant consists of five points A, B, C, D, and E (Figure 3). Since it is assumed that $u_i = 0$, the criterion for preferring mode A to mode B (equation 14) becomes

$$(P_B - P_A) + K(T_B - T_A) > 0 \tag{18}$$

i.e., mode A is preferred if the money differential between the two modes is offset by the value of time differential. Alternatively if i is a faster and more expensive mode than j, i is preferred to j if

$$K > (P_i - P_j)/(T_j - T_i) = K_{ij}^* \tag{19}$$

K* is the money differential divided by the time differential. Put differently, it is the amount of money travelers have to forgo to save one unit of time and can therefore be called the price of time. Thus, if their values of time exceed the price of time, travelers prefer the faster mode; otherwise, they choose the slower mode.

The slope of the price line is K, and the optimum combination of time and money expenditure is that where the price line touches the isoquant (mode B, Figure 3).

The optimum point is not a point of tangency, the isoquant being discontinuous at that point. The lack of tangency has in the past created some confusion about what is the value of time, how one should evaluate time savings, and how one can estimate the value of time (3, 5). It is clear from our analysis that there is only one way to evaluate time saving, namely, to use the household's evaluation. The discontinuity in the isoquant results in a difference between the value of time and the price of time. The household's evaluation is determined by its value of time. The price of time can serve only as an upper or lower boundary of that value. Thus, in Figure 3, the value of time is bounded by the two prices K^*_{AB} and K^*_{BC} ($K^*_{BC} < K < K^*_{AB}$). Had the travelers chosen the fastest mode A, the price of time could have served only as a lower boundary, $K > K^*_{AB}$. Had they chosen the slowest mode E, the price of time would have served only as an upper boundary, $K^*_{DE} > K$.

MODAL-CHOICE CHANGE AND DISTANCE OF TRIP

Both the value and the price of time may vary with distance of the trip so that modal choice changes with the distance of the trip. Thus, if it is assumed that the marginal utility of the trip and the marginal product of joint activities (e.g., reading, conversation, work) decrease with the length of the trip, the corresponding increase in the value of time should result in substitution of a faster for a slower mode.

The distance of the trip may also affect the price of time, if the time intensity of the various modes changes with distance. Money expenditures and time elapsed can, in general, be approximated as a linear function of distance M:

$$T_i = \alpha_{0i} + \alpha_{1i}M \qquad P_i = \beta_{0i} + \beta_{1i}M \tag{20}$$

where

α_{0i} = fixed time component of a trip by mode i, e.g., access and egress time, waiting time at the terminal;

α_{1i} = marginal time per kilometer, which depends on the speed of the mode;

β_{0i} = fixed money cost component, e.g., access and egress costs, the fixed component of the fare; and

β_{1i} = the marginal cost per kilometer (the marginal change in the fare).

By equation (19), the faster mode, i, is preferred if

$$K > \frac{(\beta_{0i} - \beta_{0j}) + (\beta_{1i} - \beta_{1j})M}{(\alpha_{0j} - \alpha_{0i}) + (\alpha_{1j} - \alpha_{1i})M} = K^*_{ij} \tag{21}$$

The fixed time component plays a major role in the choice of mode. Differences in access and egress time may offset any advantage a mode has in terms of marginal speed. Thus, mode i will never be chosen when $T_i > T_j$, i.e., assuming $\alpha_{1i} < \alpha_{1j}$, when

$$M < (\alpha_{0i} - \alpha_{0j})/(\alpha_{1j} - \alpha_{1i}) \tag{22}$$

The price of time K^*_{ij} is inversely related to the distance of the trip when an increase in distance increases the time differential ($T_j - T_i$) at a faster rate than the increase in the money differential ($P_i - P_j$),

$$\frac{\partial K^*_{ij}}{\partial M} < 0 <=> \frac{\partial(T_j - T_i)/\partial M}{T_j - T_i} > \frac{\partial(P_i - P_j)/\partial M}{P_i - P_j} \tag{23}$$

i.e., when

$$(\beta_{0i} - \beta_{0j})/(\beta_{1i} - \beta_{1j}) > (\alpha_{0j} - \alpha_{0i})/(\alpha_{1j} - \alpha_{1i}) \tag{24}$$

Assuming $\alpha_{1j} > \alpha_{1i}$ and $\beta_{1i} > \beta_{1j}$, a sufficient condition for equation (24) to be satisfied is $\beta_{0i} > \beta_{0j}$ and $\alpha_{0i} > \alpha_{0j}$, i.e., the fixed money and time components of the faster mode exceed those of the slower mode. Given the location of terminals (airports, rail, and bus stations) and the amount of waiting time required for things such as baggage handling and security checks, it seems that this sufficient condition is satisfied at least in the case of air travel versus ground travel. In this case the passenger does not use the faster mode unless

$$M > \frac{(\beta_{0i} - \beta_{0j}) + (\alpha_{0i} - \alpha_{0j})K}{(\beta_{1j} - \beta_{1i}) + (\alpha_{1j} - \alpha_{1i})K} = M^*_{ij} \tag{25}$$

The price of the trip consists of the money costs P and the opportunity cost of time KT, such that $\Pi = P + KT$. An increase in the value of time K increases the price of the trip by all modes (a shift from Π to Π' in Figure 4); however, it has a greater effect on the price of the time-intensive mode j, resulting in an inverse relationship between the value of time and the switching distance M*. The switching distance of travelers with a high value of time is smaller than that of low-value-of-time travelers ($M^*_1 < M^*_0$).

The relationship between K and M* specified by equation 25 can be described graphically by a rectangular hyperbola (Figure 5). Travelers with a value of time of K_0 use the faster mode only for distances exceeding M^*_0, and travelers with a value of time of K_1 ($K_1 > K_0$) switch to the faster mode already at a distance of M^*_1. Alternatively, the faster mode is chosen for a trip of M^*_1 kilometers only by travelers whose value of time exceeds K_1, and, for a trip of M^*_0 kilometers, the faster mode is preferred by everyone whose value of time exceeds K_0. Finally, the faster mode will never be used by travelers whose value of time falls short of

$$K < (\beta_{1i} - \beta_{1j})/(\alpha_{1j} - \alpha_{1i}) \tag{26}$$

CONCLUSIONS

I have shown that the economic approach that regards travel time as one of the determinants of the price of the trip provides us with a tool for analyzing the demand for transportation and modal split. However, to use this tool for policy decisions or forecasts of the demand for travel by the various modes one must know the value of time. The average wage can be used as, at best, a very crude approximation of the value of time. The difference between the average and the marginal wage rate, the cost incurred through work, the marginal disutility of work, the marginal utility of travel, the possibility of engaging in other activities while traveling, and institutional barriers to changes in the number of working hours may result in a significant divergence of the value of time from the average wage rate. To evaluate the size of this divergence and to obtain a better estimate of the value of time, one must rely on statistical estimation.

The theory suggests two possible approaches to the estimation problem: derivation of the value of time by observing the person's (or the community's) choice between various modes (or routes) and deduction of this value from the demand for a specific mode (trying to isolate the components of the price of the trip Π). Both methods abound with statistical and conceptual difficulties. Since these problems are described in detail in other studies, it is sufficient to mention only one conceptual problem that is emphasized by this analysis.

Figure 1.

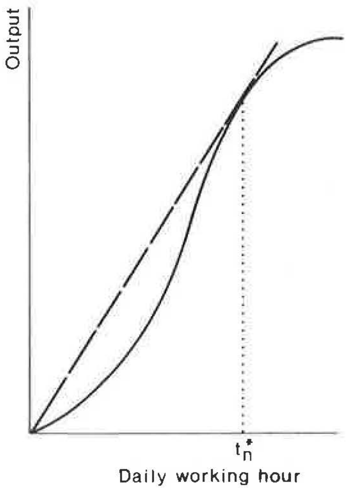


Figure 2.

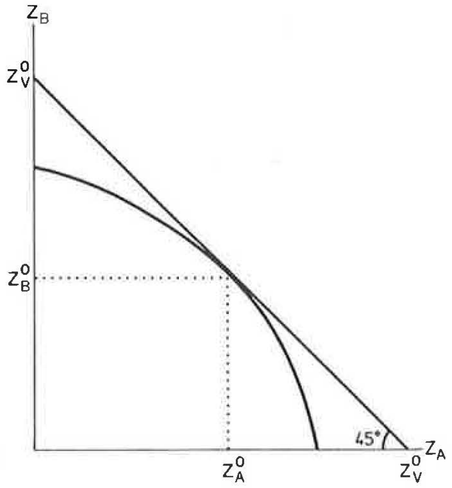
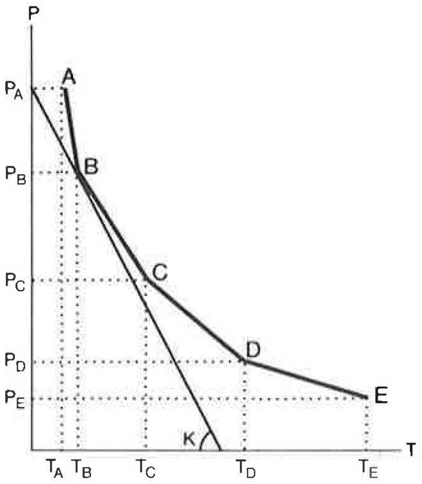


Figure 3.



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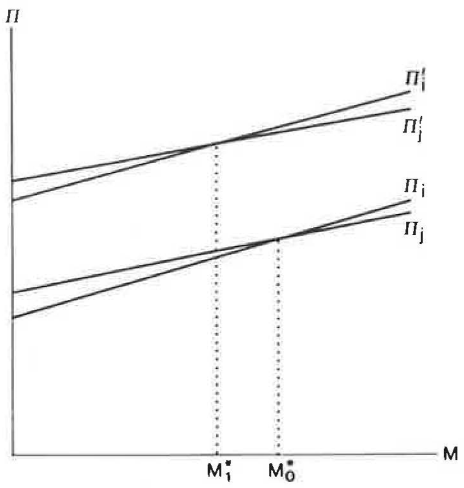
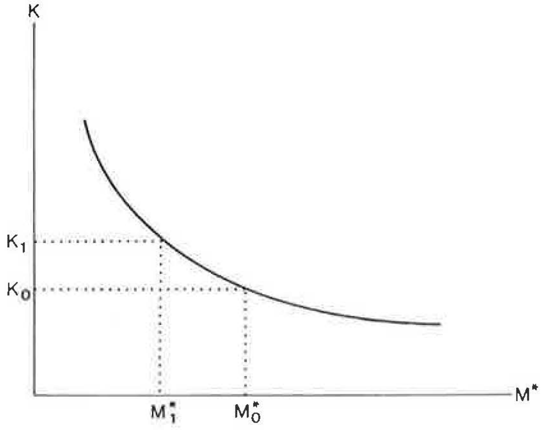


Figure 5.



There is no unique value of time. The value of time varies among individuals according to their income, wage rate, age, education, and family composition. Even for the same individual, the value of time may vary with the purpose and urgency of the trip, the time of day, and the season. Finally, travel decisions are affected by the value of time as well as by the direct utility generated by the trip, which is affected by the convenience, safety, and prestige of the mode of travel and the attributes (e.g., scenery) of the route. Most studies (if not all) fail to separate the direct utility from the value of time. For these reasons, one should not be surprised by the dispersion of the empirical findings. We may have to refine our tools, but this drawback should not diminish the usefulness of this new approach.

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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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Derivation of Values of Time From Travel Demand Models

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Models based on the application of disaggregate behavioral theories and concepts to travel demand modeling are outlined, and problems associated with their application are discussed. The basic hypothesis of these models is stated, and the inference of values of time from mode choice and route choice models is seen to greatly depend on the accuracy and adequacy of the models. A number of methodological and conceptual problems are posed in the achievement of these objectives. A basic problem that demands attention is the determination of how the hypotheses on which the mathematical techniques are based relate to the hypotheses of choice behavior. An empirical analysis and evaluation of the logit, probit, and discriminant analysis techniques and their underlying mathematical assumptions have revealed the problem of determining a basis for comparing models from different statistical techniques. The importance is stressed of establishing statistical validity and confidence in the coefficients of the model variables and of ensuring that the interpretation of the coefficients is not made on the basis of extrapolating the results beyond the range of data. Comments are made on the behavioral interpretation of the coefficients, the time difference coefficient, alternative methods of dealing with user characteristics, and impurities relating to other differences among the modes or routes. The problems of the specification of the models for different treatments of trip segments are discussed, and operational problems associated with theoretical model structures for applying logit analysis to a multiple-choice situation are reviewed.

The basic rationale for deriving values of travel time from travel demand models lies in the assumption that such models reveal the preferences of travelers and therefore indicate the trade-offs among different transportation system attributes. Specifically, if measures of both time and cost of travel by alternative modes, routes, or destinations are included in a model of travel demand, then the rate of substitution of time for money can be determined. However, the majority of travel demand models (21), developed in connection with major urban transportation studies, have been inadequate for inferring time values because of either lack of any system characteristics or the inclusion of only cost or only time.

In attempts to develop more accurate, more responsive forecasting models, a number of models have been developed recently, based on the use of explicit time and cost variables, particularly for the mode choice element of the travel decision process. The models, within this general approach, that appear most applicable for the derivation of travel time values are based on the application of disaggregate behavioral theories and concepts to travel demand modeling. With one major exception (23), the models developed on this basis have been mode choice models (12, 14, 15, 19, 27). It is the basic model, typified by these, that is the primary concern of this paper.

GENERAL STATEMENT OF MODELS

The basic hypothesis of these models is that potential travelers choose their modes or routes of travel by considering the relative efficacy of the available modes, scaled by the individual preference functions of the potential travelers. It is also assumed that the frequency distribution of probabilities of choice of any mode or route, over a total population, is symmetrical and asymptotically approaches zero for very large negative and very large positive values of the total preference function or stimulus (Figure 1). The distribution of cumulative probabilities therefore follows a sigmoid curve from zero at very large negative values of the total preference function to unity at very large positive values (Figure 2).

The first operational problem that must be resolved, in building models that obey these theoretical statements, is to determine a mathematical function that behaves appropriately. A curve such as that shown in Figure 2 could be estimated by a piecewise linear procedure. However, such a procedure requires that arbitrary limits be set on each part of the linear relationship, and this is most likely to lead to a high degree of arbitrariness in the relationship determined. A number of nonlinear mathematical relationships do exist, however, that yield a symmetrical sigmoid curve or an approximation thereto. Among these are probit analysis (5), logit analysis (2), and discriminant analysis (6). The problem with applying any statistical technique to a hypothesized relationship is that the statistical technique may impose constraints or assumptions on the process being modeled. These constraints and assumptions may or may not be consistent with the underlying assumptions and hypotheses of the process being modeled. For instance, probit analysis requires that the probability distribution be a normal distribution; however, discriminant analysis assumes the probability distribution to comprise a combination of two overlapping normal distributions. A more

Figure 1.

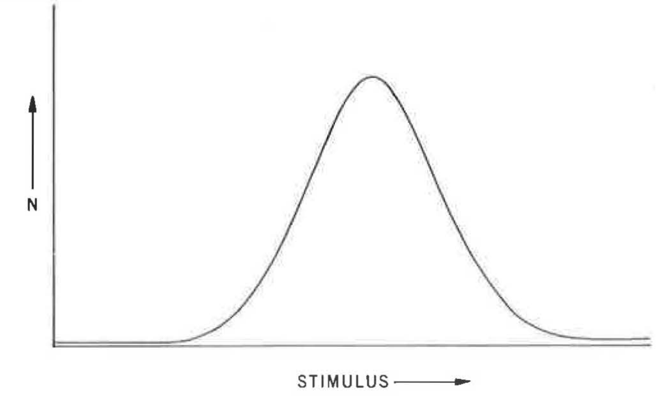
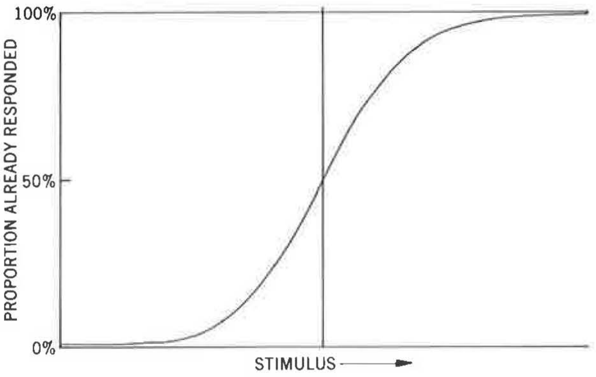


Figure 2.



detailed discussion of these techniques is to be found later in this paper.

All of the mathematical techniques mentioned so far have in common the possibility of using a linear formulation for the preference function of an individual and provide estimates of the probability of an individual making a specific choice. In discriminant analysis, the discriminant function is assumed to be a linear function of user and system characteristics. In probit analysis, the probit, or upper limit of integration of the normal distribution, is similarly assumed to be a linear function, and the logit function may be assumed to be linear (although this is open to choice by the analyst). In general, then, the preference function for any of these techniques may be represented as

$$F_i = \alpha_o + \sum_{t=1}^{n} \alpha_t S_{ti} + \sum_{q=1}^{m} \beta_q U_{qi} \qquad (1)$$

where

S_{ti} = tth system characteristic of a travel mode for individual i,
U_{qi} = qth user characteristic of individual i,
F_i = preference function of individual i, and
α and β = coefficients to be estimated.

In equation 1, the user's scaling of mode or route alternatives is assumed to be represented by the term $\sum_{q=1}^{m} \beta_q U_{qi}$. An alternative, which will be discussed later, would be to assume that the values of α are functions of U_{qi} and that the values of β are all zero.

In models of the general type of equation 1, when S_{ti} includes relative costs and times of travel for two modes or routes, it is possible to infer values for travel time savings. This can be illustrated by taking a simple form of the function F_i in equation 1 and by using cost and time differences for the relative measures:

$$F_i = \alpha_o + \alpha_1(t_{ki} - t_{mi}) + \alpha_2(c_{ki} - c_{mi}) \qquad (2)$$

where

t_{ki} and t_{mi} = travel times by alternatives k and m for the ith individual and
c_{ki} and c_{mi} = travel costs by alternatives k and m for the ith individual.

From equation 2, it is possible to infer a value of time from the rationale of investigating the changes in F_i that result from a unit change in either the time or cost difference. Thus, a unit change in the time difference will cause a change of α_1 units in F_i. The same change in F_i could be produced by a change of α_1/α_2 units of cost. Hence, a value of time may be inferred as α_1/α_2. For example, if α_1 is 0.05 and α_2 is 0.0125, with costs measured in cents and times in minutes, then in this simple case, $\frac{1}{4}$ min saved is equivalent to a 1-cent additional cost outlay, or 1 hour saved is worth $2.40.

Alternatively this function could be rewritten to give a combined cost and time difference for the evaluation of F_i. Hence,

$$F_i = \alpha_o + \alpha_2[(c_{ki} - c_{mi}) + (\alpha_1/\alpha_2)(t_{ki} - t_{mi})] \qquad (3)$$

In equation 3, the factor α_1/α_2 may be regarded as the conversion factor to allow costs and times to be added together. It therefore represents the monetary value of a unit of time. Regardless of the addition of further variables in the formulation of F_i, this inference of a value of time may still be drawn.

Since the coefficients determined by model calibration are for the total sample population and are not specific to each individual, it can be stated that a unit change in the cost difference has, on the average, an equivalent effect to a change of α_1/α_2 units of time difference. This average equivalence is based on observed behavior of choices among modes and routes and results in the estimation of an average value of travel time savings. It is most unlikely that this average value of time will be the marginal value of time savings for any individual. The sample population used to build a model such as equation 2 will generally include three groups of travelers: those who (a) make trade-offs between costs and times, (b) choose a logical alternative that is both faster and cheaper, and (c) choose an illogical alternative that is slower and more expensive. Only the first of these groups provide useful information on positive time values, and these are marginal values only insofar as the actual available trade-offs allow. (For example, a person who gives up a possible cost saving to obtain a time saving will provide the analyst with an estimate of value of time that is less than or equal to his or her marginal value of time; however, the person who makes the reverse decision provides a value of time that is greater than or equal to his or her marginal value of time.)

The major issue here is whether the desire is to obtain marginal values of travel time savings or average values [this problem is raised by Harrison and Quarmby (7), but is not resolved]. The issue clearly depends on the uses to which the time values are to be put. Generally, time values are mainly used in travel demand models and in economic evaluation, as discussed by Reichman and Stopher in papers in this Record. When applied to travel demand models, an average value of travel time savings would probably be acceptable, provided that the mix of traders, logical choosers, and illogical choosers was approximately the same as in the situation in which the time values were inferred. However, if the application called for estimation of travel behavior under circumstances that offered different trade-off opportunities, use of an average value of travel time savings would probably lead to erroneous predictions. Similarly, in applications to economic evaluation, newly created time savings form a major part of the benefits of a potential project. Under these circumstances, it would appear that marginal values of travel time savings should appropriately be used. Since comparisons of marginal and average values of travel time savings have not been made, one cannot assert how serious these problems are or state that average travel time values should not be used for evaluation or travel demand forecasting. However, it is clear that the average travel time values derived from choice models must be used circumspectly and with an understanding of the possible inappropriateness of these values.

However, note that the values of α_1 and α_2 will depend on the sufficiency of the specification of the model and also on the accuracy of measurement of the parameters in the model, the values of S_{ti} and U_{qi}. Both measurement and specification errors will lead to erroneous values of α_1 and α_2 and, hence, to an incorrect value of travel time. Furthermore, the error variance of the ratio α_1/α_2 will be a complicated function of the error variances of α_1 and α_2, particularly if α_1 and α_2 cannot be assumed to be statistically independent.

To illustrate this problem, one may consider a simple (and possibly unrealistic) case in which α_1 and α_2 are assumed to be random, uncorrelated variates (i.e., the covariance of α_1 and α_2 is zero) and in which the ratio is assumed to be normally distributed. In such a case, the variance of the ratio α_1/α_2 is given approximately by [the variance when cov(α_1, α_2) is nonzero is given elsewhere (11, p. 232)]:

$$V(\alpha_1/\alpha_2) = [\alpha_2^2 V(\alpha_1) + \alpha_1^2 V(\alpha_2)]/\alpha_2^4 \qquad (4)$$

where $V(\alpha_1)$ and $V(\alpha_2)$ are the variances of α_1 and α_2. Using the previously assumed values of α_1 and α_2 and assuming the variances of the coefficients to be 0.000 02 for α_1 and 0.000 002 for α_2 give the variance of the ratio α_1/α_2 as $V(\alpha_1/\alpha_2) = 0.78$, approximately. Under the normal distribution assumption, one would obtain 95 percent confidence that the true value of travel time would lie between about \$0.60 and \$4.20. Clearly, such a range of values is excessive. Yet the error variances in α_1 and α_2 provide t-scores for the coefficients of the order of 8.5; these are clearly significant well beyond the 99.9 percent confidence point and define very narrow confidence limits for the coefficients. Hence, it is probable that the error variances of α_1 and α_2 will have to be much smaller for a significant value of the ratio α_1/α_2 than is needed for satisfactory fitting of the basic relationship of equation 1.

Two observations are in order here. First, it is not at all clear that the assumptions made in the above illustration are tenable. Rogers, Townsend, and Metcalf (18) show the value of travel time distributions for five values of time. In all cases, the distributions are skewed, thus placing doubts on the reasonableness of the normality assumption. Lianos and Rausser (13) showed that, provided $E(\alpha_1) \neq 0$ and $E(\alpha_2) \neq 0$, the underlying distribution of α_1/α_2 can be determined and will probably have derivable moments; this permits the computation of a variance but does not necessarily provide a basis for determining confidence intervals (11).

Second, note that, notwithstanding the extent of the theoretical errors of estimation of values of travel time savings, the actual estimates produced by the various studies have been remarkably close. Most studies have provided estimates of commuter travel time values that range between 20 and 40 percent of the wage rate for most income groups and that represent dollar values of between \$1.75 and \$3.50 per hour of commuter travel time in most cases. These average travel time values clearly lie well within the confidence limits suggested by the above example. However, this may suggest that apparent systematic variations in travel time values with income are spurious and coincidental. Certainly, no investigator has explicitly reported thus far on any detailed analysis of the statistical significance of time value variations across income groups. This is clearly a potentially useful research topic that could yield significant information.

In summary, the inference of values of time from mode choice and route choice models greatly depends on the accuracy and adequacy of the models; as yet, this form of modeling is still in its infancy. It poses a number of problems that need to be addressed so that the time values resulting from this type of analysis will be less subject to question than they are at present. The remainder of this paper details a number of these problems and suggests some possible research that might lead to their successful solution.

METHODOLOGICAL AND CONCEPTUAL PROBLEMS

Mathematical Technique

As previously noted, the types of models that are most responsive to the inference of time values are probabilistic, disaggregate models that have been constructed by using probit, logit, or discriminant analysis. One of the major differences between this type of modeling process and the more conventional travel demand modeling is that the underlying basis of these probabilistic models is a hypothesis of the choice behavior of an individual. This results in more efficient use of data and tends to lead to the construction of more statistically reliable models. Furthermore, the disaggregate models have almost exclusively incorporated measures of both time and cost, thereby permitting an analysis of revealed trade-offs. [The primary instance of an aggregate model that included both times and costs is the Traffic Research Corporation model (9), but this used ratios and therefore does not supply a single estimate of an average value of travel time.] Since the primary purpose of this paper is to discuss how values of time have been derived from travel demand models and not how they could be derived, the derivation from aggregate models is not discussed in detail here. Suffice it to say that there appears to be no a priori reason why aggregate models should not be used as a basis for deriving values of travel time. However, it does seem likely that such models will be more seriously affected by statistical significance issues and the averaging effect on the derived values.

The basic problem is to determine how the hypotheses on which the mathematical techniques are based relate to the hypotheses of choice behavior. This problem has so far not been tackled in great depth within the context of travel choices. It is perhaps worthwhile to note some of the issues that are encountered in tackling this problem; these, in turn, form the basis of possible research to resolve the problem.

For the most part, the hypotheses on which each technique is based do not appear to be unreasonable but do differ significantly. Although hypotheses can be proposed on the choice process of an individual, information on the actual choice process is insufficient for clear judgments to be made regarding the appropriateness of such hypotheses and the applicability of the mathematical techniques per se. Therefore, methods must be devised for comparing the results of the applications of the three techniques, and all the mathematical assumptions underlying the techniques must be fully investigated and evaluated against the observed properties of the individuals whose choices are being modeled.

An initial empirical analysis of this type has been attempted (22) and has clearly demonstrated some of the problems that arise in such an empirical task. The major problem that arises is determining a basis for comparing models derived from different statistical techniques. This problem, and some solutions to it, are discussed in detail elsewhere (22) and will not be repeated here. The results of that research suggest that discriminant analysis is somewhat inferior to probit or logit analysis, and that the latter two are statistically indistinguishable in performance. However, these results are based on restricted data sets and cannot be assumed to be generally applicable. The procedure used in that work (22) to compare the mathematical techniques does appear, however, to be useful for general application to other data sets. Additional development of comparative techniques would, however, be considerably beneficial for resolving the question of mathematical procedures for model building.

Meaning of Coefficients

Since the probabilistic, disaggregate travel demand models are based on a hypothesis of choice behavior, attempting to place behavioral interpretations on the coefficients of the model variables (values of α and β in equation 1) does not appear to be unreasonable. Effectively, the inference of a value of time from these models is such an interpretation. This specific interpretation will be treated in more detail in a later section of this paper.

Before any interpretative statements are made about the coefficients, the statistical validity and confidence in these coefficients must be established. Care must be taken to ensure that the interpretations are not made on the basis of extrapolating the results beyond the range of the data. Until knowledge of the entire modeling procedure is radically increased, extrapolations outside the range of data used for calibration must be fraught with dangers, particularly since confidence that the model accurately reflects the underlying choice process is currently unestablished.

Little can be said at present about the behavioral interpretations of the coefficients of transportation system attributes other than time and cost since the development of models that incorporate further terms is still a matter for future research. However, some researchers have attempted to include comfort or convenience indexes (12, 29). Interpretations of such coefficients will also depend somewhat on the mathematical technique adopted for model building and on the solution to other problems dealt with later in this paper. Since general results have not yet been achieved for attributes other than time and cost, interpretations of other coefficients will not be discussed here. One of the major problems of concern is the inclusion of user characteristics in the model and the way in which they are included.

In many cases, the travel demand models discussed here have entered user characteristics as additional linear variables, as shown in equation 1. This is effectively a statement that the time difference coefficient is a linear function of income. The linear form of inclusion is effectively a behavioral assumption that the choice is based on system characteristics by themselves, with the addition of an individual bias. This bias is the additive value of the user characteristics in the model. However, an alternative assumption is possible that, in many ways, appears to be more intuitively satisfying in terms of behavior. This assumption is that the weights (coefficients) attached to each of the system characteristics will depend on the user characteristics. In other words, an individual bias is assumed to exist on the importance of each system characteristic rather than on the final choice. This form of assumption can be represented mathematically as follows:

$$y = \alpha_0 + \sum_{t=1}^{n} \alpha_t' S_t \tag{5}$$

where

$a_t' = f(U_1, U_2, \ldots, U_m)$ and
y = general preference function, such as probit Y and log G(X).

In a few instances, alternative methods of dealing with user characteristics, notably income, have been attempted. A number of studies (4, 8, 12, 25) have entered income as a multiplicative term with time difference. The use of such a product term is a restricted version of the second assumption, discussed above, since it assumes that one coefficient is a function of one user characteristic. It is interesting to speculate why income should, in these applications, be considered to affect the weighting of time differences only, and not cost differences. The rationale appears to have been one of attempting to evaluate directly an income-dependent value of travel time savings. Inclusion of income in more than one variable may conceivably generate serious intercorrelations among the variables, thereby leading to poor estimations of the model coefficients. For elimination of this problem, data may be stratified by income, and separate models built for each of several income groups (8, 19, 22). Significant differences occurred among all coefficients over the different income groups except in Hensher's data (8), where small stratum populations led to large standard deviations on the coefficients and relatively poor curve fitting.

Clearly, these two alternative assumptions have extensive implications on the meanings attributed to the coefficients of the system characteristics.

There is, however, one element of the model that is largely unaffected by such assumptions. This is the constant term α_0. For interpretation of the meaning of the constant, a possible functional form may be considered. Let

$$y = \alpha_0 + \sum_{t=1}^{n} [\alpha_t(S_{t1} - S_{t2})] \tag{6}$$

and assume a logit model of the form

$$P_2 = e^y/(1 + e^y) \tag{7}$$

If choice depends on the differences in mode or route characteristics, then two modes or routes with the same system characteristics should yield a 50:50 split, i.e., $P_2 = 1/2$. Inspection of equation 7 shows that when $P_2 = 1/2$, $y = 0$; this will only occur with identical system characteristics if α_0 is also zero. If α_0 is not zero, then identical system characteristics give rise to a value of P_2, such as

$$P_2 = e^{\alpha_0}/(1 + e^{\alpha_0}) \tag{8}$$

Hence, the constant term α_0 represents the bias for or against the second alternative (equation 8) on grounds other than the specified system characteristics. It may be proposed, alternatively, that y is given in terms of a linear function of both user and system characteristics:

$$y = \alpha_o + \sum_{t=1}^{n} [\alpha_t(S_{t1} - S_{t2})] = \sum_{q=1}^{m} \beta_q U_q \qquad (9)$$

In equation 9, α_o has two possible interpretations. If user characteristics are fully specified, then α_o has the same interpretation as before. If user and system characteristics are both only partially specified, then α_o will represent the bias for or against an alternative compounded both of individual bias and the effects of nonspecified system characteristics. It is clear therefore that the constant term has no bearing on the value of time or on the meaning of any other coefficient.

However, incomplete specification of the model will affect the value of the coefficients of time and cost and also the constant term. Certain elements of comfort and convenience are most probably time dependent, e.g., standing may be acceptable for 5 min but is unlikely to be so for 30 min. If comfort and convenience variables are not specifically included, then some part of the choice variance associated with the time-dependent comfort and convenience attributes is likely to be included in the travel time coefficient. Since some of these comfort and convenience attributes will be likely to vary not only by mode but also by time of day and direction of travel, the inference of a single value of time from such incompletely specified models is of somewhat dubious value. The theoretical analysis of de Donnea (4) provides an additional reinforcement to this argument and clearly demonstrates that a true value of time can only be derived from a fully specified choice model.

These considerations of comfort and convenience will also apply to route choice models, in relation to time-dependent attributes of comfort and convenience between alternative routes. Although past route choice derivations have explicitly assumed that only cost and time differences exist between toll roads and free roads, there are probably comfort differences also, some of which will be time dependent.

The danger of lack of specification in the choice models is that the value of travel time derived will include impurities relating to other differences between the modes or routes. The presence of these in the estimated value of travel time will then have serious and important implications regardless of whether the value is used in other demand models, or as part of an economic evaluation procedure.

There is some extensive controversy surrounding the idea of a true or pure value of travel time. It is generally accepted that different travel activities generate different utilities. For example, waiting probably has far less utility than walking, which, in turn, probably has less utility than riding in a vehicle (7, p. 3). However, waiting in a bus shelter probably has a different utility than waiting on a street corner or in a subway station. Thus, the utility of the time spent in an activity depends on the activity content of the time and the circumstances under which it is consumed. A number of studies have divided time by activity content (14, 29), but no studies have addressed the circumstances in which the activity is carried out. Furthermore, the segmentation of travel time does not address problems such as the difference between waiting for a vehicle transfer and waiting for a demand-actuated vehicle (e.g., taxi, dial-a-bus vehicle), where this is the sole mode of travel for a trip.

The existence of a pure value of time is a subject for philosophical debate. However, there are a number of parameters associated with the utility of travel time that should be explicitly recognized and taken account of so that values of travel time can be derived that can be applied under different travel circumstances. Segmentation of travel time will partially achieve this. Quantification of convenience and comfort may provide some, or all, of the balance of the required information.

The initial research for this problem is to determine means of including, explicitly in the models, variables describing attributes such as comfort and convenience. This requires, first, the derivation of some form of mathematical expressions for various comfort attributes of travel modes and routes and, subsequently, the development of models that include these attributes, insofar as they are important to the decision-making process. Methods of marketing analysis and psychometric scaling techniques appear to hold out the greatest promise for proceeding toward this goal.

Trip Segmentation

The majority of trips made in an urban area comprise several segments. Most commonly, transit trips comprise three segments: access to the transit facility, line-haul, and egress to the final destination. In relation to values of travel time, the problems that arise here are principally two: how to build a mode choice model for such a situation and the implications of this trip structure on the value of time.

This paper will not discuss at length the options for handling trip segments in mode choice models [a number of alternatives are discussed elsewhere (17)]; it will focus on the specification of the models for different treatments of trip segments. As discussed in the preceding section, problems arise mainly when the models are not fully specified. Trip segments may be handled by dividing up the times and costs between the segments, e.g., access, egress, and line haul, or by taking line-haul times and costs only or by using an average overall travel time and cost. Under each of these alternatives, with incomplete specification of the system attributes, different values of time will be obtained. Quarmby (14) found considerably different values of travel time for overall travel time and excess travel time (e.g., walking and waiting). Other researchers have similarly found different values for different pairs of modes (19), and work in Chicago has yielded different values of time for each of walking time, waiting time, and line-haul time.

Again, problems arising from alternative treatments of trip segments can be resolved by full specification of system variables. This includes not only measures of comfort and convenience but also complete specification with respect to the separate segments. A treatment using only line-haul system characteristics or only access and egress characteristics probably would yield inflated or deflated time values because of the lack of specificity.

Measured and Perceived Mode Attributes

An important consideration in formulating behavioral mode choice models is the relation between objective and subjective estimations by the traveler of the system characteristics. Objective values are those values that are determined by engineering measurement, although subjective values are those values perceived by the (potential) traveler. The difference between objective and subjective values of, say, travel times or travel costs arises from two sources. One is inadequate information about, or experience with, alternative modes. With inadequate information or experience, people will, to make choices, fill in the necessary judgments subjectively. Obviously, this may bear little relation to objective reality but is nevertheless the basis on which choices are made. Another is a bias that persists even with adequate knowledge of the alternatives. By definition, this bias is a stable preference function.

It is obvious that, for both predictive validity of the model and valuation of travel time differences, the former process is most critical since it may be assumed that any effects of a stable preference function may be resolved by a simple linear transformation. In fact, model calibration achieves this. The problem caused by lack of information is that a priori there is no way of knowing how these deviations from objectivity are distributed nor at what rate learning modifies the subjective values to make them approach objective ones. Ideally, if the distribution of subjective values around objective values of the system is normal, the errors will sum to zero. Alternatively, a consistent relationship may exist between subjective and objective values.

Since time values, inferred from behavioral mode choice models, are derived from the coefficients of time and costs in the models, the primary concern for accuracy of the time values will arise from the traveler's comparative knowledge of these two parameters. It is clear from the work of Watson (28) that research is needed to investigate the biases and patterns of random estimates of mode and route attributes. This may initially be undertaken by building travel choice models on the basis of objective measures of mode attributes and, subsequently, by investigating the unexplained variance. A large unexplained variance for the model would be indicative of a large, and therefore important, random estimation element in subjective values of mode attributes. It is not yet clear what research effort might then be needed to analyze and measure this random estimation element, assuming it is measurable.

Variations in Value of Time

The discussion in this paper has referred to only one time value or to one that might vary according to the relative disutility of certain trip segments, and to assume that only one value of time exists seems implausible. Currently, several different studies have suggested that the time spent on the journey to work is valued at about one-quarter to one-half of the wage rate. On the other hand, vacation travel appears to be valued at between ½ and 1½ times the wage rate (26). To hypothesize that the value of travel time will vary with trip purpose therefore seems reasonable. Such values can probably be obtained by studying travel choices for the various trip purposes and calibrating models to explain the choices. However, the traditional breakdown of trip purposes used in current transportation studies (3) may not necessarily be the ideal set to permit identification of the most pertinent travel time values. In carrying out studies of non-work-trip travel choices, consideration must first be given to hypotheses of variation in travel time values and model formulations as the basis for determining the most appropriate strata for trip purpose.

The stability of time value with trip length or with time savings is also of concern. First, most of the probabilistic models developed so far use time and cost differences and have been calibrated on relatively short trips (usually <1 h). The hypothesis behind the use of differences is that time and money savings or expenditures are valued the same whether they are obtained on a 10- or 60-min trip. There is good reason to suppose that this hypothesis does not hold for long trips and that the value of time and cost savings will be modified by the total outlay of time or money involved on a long trip. For example, Watson (29) found that travel time difference divided by total journey time was more effective for his intercity study than simple travel time differences.

In addition, the values of time determined from present travel choice models have been determined for a relatively small range of time differences (generally, from 5 to 20 min), and the stability of the values by time saving and the validity of extrapolating values to smaller or larger time savings beyond the observed range have been the subject of relatively little research (25). This problem requires further research but, by its nature, also requires a much larger data set than has generally been available in the past for probabilistic travel choice modeling. Extension of the range to smaller time savings may be potentially very troublesome, however. By the time one is considering values of time savings of less than 5 min, the time savings involved appear to rapidly approach the point at which they no longer affect travel decisions. Furthermore, reported time values are generally accurate only to the nearest 5 min and thus provide the analyst with insufficient information to investigate the effects of very small time savings. Hence, estimation of the value of time for small time savings is likely to be subject to considerable random variance.

CONCLUSIONS

This paper outlines the basic methods of inferring values of travel time from travel choice models and discusses a number of the problems that arise in this application. In general, little research is in hand to determine the solutions to these problems.

Most of the problems discussed have as much bearing on the production of valid travel choice models as they have on the production of valid travel time values. As such, it appears that a major research effort on the building of probabilistic, disaggregate travel choice models is one of the possible ways to resolve the problems of travel time evaluation. Both the travel time values and travel choice models from this approach would be considerably useful to decision makers in evaluating alternative transportation plans.

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Applications of Value of Travel Time to Economic Evaluation of Transport Investment Alternatives

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This review of conventional evaluation techniques and the changing viewpoints and techniques of economic evaluation focuses on the principal techniques applied to transportation investment, the estimation and uses of travel time values, and the value of travel time in cost-effectiveness analyses. The implications of the value of travel time for techniques involving cost-benefit estimation are also examined. The primary constituents of user benefits are reduced travel time and reduced automobile operating costs. This gives rise to the need to convert time savings in minutes to an equivalent monetary value. An attempt is made to establish what time values are relevant for economic evaluation, and it is stated that nonworking time has value and that this value should be used to determine benefits accruing from transport projects that result in time savings. The value of travel time will enter the evaluation process through the procedures for estimating future use and travel times on a new transportation facility. The problems encountered in such use of travel time values are discussed. These include the possible inaccuracies in travel time estimations, the estimation of monetary value of time savings, the problems associated with variations in travel time value, and the estimation of the amount of induced traffic. The value of induced travel time and time savings, together with the issue of consumer surplus are also discussed. An alternative evaluation technique that is superseding cost-benefit analyses is cost-effectiveness. In this technique, which is based on the systems analytic approach to transportation planning and which does not require the conversion of time savings into monetary terms, the achievement of certain time savings may be expressed as a goal of the transportation project. This can be directly assessed for effectiveness. Use of cost-effectiveness will lead to changes in uses of the values of travel time and travel time savings. Such values will assume increased importance in determining goal achievement and in permitting goal modification in an evaluation process that seeks to achieve prespecified goals.

In the process of planning investment in transportation, one can usually find an evaluation phase, designed to assist the decision maker in choosing among alternative plans or in deciding whether to invest money in transportation at all. This evaluation process is intended to answer two basic questions: Is the plan worthwhile? and If the plan is worthwhile, when will it be worthwhile? In transportation investment, these questions are customarily asked of the users of transportation facilities (or the potential users) to estimate how worthwhile the project is in monetary terms. In the last few years, the entire framework of economic evaluation has entered into a state of changing viewpoints and changing techniques. These will be dealt with, however, in more detail, later in this paper. For the present, the concern is with the conventional evaluation techniques.

At least three principal techniques of cost-benefit analysis have been applied to transportation investment: net present worth, cost-benefit ratios, and internal rate-of-return (13). These techniques can be applied with varying degrees of sophistication. From the viewpoint of the economist, the techniques should be applied by estimating costs and benefits for each year of the project life and by appropriately discounting these monetary streams to the present, or a base year. In practice, highway economists estimated costs and benefits for an average year in the life of the project and computed the economic evaluation on the basis of such figures. Implications for the value of travel time will be examined for both procedures of application of the techniques.

In such economic evaluation procedures, the costs and benefits, for each alternative plan, must be determined. The costs associated with highway projects would generally comprise planning, right-of-way acquisition, construction, maintenance and policing of the facility, relocation costs, accident costs, and user travel costs. The total benefits of the project in an economic evaluation have generally included (according to highway economists) the user benefits. Clearly, the above listings of costs and benefits are not irrefutable. Apart from any other questions, costs can be regarded as negative benefits, or benefits as negative costs. In many cases, a clear distinction between costs and benefits does not exist. Yet the evaluation procedures (with the exception of net present worth) call for computations that are clearly sensitive to the definition of costs and benefits. However, Fleischer (5) has shown that, as long as a consistent treatment is used for all elements of costs and benefits for all alternatives, in terms of classification into either costs or benefits, the three methods of economic evaluation will lead to a single ranking of the alternatives.

The primary constituents of user benefits are likely to be reduced travel time and reduced automobile operating costs. For an economic evaluation, such benefits must be expressed in monetary terms, hence giving rise to a need for values of travel time savings to be applied to convert time savings in minutes to an equivalent value in, say, dollars and cents.

ESTIMATION OF TRAVEL TIME VALUES

As noted above, the major context in which travel time is valued is in terms of savings of travel time related to highway or other transportation projects. It should be stressed that travel time cannot actually be saved and, in fact, no form of time can be saved—it can simply be used in an alternative manner. Therefore, the concept of travel time savings refers rather to a diversion of time, which would have been used for traveling, to some other use. It should first be established why travel time, or travel time savings, should have a value. That travel time spent during working time has a value is obvious. Such time is being paid for by an employer and therefore has value or worth to the employer. Similarly, a saving of such time should permit that time to be diverted to more productive uses; this would increase gross national product (GNP) and appear in national income accounting. Any time, other than time spent traveling during working hours, should have a value because of an individual's ability to use that time for some other purpose and thereby to increase his or her total utility. To a large extent, the value that such time will have is related to an individual's perception of what he or she can do with the time that is saved from travel and that is in no way related to the GNP.

There has been a lengthy controversy over the existence of a value for travel time that is incurred during nonworking time. Numerous viewpoints have been put forward relating to travel time values of nonworking time. There is a strong segment of opinion that maintains that leisure time can in no way be traded for goods or services, and therefore has no economic value (12). Another opinion holds that, since savings of nonworking time are not reflected in GNP, they should not be considered in an economic evaluation of a public project. In my opinion, the latter statement demonstrates a shortcoming of national income accounting rather than a valid argument for the exclusion of travel time savings of nonworking time in the economic evaluation of alternative transport projects.

The existence of overtime rates of pay has led at least two writers to diametrically opposite opinions about the existence, or nonexistence, of a value of nonworking travel time. Bellis (2) states that

> Some authorities like to equate vehicle time to earning power. This seems acceptable for commercial vehicles but not for passenger cars. A man's leisure time is worth more than his working time as evidenced by the one-and-one-half time and double time for overtime.

On the other hand, Glassborow (6) says that

> In practice, both the eagerness shown by workers to obtain their share of overtime, and the insistence in agreements to reduce working hours that the weekly wage shall be unchanged, attest that little value is placed on leisure and high price on effort.

In general, however, prevailing opinion among transportation planners and highway economists is to accept the idea that nonworking time has value and that this value should be used to determine benefits accruing from transport projects that result in time savings.

The concepts and mechanics of placing values on travel time savings are discussed by Reichman and Hensher in papers in this Record and will not be discussed here. It is sufficient for the purposes of this paper to establish what time values are relevant for economic evaluation.

USE OF VALUES OF TRAVEL TIME IN EVALUATION

In standard economic evaluation procedures, value of travel time may potentially enter the calculations in two roles. An important factor in the evaluation procedure is the estimation of future travel on the facility under study. This forecast of travel will provide estimates both of the number of users of the facility and of the travel times on the facility, the latter being determined through speed-volume-capacity relationships. For computing future travel volumes, a set of travel demand models should be used. Reichman and Stopher in a paper in this Record point out that it is becoming increasingly apparent that value of travel time is an important constituent of travel demand models. Hence, it is possible that value of travel time will enter the evaluation process through the procedures for estimating future use and travel times on a new transportation facility.

A major constituent of the benefits of a transport investment has frequently been travel time savings. Such savings are estimated by the technique discussed in the previous paragraph. So that such benefits can be entered into a cost-benefit procedure, the travel time savings must be expressed in monetary terms. This monetary conversion is accomplished by the use of the value of travel time. Hotchkiss and Hensher (8) estimate that 25 percent of all economic benefits from urban road works in Australia were attributable to travel time savings. Of the benefits from the U.S. Interstate Highway System, it has been estimated that between 72 and 81 percent are derived from travel time savings (4). Clearly, the determination of time savings and the conversion of time savings to monetary measures are no mere academic exercise but are rather an extremely important part of the execution of an economic evaluation. It is also clear that, since travel time savings appear to have such a prominent place in total transport benefits, misestimation of the benefits accruing in monetary terms, from travel time savings, will have a serious effect both on the determination of the economic viability of a particular transport project and on its ranking among other alternatives.

The problems of the methods for determining values of travel time and the estimation of reliable values have been dealt with elsewhere [(7) and in a paper by Stopher in this Record] and will not be discussed here. Assuming that reliable and correct values have been determined for the present values of travel time, many problems yet exist for applying these to an economic evaluation. It is these latter problems that are the main concern of the remainder of this paper.

Future Values of Travel Time

Since any transportation project will be accompanied by costs and benefits over a period of time into the future, future time savings must be estimated and converted to monetary terms. This requirement gives rise to two problems. The first problem is estimating future travel time savings. For economic evaluation, future travel time savings should be estimated at least at yearly intervals. The procedure for this will involve the estimation of traffic volumes and, hence, travel speeds for the facility under consideration. Present travel forecasting techniques are inadequate for predicting travel for a single point in the future and involve an extremely cumbersome procedure to provide such a prediction. Estimation of yearly travel volumes would therefore require excessively expensive computation, yielding forecasts of doubtful accuracy and usefulness. For estimates of travel speeds and, hence, time savings, the estimated travel volumes must be substituted into a speed-volume relationship. Differences of speed from one year to the next are likely to be small, and the estimation of them will be subject to considerable inaccuracy. This inaccuracy will be compounded by the errors generated in producing the forecast travel volumes. Thus, the estimation of future travel time savings is fraught with inaccuracies and problems, and the estimates obtained must be handled circumspectly.

The second problem is to estimate the monetary value of these travel time savings. It has been customary to apply a single value of travel time, based on present measurements, to estimate the monetary value of future travel time savings. However, several studies have suggested that the value of travel time is related to the individual's income level (1, 9, 11). If this is the case, then values of travel time will change as real income changes; this introduces a requirement to estimate values of travel time for each year of the project life, based on forecast real income increases.

Given the past importance of travel time savings in the benefits of transportation projects, it is clear that the problems described here should be the concern of some major research effort. Clearly, the adoption of the present value of travel time will lead to an underestimate of benefits (with a growing economy) and, thus, more cautious investment decision making. However, the effects of the misestimation of the travel time savings cannot be easily categorized as leading to underestimation or overestimation of benefits. The conclusion to be drawn here is that the primary research should be to improve estimates of future amounts of travel and future travel speeds, rather than to improve value of travel time estimates alone. It is also relevant that time savings are real benefits generally only for rural projects and for public transit investments. Urban highway projects may generate reduced travel times for a short period of the investment life, but the prime benefits of such projects are in increased capacity and therefore increased mobility. In both cases, benefits will be closely related to future travel amounts, but will be less closely related to value of travel time per se. In that value of travel time may play a major role in estimating future travel (as discussed by Reichman and Stopher in a paper in this Record), then value of travel time still plays an important part in providing estimates of the benefits of proposed transportation investment.

Multiple Values of Travel Time

Recent work has suggested both empirically (11) and theoretically (3) that a number of values of travel time may exist. Specifically, it appears that value of travel time is likely to vary with traveler income, trip purpose, and amount of time saved (11). If such variations in value of travel time are of any significance, then it would seem necessary to incorporate the separate values in the estimation of benefits from transportation projects. Such a procedure clearly compounds the problems of benefits calculation as discussed in the previous section.

First, the use of multiple values of travel time will require that future values of each travel time value be estimated for the project life. Second, it will necessitate that traffic flows on a projected facility be determined by trip purpose, income, and amount of time saved so that monetary travel time savings can be estimated. Furthermore, this breakdown of traffic flows would need to be estimated at yearly intervals for the entire project life in a strictly correct economic evaluation procedure.

Given the present inadequate ability to make annual predictions of traffic flow on a facility, particularly on a planned facility, whether the complexity of computation described here has any justification is questionable. The first question for research to answer is whether this degree of detailed estimation of traffic flows can possibly be achieved. If it can be achieved, then the next question is to determine if the detailed estimation of time savings will likely lead to different decisions than would be made based on a more gross estimation procedure. If the answer to either of these questions is negative, then research is needed to determine what, if any, separate estimation of travel time savings and values of travel time are required and how aggregate values of travel time should be estimated. For instance, if it is determined that one value of travel time should be used for time savings of less than 1 hour, one must still specify how a value, for all time savings less than 1 hour, should be calculated.

Induced Traffic

The discussion of the estimation of benefits has thus far been concerned primarily with benefits from time savings. However, many of the benefits from transportation projects, particularly urban highway projects, may accrue from the provision of increased capacity that is used by travelers making trips not made before, i.e., induced traffic. So far, attempts to estimate the amount of additional travel that will occur as a result of an improvement in a transportation facility have met with little success. Thus, the first problem in this area is to be able to estimate the amount of induced traffic. It is, of course, most probable that the estimation technique will involve the use of values of travel time, since demand for travel will be related to such values.

The second problem relates again to the specific values of travel time. The discussion thus far has focused on values of travel time savings. In the case of induced travel, however, the appropriate value is the value of travel time, not just that of travel time savings. As has been discussed by Stopher, in a paper in this Record, travel time savings and total travel time quite likely will be valued differently. At present, no values have been put forward for total travel time nor has any theoretical work been done to show how such values should be derived.

Apart from the fact that distinctions between induced travel and other travel and between the value of total travel time and travel time savings will lead to different estimates of benefits for specific alternatives, they may also lead to radically different transportation policies. Based on a traditional highway economics approach, if total travel time is valued more highly than travel time savings, then projects that provide considerably increased capacity and are likely to induce large amounts of additional travel are likely to be favored over projects that would speed up present travel movements. In fact, because of the difference between total travel times and possible time savings, if total travel time has positive value, greater benefits will probably always accrue to one induced trip than to one trip on which a time saving is possible.

Research is clearly needed in the prediction of induced traffic and in the evaluation of the value of total travel time. The first of these research topics is the determination of the demand and supply schedules for travel. Induced travel is simply the effect of a shift in supply for a given demand schedule. The fact that current estimating procedures do not provide adequate estimates of induced travel is largely a reflection of the fact that current so-called travel demand models are not demand models in the sense of estimating the demand schedule for travel.

Finally, the estimation of benefits from travel time savings constitutes an estimation of the increase in consumer surplus for existing travelers. On the other hand, the estimation of benefits from increased travel, although some consumer surplus is included, is largely an estimate of increased consumer expenditure on travel. It has been argued (13) that consumer surplus should not be included in estimating the benefits from transportation projects. If one accepts such arguments, then the benefits from transportation projects are total consumer benefits minus consumer surplus. Such benefits also, like induced travel, require estimation of the value of total travel time. Thus, consumer surplus changes can be estimated by using the value of travel time savings, although net consumer benefits require the use of the value of total travel time.

VALUE OF TRAVEL TIME IN COST-EFFECTIVENESS

The emphasis in the paper has thus far been on the value of travel time as a means to convert the travel time savings, resulting from a proposed transportation project, to monetary terms for use in a cost-benefit analysis. An alternative evaluation technique, which is, to some extent, superseding cost-benefit analyses, is that of cost-effectiveness analysis (10). This technique is rooted in the systems analytic approach to transportation planning, in which a primary task is to specify goals to be met by any transportation project. The cost-effectiveness approach then assesses the degree to which each goal is met by a potential project and the cost at which goal achievement is attained. The analytical stage of the evaluation terminates when the information on costs and goal achievement has been arrayed. The decision maker is then able to select a project on the basis of the information provided by the analyst. It should be noted that, unlike traditional cost-benefit analysis, cost-effectiveness analysis does not aim at rank ordering alternative projects, nor does it usurp the role of the decision maker.

More important for this paper, the cost-effectiveness approach does not require the conversion of time savings to monetary terms so that an evaluation can be carried out. Rather, the achievement of certain time savings may be expressed as a goal of the transportation project and, thus, can be directly assessed for effectiveness. Furthermore, careful specification of goals that relate to travel time can remove many of the problems generated by the more traditional valuing of time savings in cost-benefit analysis. Problems relating to equity, whose travel time should be considered, and times of day when travel times should be affected can all be handled adequately by goal formulation. Conversion of time savings to monetary savings is clearly no longer required.

It might be concluded from this that the replacement of cost-benefit analyses by cost-effectiveness analyses would lead to the disappearance of the need for values of travel time, at least in what has traditionally been the major application area for such values. However, a consideration of the requirements of cost-effectiveness analysis shows such a conclusion to be misleading. Although the role of values of travel time savings as converters of time to money may disappear with the adoption of the cost-effectiveness technique, values will still be required to determine the effectiveness of a transportation project. The assessment of the effectiveness of a project in achieving various goals, including but not limited to travel time goals, will generally require estimation of the travel volumes that will occur if that project is adopted. As discussed by Reichman and Stopher in a paper in this Record, values of travel time savings are likely to play an important part in travel forecasting processes. In fact, if current travel forecasting trends are maintained, values of travel time are likely to play an increasingly important part in the travel forecasting process.

Finally, a planning process that seeks to achieve prespecified goals is not necessarily irrevocably tied to a single set of prespecified goals. The goals set may be such that achievement of all goals is not possible within the available (or any reasonable) budget or under any possible transportation project. Under such circumstances, some modification of goals is likely to be undertaken to permit the planning process to generate some alternative projects. This may frequently happen when goals are mutually exclusive, and the modification may be to set lower levels of achievement for one or more goals. For example, goals of increased mobility and reduced environmental pollution are likely to be jointly unattainable under present technology unless one is careful to specify by how much mobility is to be increased and pollution reduced. The modification of goals in this manner is, effectively, based on a value judgment. The analyst, or the decision maker, is placed in the position of determining which goals to hold unmodified and which ones to modify and by how much. Knowledge of values of travel time could be instrumental in assisting such goal modification by making explicit the value of one goal, against which modification of another goal could be assessed. In the earlier example, for instance, a reduction in the mobility goal could be determined as being equivalent to a certain penalty in travel times. Such a reduction might allow the pollution goal to remain unmodified. The cost of retaining the pollution goal could thus be determined.

In summary, the use of cost-effectiveness as an alternative evaluation procedure to cost-benefit analysis will lead to significant changes in the uses of values of travel time in evaluation, but will probably not lead to any diminution of their importance. Instead of being used as a conversion mechanism for travel time savings, values of travel time and travel time savings will assume an increased importance in determining goal achievement and in permitting goal modification in an evaluation process that seeks to achieve prespecified goals.

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Conceptual Problems in Evaluation of Travel Time

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A number of conceptual problems in the evaluation of time as currently practiced are discussed. A number of assumptions implicit in a theoretical approach to the value of time are stated explicitly, and two economic analyses of the value of time are compared. This involves, in particular, a critical discussion of the validity of the modified consumer behavior theory as it is currently being applied to this problem. A suggestion for broadening the issues involved is made stressing some properties of time that have so far not been included in the research effort.

The principal tool that specifically deals with time and cost attributes of the transportation system as they relate to travel demand is the mode choice model (1, 2), which is an element of the set of travel demand models, commonly referred to as the urban transportation planning (UTP) process (3). Among other properties, the UTP process enables an assessment of savings in time associated with various modal characteristics and network configurations for given spatial distributions of origins and destinations. Both the gravity (or trip distribution) model and the mode choice model have been applied to intraurban travel, although an extension of the comprehensive UTP process to interurban movements has yet to be sucessfully formulated (4, 5).

More recently, the urban transportation planning process was reformulated in a more economic framework, where the various stepwise models, such as generation, distribution, and mode choice, were described as a decreasing order of consumer choice situations. Thus, trip generation models reflect choice between various activities, assuming that these can be performed only at different geographical locations and by using various transportation modes. Trip distribution refers more explicitly to the choice between different locations, and mode choice models are even more restricted in the sense that they determine only the selection of the transportation mode to be used (6, 7).

CONCEPT OF TIME EVALUATION

To establish meaningful estimating relationships of the transportation system in a planning context, particularly in the predictive and evaluative elements, conceptually sound methods have to be developed to attach monetary values to the travel time characteristics of the system. A variety of approaches to this problem have been suggested that usually relate concepts of two general bodies of economic theory: consumer behavior theory and macroeconomic theory (8, 9). However, a number of assumptions about the properties of the temporal dimension, which are implied in both approaches, need to be specified.

The first premise is that the main property of time to be evaluated is its duration. Assuming that time constitutes a continuous flow, the duration of elapsed time between two instants can be measured, and an interval can be defined that is affected neither by the passage of time nor by its activity content. A common characterization of such a content-independent time interval is objective or absolute time.

For a meaningful evaluation of objective time, a second premise is necessary. Since the flow of time per se cannot be arrested, condensed, or expanded at will, the activity content, or the process taking place in time, is subject to evaluation because it can be controlled (10, 11). Travel time reduction should therefore be considered as a deliberate substitution of the time allocated to a specific activity, namely, movement over space, for another activity, conveniently classified as work (production) or leisure (consumption). In this sense, the value of travel time is frequently referred to as the opportunity cost value of time. One definition of the value of travel time is, therefore, "that amount of money which an individual is prepared to forego in order to save himself one unit of his journey time" (12).

It is the third premise, that activities have different values or utilities in an economic or social sense, that causes much difficulty. Otherwise, the value of time would have simply been the national income divided by the total time of all individuals in the nation (13). This difficulty arises not only because different values necessarily cause problems in terms of measurement, but mainly because the value of time measured macroeconomically and that derived from consumer behavior theory are fundamentally incompatible.

THEORETICAL BASES FOR CURRENT ESTIMATIONS OF VALUES OF TRAVEL TIME

One major area of application of the macroeconomic approach to the evaluation of travel time lies in the appraisal of transportation system improvements. The problem consists essentially of an efficient allocation of resources in the economy, in general, and in the transportation system in particular. For a variety of reasons, public agencies provide services to the public free of charge or at prices unrelated to the costs of providing them. For assessing the effects of the expenditure and for evaluating it, the technique of cost-benefit analysis has been used (14). In transportation systems, the main effect of improvements consists of user benefits, primarily in terms of travel time savings. This is particularly true of improvements in air traffic control and navigation systems and in virtually all highway improvements (15, 16, 17). Alternatively, a conceptually identical approach is to evaluate the annual economic losses due to unproductive travel time (18, App. 1).

For one category of time-consuming human activity, one can establish a value based on the market mechanism. A market for labor exists so that time saving in journeys undertaken during working time can be assigned a value related either to the wage rate or the earning power, assuming that productivity during the trip is nil. Similarly, when productivity during the trip is positive, as in the case of commercial vehicles' travel times, there is little conceptual difficulty to determine the value of time savings due to improvements in the infrastructure (19). Some questions remain unsettled about the stratification by occupation and the nature of the overheads to be assigned, but this does not necessarily affect the theoretical soundness of the estimating procedure.

The main difficulty arises, of course, when the same theoretical approach is used for the evaluation of nonproductive, or leisure, time. In fact, even that most frequent of all trips, the daily commuting to work, cannot strictly be considered as part of the productive time that has an objective market value. A variety of solutions have been suggested to this problem; none of them is entirely satisfactory. One approach is to apply a dollar value to travel time on the basis of the constant money wage rate. Its implicit underlying assumption is that all the time saved in travel could be invariably used for productive purposes. Such an assumption is untenable both from an intuitive, common sense approach and from empirical data derived from consumer choice studies. In other words, empirical consumer choice studies, which usually include many commuting trips, may generate different working time values than those obtained from wage rate studies.

Another approach has been to apply the concepts of the value of time as derived from the individual consumer choice theory to justify public investments. The assumption here is that transportation improvements have an important social, in addition to a strictly economic, benefit. Whereas economic benefits may be considered solely in terms of the combination of time with labor services in the production process, social benefits include the whole set of activities for which people deliberately make use of their time and money budgets. Thus, the social benefits accruing from a reduction of traveling time can be regarded as the sum of money values that all individual beneficiaries of the project attach to their time savings (9, 20, 21). The main advantage of this approach lies in the possibilities to measure empirically revealed values of time savings in situations where a choice between money and time exists. These emprical studies and their conceptual basis will be discussed in detail later. It should be noted, however, that, by accepting the values of time as determined from empirical choice situations for project evaluation, a number of additional assumptions have to be made: (a) Small increments of time saved by individual travelers can be added up when viewed as an aggregate for a large number of travelers (22), and (b) economically defined savings can be added to socially determined savings. In other words, time savings that resulted in an increased productivity of resources in the economy are assigned a monetary value in the same currency as the national accounting system. If social or welfare benefits from travel time savings are included in the evaluation of investments, then they are presumed to be valued in terms of this currency, although in reality they are not reflected in the national accounts. Not surprisingly, the following words of caution are found in a recent review of the evaluation of highway improvements (23):

> It is advisable to treat travel time as a separate item in economy studies in order that the decision maker can see readily the amount of over-all gains that are priced out on the basis of the dollar value of time and those gains that are actual bona fide reductions in expenditures for travel.

VALUE OF TRAVEL TIME IN PREDICTING TRANSPORTATION DEMAND

Recently a considerable research effort has been directed toward an elaboration of the traditional consumer behavior (or individual utility) theory so that the problem of travel time evaluation could be incorporated (20, 21, 24, 25, 26, 27, 28). In the typical consumer choice situation, a good is purchased for its utility, which is a function of the sum of its attributes or characteristics (29). Any given trip may be considered as a good, associated with a set of attributes such as time and comfort, which are on sale for money at the marketplace (30, 31). The choice situation usually consists of the possibility of marginally substituting a certain attribute for money within the general constraints of income and time scarcities inherent in economic decision making. According to the theory as reformulated above, the marginal utility of any activity can be inferred from the wage rate and the utility of other foregone activities. In the case of a trip, a reduction in time spent on travel is valued at the margin as being equal to the free wage rate and another usually negative factor, consisting of either the disutility of work or the disutility of travel or both. The important contribution lies in the clarification of the conceptual inequality of the various monetary values of activities on the basis of their individual utilities. In other words, the modified consumer choice theory explicitly identifies conceptually many values of travel times, rather than a simple, constant value for the working time travel and the leisure time travel. This allows for a wide range of values, based on the traveler's preferences (32).

An important corollary to the new approach in evaluating travel time is the possibility of measuring empirically the revealed trade-offs of travel times saving for money (27, 31). However, a number of conceptual problems still remain to be solved, so that results obtained from the field cannot yet be considered as generally applicable. The first problem relates to the definition of the utility of travel time savings. We have already introduced one element of the utility of travel time savings, in the form of pure opportunity costs. According to this approach, although no positive or negative utility is being attacted to the time devoted to transportation, a generally positive utility is attached to the alternative uses of the time saved for leisure or work.

However, the value of travel time depends both on the use to which such time saved would be put and on the disutility generally attached to traveling (26, 27, 31). In the evaluation of the disutility of traveling, travel time cannot be viewed independently of other trip attributes, particularly those relating to comfort. Let us suppose that we were in a position to establish a composite measure of the disutility of a trip, in terms of the physical and mental effort required to perform the activity of traveling. It would be difficult to separate time spent and comfort as attributes to this total effort; they are joint attributes because the comfort and discomfort may depend, among others, on trip duration

The problem of separating trip duration as an attribute of the disutility of traveling has several practical implications. These can be recognized in the great care that is being taken to find ideal choice situations in which travel time savings can be evaluated on the basis of real-world evidence. In the first choice situation, which involves time savings due to change in modes, it may be difficult, conceptually, not only to determine value of time saved but even to predict the actual mode chosen. Let us assume that there is a person with positive income, who faces two alternative means of travel with identical money outlays for a trip from his or her hometown to another town for an important meeting: a 10-h overnight sleeper train journey as opposed to a 3-h air trip early in the morning of the meeting. If the trip duration is the main element of disutility, then it is probable that the traveler will choose the air trip. However, if the degree of measurable comfort on the train greatly exceeds that of the airplane, so that the total effort of traveling by air is greater than that required for the train journey, then the prediction would be for the traveler to use the train.

The second choice situation that has been suggested in the literature (33) involves similar modes, along identical routes, but with varying speeds, such as a normal train versus the Trans Europe Express or a subsonic versus supersonic air trip. The faster mode usually requires a greater money outlay so that, a priori, this might be a good choice situation to determine the value of travel time savings. Still, even in this case, the assumption has to be made that the level of comfort is identical in both trips. Now, when the train substitution is made, it is clearly demonstrable that the level of comfort in the faster train is higher than in the normal train. For the supersonic transport, the assumption would be that the level of comfort is independent from trip duration or that to remain confined to a seat for 3 to 4 h does not differ much from a 6 to 7-h confinement. This again may well be an unrealistic assumption.

The same problem exists in the freeway-tollway choice situation, which involves small time savings, say, less than 5 min. From the disutility viewpoint of minimizing effort, these time savings, provided adequate measurement techniques are devised, could not be ignored, but again it is unrealistic to assume similar driving conditions on both routes. No attempt will be made in this paper to resolve this problem. It may be that time savings combine benefits from both opportunity costs and disutility of travel and thereby provide a solution. However, the internal consistency of evaluating time savings as a sum of these two effects has still to be investigated so that it can be determined that problems of double accounting of the time duration do not arise. Both Phillips (28) and de Donnea (31) conclude that, in effect, such an approach makes it impossible to estimate the pure opportunity cost value of time. Instead, they suggest values for bus, expressway, and individual travel and for different trip purposes. In other words, they provide time saving evaluations for given comfort levels.

Another problem raised by the application of a modified consumer choice theory to the evaluation of time concerns the equivalence of average and marginal time savings. Strictly speaking, the derivation of the equilibrium conditions is based on Lagrange multipliers that necessarily use marginal rather than average or total terms. It is this characteristic that differentiates clearly between individual consumer behavior theory and macroeconomic theory, in which weighted average or total values of time may be derived.

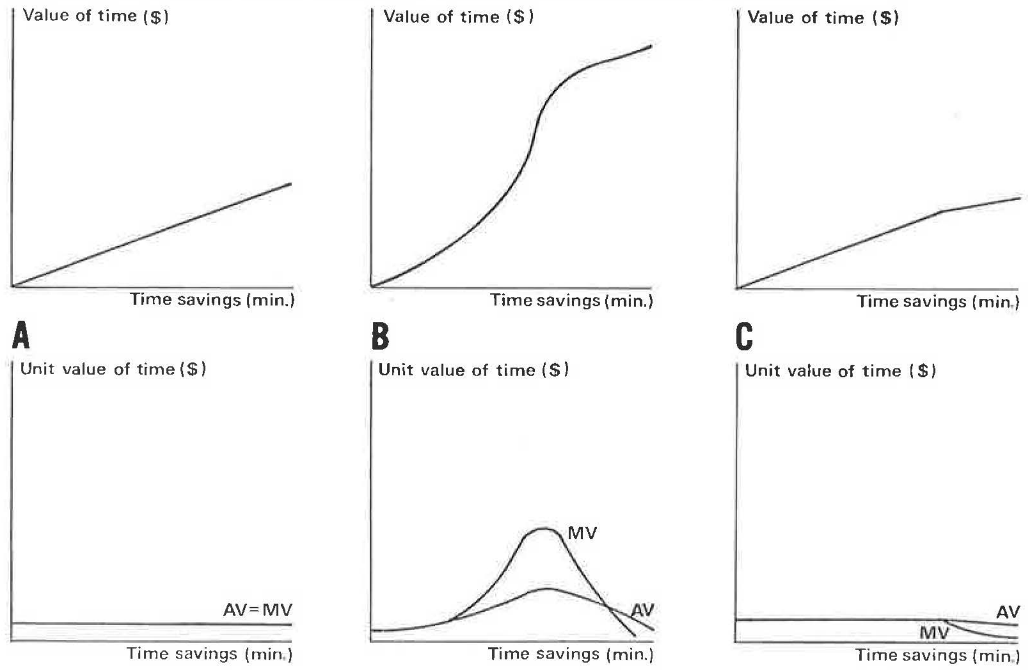
To begin with, one must determine what constitutes marginal time savings. Ideally, since time is a continuum, measured unit intervals may be infinitely small. Alternatively, a practical marginal time interval could be 1 min, or, if some perceptual or behavioral bases are allowed for, this could be stretched to 5 min. This would admittedly sacrifice a rigorous marginal analysis. In reality, however, there is a great deal of confusion between marginal time savings as described here and time savings resulting from the differences between travel times by mode or route in the real world. Time differentials constitute marginal time savings in the theoretical sense only if they are small, probably of the order of 5 min or less. Any time saving above this interval may be considered marginal only if it is assumed, a priori, that average and marginal time savings are equivalent. There are obvious implications from this observation in terms of the compatibility of travel time differentials within urban regions and those of interurban travel, which may vary by at least an order of magnitude. A typical example of the lack of distinction between average and marginal time savings is found in a recent empirical study of interurban travel in Italy (34). In this case, the value of time was the difference between the value of x min spent on making a journey on the Autostrada plus y min spent on some other activity and the value of x + y min making the same journey by the ordinary roads.

It has been indicated that a general application of the marginal value of time concept to the real world depends largely on the relationship between these marginal values and the average value of time. A preliminary assumption of continuity simplifies the nature of this relationship. If the value of time remains constant, irrespective of the amounts of time saved (when even the smaller amounts of time saved are evaluated), then marginal time savings are equivalent to average time savings. In such a case, the relationship between time savings and their value is linear and starts from the origin (Figure 1a). A number of studies have implicitly or specifically made this assumption (27, 28, 35), although Harrison and Quarmby (27) admit that

> At a theoretical level it has to be allowed that the valuation determined at the existing margin may not adequately reflect the importance of all changes in aggregate, since there can be no general reason to suppose the equality of marginal and average values.

Actually, at least two other assumptions on the relationship between average and marginal value may be made with some degree of plausibility: (a) Marginal and average values are not two indentical functions of time saved, although they may occasionally interesect; and (b) at that point they have similar values (Figure 1b). Conceptually, divergent values of marginal and average time savings may be inferred simply by using

Figure 1. Marginal versus average values of time savings with a continuous time value function.



the same assumption generally applied in consumer behavior theory. This assumption suggests that the utility or value of a good or an attribute of a good depends on its relative scarcity or abundance, and, therefore, the typical shape of individual preference-indifference curves is produced. In an updated analysis, Thomas (36, 37) indicates that automobile commuters' marginal values of time, measured minute by minute, vary considerably, and reach their maximum at about the fourteenth minute saved. In this empirical study, it appears that both small and large amounts of time have less marginal value than intermediate amounts. This nonmonotonic property of value of time savings still requires theoretical or behavioral foundations.

Based on this general premise, another assumption may be suggested, that both average and marginal value of time savings should be smaller on interurban trips, when there is a large use of travel time and greater amounts of time saved than in urban travel when there is generally less travel time. A graphical representation of the view that marginal and average values are constant in urban travel, but slowly decrease in interurban trips, is shown in Figure 1c. In fact, Harrison and Quarmby (27) suggest that this type of relationship may exist, although they derive it from a different approach altogether.

Finally, an argument could be made in favor of relaxing the continuity assumption in the relationship between time savings and their values. This would help explain the various suggestions made about evaluating time savings by air as a function of the hour of the day or the number of hours saved and also why very small amounts of time saved may be disregarded (17, 38). In other words, the possibility that the function of time savings, or value of time, has a stepwise nature should probably be seriously explored.

In this analysis of the use of the consumer choice theory in travel demand prediction, a fundamental weakness in the property of the theoretical constructs used in the equations of the value of time is that both sides of the equation cannot be measured independently. Since cardinal utility has been rejected as a quantitative tool in economic evaluation, what remains is an equation that can be solved directly only in terms of the opportunity cost value of time; however, the utility of leisure, the disutility of work, and the disutility of travel are unknowns. This has led, in several cases, to a tendency to use time and value of time as a proxy for these unknowns, and, thereby, the problem of cardinal utility is bypassed (39). The use of value in such cases is based on the assumption that, when activity contents of alternative time uses are being traded, value can be attached to differences in each activity content. However, such procedures cannot per se improve on the evaluation of time itself, and great care should be taken in interpreting results derived by these methods because possible errors may be compounded.

DIRECTIONS FOR FURTHER RESEARCH

Future research on the theoretical aspects of the value of time may develop along a number of interrelated lines. First, a taxonomy of values of time will likely be available based on the work of the U.K. Ministry of Transport (22) or Burco and Thomas (40), in which a matrix of values of time will be designed along two dimensions: (a) density of trips from urban core to intercity and (b) trip purpose from commuting to vacation or recreation. User attributes would appear as coefficients of the system characteristics, particularly time and money outlays (41). Such a matrix would probably represent the end product of the theoretical constructs as they exist today and take into account the limitations referred to above.

An entirely different approach to the evaluation of time, which may eventually broaden the theoretical basis for the evaluation of time in a significant way, is to reconsider the basic philosophical and socioeconomic premises of time and their evaluation. Because time is treated in terms of its duration and activity content, perhaps other properties of time are being obscured. Specifically, the property of the irreversibility of time or its unidirectional flow and its cyclical nature are of particular importance if the utility of time is being considered. For example, it is clear that one hour, between 5 and 6 a.m., is not strictly equivalent to another hour, between 5 to 6 p.m., although in terms of duration they are necessarily equivalent. Incidentally, this is implicitly recognized in the modified formulation of the consumer behavior theory, as suggested by Foster (30), in which constraints are placed on income and time budgets but not on the nonpecuniary advantages and disadvantages of the activity for which time and money are involved. In other words, the utility of an activity will vary according to the time of day or generally to the period in which it is undertaken; therefore, the additional properties of time do not appear in the simple time budget constraint but rather in the utility or disutility level of the various activities.

A possible way to approach the structured use of time in individual and social behavior could be by means of time budgets, in terms of either total travel time budgets or specific travel time budgets, according to the daily, weekly, or yearly cycle of human activities in a social context. An interesting problem, in this context, would be the evaluation of travel by the elderly. On the one hand, since they are mostly retired, alternative uses of time do not generate income. On the other hand, travel time budgets of elderly people appear to be particularly constrained to certain modes, routes, and hours of the day (42).

Another direction for further research, apart from the more social orientation suggested above, is behavior-oriented studies of travel time. As Reichman and Stopher, in a paper in this Record, point out, it is hoped that more understanding will be achieved on the perceptual and attitudinal problems related to travel time savings versus total travel time. This question relates to the value people place on the fact that they can control their time, irrespective of its utility or opportunity costs.

It is hoped that these suggestions might lead to a better understanding of human allocation of time. The inclusion of time into travel demand models will probably necessitate a significant shift from current consumer behavior theory to a different type of modeling. At present, there are indications that concepts based on analogies to energy conservation flows may provide some useful insights into the more general problem of time budgets and human control over time.

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Review of Studies Leading to Existing Values of Travel Time

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This paper attempts to emphasize the most empirical contributions to the valuation of travel time under varying circumstances. Most of these studies estimated these values as by-products of single or simultaneous travel choice and demand models in which the emphasis is on prediction rather than on capturing the concept of the notion of the value of travel time. Most of the studies discussed have produced total sample values of travel time savings due largely to the inadequate sample sizes required for stratifications and have resulted in insignificant income-related values. However, the values do tend to show some semblance of consistency when converted to international units, but before improved (stratified) empirical estimates can be made, improvements to the procedures previously used to obtain estimates are required.

This paper discusses the approaches adopted in recent empirical studies to estimate the value of travel time savings (VTTS) for work and nonwork circumstances. The three areas in which empirical research has been concentrated are work travel time, commuting time, and nonwork, noncommuting time.

VALUE OF WORK TRAVEL TIME

Work travel time encompasses travel by individuals as part of the work function. With few exceptions (2, 3, 4, 6, 9, 12, 16, 17), useful empirical evidence is absent. Most other useful studies are carefully reasoned expository arguments, based on the economic theory that employers will hire labor as long as its value to them is greater than its cost. Thus, at the margin, the wage rate is a useful measure of the value of production lost or gained by changes in the work force, providing that the labor adjustments are small relative to the markets in which the prices are set and that no changes result in wage levels.

Imperfections in the economy distort the appropriateness of the wage rate as a base measure; for example, continual exchange opportunities between income and time are confounded by minimum-wage, maximum-hours legislation. Empirical work, however, has not advanced sufficiently to provide a definite alternative. The behavioral studies (2, 3, 4, 6, 9) are the only attempt to provide an alternative measure of the value of work time, but with limited empirical success.

There appear to be well-defined areas of evidence: the macrochoice models used in the United States for the valuation of business-travel time savings for air passengers, the microchoice model used in the Italian Autostrada route choice study (2), the Sydney-Newcastle route choice study (54), and the case study (interview) and survey methodology undertaken in the United Kingdom to determine the marginal wage increment as part of the overall valuation of work travel time for road transport. This latter approach focused on a broader spectrum of occupational and income groups. In this paper, the U.S. and U.K. approaches will be reviewed separately.

Macrochoice Methodology

The consensus of opinion on the value of work travel time savings associated with air travel is that it varies from 2.5 times the average earnings rate (8) to the average earnings rate (1, 7, 10). The major objective of these studies was to improve the explanation of demand by introducing time as part of the price of travel rather than as a factor affecting tastes. However, two authors of research reports also made frequent reference to the theoretical and empirical estimation of the value of business air travel time. Using a trip distribution function on home interview data, Gronau (4, 5, 6) selected a value by maximizing the variation in the demand for trips between zonal pairs (in a single origin-multiple destination network). This is demonstrated by the explanatory variables when different arbitrary values for the income-time ratio, from 0 to 1, are used. De Vany (3) used aggregate data and inferred an indirect estimate of the value of time from the aggregate elasticity measure, i.e., the ratio of the percentage change in the time spent traveling to the percentage change in the price, when the price change is small.

From a number of alternative hypotheses on behavioral interaction, Gronau, in his initial research (4), describes the demand for trips between origin i and destination j in terms of the generalized cost of the trip (comparison of the price of the trip and the trip's elapsed time, weighted by the mean hourly earnings, designed as a direct estimation of the value of time as a percentage of the average wage rate k), the traveler's income, and the measures of origin and destination attractiveness. The function stems from Gronau's assumption that the value of time is necessarily assumed to be proportionate to the wage rate, since the iterative maximum likelihood procedure does not allow for a more complicated and perhaps more realistic assumption. Individuals with a higher income have a higher value of time and are more likely to use the faster mode. Since the comparative advantages of alternative available modes are related to the distance traveled, Gronau introduced distance into the generalized cost function for identification of the kinks in a time-price isoquant. For any given time-price relationship, the value of time k determines the kink at which the individual is located.

Gronau has thus identified the segmented market for business travel for time and cost trade-offs and has provided a distribution mechanism for valuing air travel time. In the initial research Gronau used simple regression (4). Considering all business trips, he estimated an implied income-time ratio k of 0.40 from an equation for which r^2 for the whole equation was statistically significantly greater than the r^2 for other equations. This work, however, emphasized the effect of travel time on the demand for travel and did not estimate the value of time. In a later study (6), which looked at professional occupations only (78 percent of the sample), an alternative method was introduced. The dependent variable was changed to represent the probability of travel to a given destination j within a given income group i. All trips originated in New York. Weighted regression was used on cell means (destination by income). The empirical estimate of the value of domestic business air travel time derived from more efficient estimates was approximately equal to the average wage rate. Given the structure of the travel market, the latter result appears more realistic, assuming that a high positive correlation between the value of time and the wage rate does not indicate that a homogeneous constant exists for any proportion of the population. This is substantiated by only marginal differences in the values of r^2 in the estimating equations (6, Table 7) and the totally different result in the earlier study.

Gronau suggests that VTTS is essentially an empirical matter on which the only guidance given by theory is that it is positively related to the wage rate. Whereas Gronau used a single origin data set that included the income of each traveler, De Vany did not have access to such data for city pairs and had to face the problem of using zonal income data. De Vany related the number of annual business air passenger trips between city pairs to the fare per kilometer for a trip between i and j, the travel time per kilometer, the distance between cities, the populations of the respective cities, and their mean zonal income.

Distance was introduced as a price and time elasticity determinant on the grounds that the ratio of price to trip time varies systematically with distance and that the theory indicates that, as the ratio p/wt changes, where w is the wage rate, price and time elasticities change. Note the similarity to Gronau's assumption. Although Gronau used one of the few data sets that gave the income of each traveler, De Vany noted that most intercity studies usually create difficulties in identifying income levels and the average wage rate. Apart from this inconsistent evidence about the assumption that wage rate differentials are due to intercity heterogeneity (although cities are too alike for income variance to show), De Vany recognized the general deficiency and adopted an alternative procedure of calculating the value that travelers must have placed on their time to have produced the estimated time and price elasticities.

The distance variable was included to convert travel time and price from rates per kilometer to total time and cost. If distance is maintained as a constant, the effect of fare and time changes on routes of differing lengths can be compared. If we use the theoretical relationship that

$$(\partial T/\partial t) = w(\partial T/\partial p) \qquad (1)$$

and require that the consumer's response to time changes be tied to his or her responses to price changes through the value of time, then multiplication by pt/T_{ij}, where T_{ij} is the number of annual passenger trips between city i and city j, gives

$$we_p t = e_t p \quad \text{or} \quad w = (e_t p)/(e_p t) \qquad (2)$$

the standard point elasticity of demand definition. At mean trip lengths of 1046 km (650 miles), with e_t = -0.47 and e_p = -1.08, the value of air travel time in 1968 was $7.54/hour. De Vany suggests that this value approximates the average wage rate. This lends support to later findings of Gronau but disagrees with his earlier finding that, for intercity travel, time is a considerably less important determinant than standard theory might indicate. The use of an average elasticity measure (related to the assumption of constant elasticity), however, is likely to conceal more than it reveals, especially if the time difference is a composite of the various heterogeneous components of travel time (i.e., walking, waiting, transferring, and in-vehicle time).

These macromodels have some questionable features.

1. Given that the elasticities of price and time are acceptable in magnitude and sign, a prediction of the demand for future modes would require the assumption that elasticities are stable over time. As a short-run model, Gronau's assumption appears to be realistic that price and time for air travel do not react to any changes in the demand for trips because of their administered nature (set by government agencies). In addition to these fixed (relative) prices, any change is difficult to measure in the short run. With this constraint, the whole question of the inadequacy or irrelevance of the elasticity approach for short-run valuation of air travel time is raised. Based on this objection, land-mode situations seem more suited to elasticity interpretation. Time-series data are required for an investigation of elasticity changes over time.
2. In addition to the stability of elasticities per se over time, a compounded potential instability seems to be due to the initial aggregation of the data set, i.e., using mean zone estimates for price and time, particularly for excess trip times, connecting mode costs, and income in the case of De Vany. Such an approach introduces all the associated features such as ecological correlation and the possibility of intrazone variance exceeding interzone variance. Ecological correlation occurs when the coefficients of correlation are computed on the basis of measures applying to territorial or zonal groupings as a whole in contrast to correlations between the cases contained within the groupings.
3. Both studies, by considering one time variable, implicitly assume equal importance for all components of travel time (waiting, walking, transferring, and in-vehicle time). This criticism is directed to travel up to 322 km (200 miles), for which the overall trip by bus can often have a comparative time advantage over the air trip because of the delays involved in access and egress in air travel. Gronau suggests that air travel is an effective competitor only for trips in excess of 217 km (135 miles).
4. The elasticity measure is defined in terms of small price changes. When the price changes between

modes are large, then an alternative elasticity measure appears more appropriate, unless the Gronau and De Vany assumption of constant elasticity over the entire range is made. Whenever two time-price situations lie along a curve of constant point elasticity, the arc elasticity will be the appropriate measure and equal to that constant value, regardless of the size of the step.

5. The value to the employer of work travel time savings, which might include any reductions in disutility to the employee, must consider for a given level of production the direct and indirect savings in labor costs due to travel time savings. In addition, the distribution of travel time between the employee's and the employer's time could make a considerable difference in the deviation of a final value of time from the wage rate (15). When consideration is given to such an influence, the value of time is likely to be less than the average wage rate.

6. Some potential confusion could arise through the use of the two phrases price of time and value of time. The consensus of opinion leads to the following definitions: The value of time is the amount of money an individual is willing to pay to save a unit of travel time; the price of time is the amount of money an individual has to pay to save a unit of travel time. Gronau emphasizes the price of time, although the inconsistency associated with interchanging the words price and value can be confusing. Although one could argue that the price of time can equal the value of time in a constrained financial context, the presence of imperfections and distortions leads to disequilibrium where there is a divergence between the market rate of exchange and the marginal rate of technical substitution. Hence the price of time does not equal the value of time. Gronau's conclusions are only correct if a position of equilibrium is assumed. This is empirically unlikely. Although he refers generally to the price of time, perhaps on some occasions he should be referring to the value of time.

Both authors appear to recognize the associated marginal wage increments; however, no allowance is given for this. This might be explained by the multiple-purpose journey data set and apparent desire to use the same model for all journey purposes, a give-and-take compromise approach, without considering the heterogeneous structure of the choice process involved under differing circumstances (26). This same criticism applies to the Italian Autostrada route choice study (2). Such an implicit stand prejudges the suitability of such an approach for work trips, but is quite acceptable for commuter and leisure trips (ignoring at this stage the relative merits of the disaggregate, probabilistic, behavioral models).

Production Cost Approach and Nonwage Overheads

Although U.S. air travel studies have emphasized procedures that show promise in estimating a behavioral value of time (i.e., for prediction), they make no contribution to the calculation of resource values of time required in evaluation. The empirical method used in the United Kingdom appears to provide a more promising mechanism. Within it, all resource costs can be considered that are associated with employment of labor as a factor of production that undertakes travel on behalf of the employer. This section looks briefly at the procedure adopted for assigning a meaningful markup on the wage rate to allow for other costs of hiring labor. These other costs are elements [referred to as the marginal wage increment (MWI)] that are saved if the labor-time input ratio is reduced while production remains constant. Travel time saved by employees in the course of their work can be regarded as a change in productive time and hence, if production remains constant, both direct and indirect savings in labor costs will result. In the absence of direct evidence, a markup of 10 percent was applied to the gross wage rate, including income-related payments. Three studies have been completed in the United Kingdom (12, 16, 17), each study being essentially exploratory because of the absence of prior guidelines.

The initial study (12) was designed to review existing British evidence on the effect of road improvements on the MWI and used a technique of personal interview with a senior official of the larger companies representative of their industries. The study indicated an absence of substantive evidence and a general unwillingness to accept that there could be any material and quantifiable changes in overhead due to road improvements. Under pressured, biased interviewing, two respondents estimated savings in overhead from a fraction of 1 to 3 percent and a third estimated under 5 percent. Other respondents were reluctant to concede any saving at all in overhead (12, p. 2).

A major criticism of this approach, apart from the "guesstimation" potential, is the difficulty, over time, of separating the unique impact of the road improvement from those technological and institutional factors (e.g., speed limit) external to the firm and the firm's maintenance trade-off adjustments. Respondents would be acting in a rational manner by refusing to give an estimate of overhead changes due to a specific improvement. In response to the issues raised in this initial pilot study, two other studies were undertaken.

One of these studies (16) investigated 165 firms in the consumer goods industry for which transport was an important ancillary activity. The short-term MWI was found to include meal allowances, overnight expenses, special clothing and uniforms, samples, literature and tools, and welfare benefits (e.g., pensions). The percentage markup of such costs on salary suggested an MWI of about 20 percent, double the previous 10 percent. The single most contributory expense over all person categories considered (salesmen, transport drivers, and service engineers) was overnight expenses. This approach to estimating the short-term MWI offers a more causally meaningful procedure than the alternatives suggested, despite limitations of sampling error and the difficulty of deciding on the assignment of costs attributable to marginal employee or other factors.

The most recent study (17) selected 17 firms that had large distribution networks to assess the longer term savings resulting from reorganization of distribution and administrative charges that include overhead. Detailed information on costs related to constant output and on costs related to a particular site was obtained from food and allied industries. The main finding indicated an unclear relationship between the average long-term cost saving per driver because a decision to reduce the number of depots generally produces a restructuring of investment outlay, and this changes the composition of the MWI (17, p. 8). The only possible conclusion was that the long-term MWI must be larger than the short-term MWI; otherwise, the investment would not take place.

The research team of the Commission of the Third London Airport, using the above findings, raised the wage rate 50 percent to obtain a value time of business air travelers. It was argued that overhead costs and income-related payments of business air travelers are higher than those of business travelers in general. However, Dooley and Young went a step farther and investigated the categories of overhead costs themselves. They recommended a markup of 200 percent for overhead.

Again the use of one single percentage markup is subject to doubt. Research is required to investigate not only the components of overhead and other costs but also the incidence and magnitude of such costs for industries that are significantly involved in either air or land travel. Such a study for air travel has recently been completed in Australia (15). The total resource costs incurred by the employee, the employer, and the community as a result of an employee's undertaking business air travel were considered. The resource values of time savings for both domestic and international business travel were found to be less than the average wage rate for each of the six outward and return trip stages. This is in contrast to the 150 percent of the average wage rate suggested by the Commission on the Third London Airport. A behavioral value of time for the outward access portion of a business domestic air trip was also estimated in the context of a choice between various private and public land modes and was found to be greater than the resource value but less than the average wage rate. The detailed values are not yet available for quotation. A number of comments can be made about this approach.

1. Speculation on long-term savings attributable to a particular site is usually unreliable, unless recent reorganization has occurred.
2. Survey or interview methods suffer from the miscomprehension of the respondent (and often the interviewer) about overhead costs as defined in terms of the MWI. This produces undesirable ramifications when firms interpret overhead in the cost accounting sense.
3. In the long run, regional diversification and the decision on choice of depots can spread the distribution costs over a wider region. A trade-off between these regional costs with the reduced costs of fewer depots must be considered to determine the directional change of the MWI.
4. No way has been found to assess whether the overhead costs that make up the MWI would in fact be saved by reducing traveling time of employees (14, p. 67).
5. Traffic densities are an important determinant of stability of the MWI. When traffic densities are lower and roads are improved, the chance is less that newly generated traffic will cancel the advantages of any original savings in overhead. Hence, regional diversification and traffic density must both be considered in any long-term assessment of the MWI. Fullerton and Cooper (12) did give evidence to suggest that, for short-range urban travel, increasing traffic density over the slow rate of road improvement countervailed any potential savings in overhead attributable to road improvements. Given that approximately 35 percent of working time appears to be a fairly typical proportion of time spent traveling (17, p. A4) and that 50 percent of journey distance is under 80 km (50 miles) (16, p. 4), the assertion of countervailing reaction might be justified.
6. With the exception of the Australian air study by Hensher (15), the above approach ignores any change in utility to the employee as a result of a travel improvement, i.e., the disutility of the travel experience itself.

This discussion on the production-cost approach has shown that little research into the value of work travel time has been undertaken. The 10 percent MWI traditionally used in the United Kingdom for land-mode activities and the 50 percent MWI used for air travel must be placed in doubt, especially as an average long-term MWI. The paucity of empirical evidence from all procedures adopted only serves to emphasize that the value of work travel time is at least equal to the average wage rate for nonair travel and is less than the average wage rate for air travel.

VALUE OF COMMUTING TIME

Haney (23) conducted a survey about VTTS that indicated that existing values of travel time in the United States were largely based on intuition and nonbehavioral engineering estimates and lacked reliable theoretical content. The most common approaches emphasized a valuation based on operating costs or tolls. In the United Kingdom, the Victoria Line rail study prompted a detailed look at the VTTS. Before that, most values were suggestions, assumed values, or derivations from car operating cost models, and not much consideration was given to the perceptual process inherent in individual value.

Since 1965, a number of important studies have been completed that estimate VTTS by studying the apparent trade-off between time and cost by travelers who have a choice of mode or route (6, 18, 19, 20, 21, 22, 24, 25, 26, 27, 29, 30, 31, 32, 36, 37, 38, 40, 41, 42, 43, 44, 50, 52, 53, 58, 59, 61, 64, 65). These studies are by no means unequivocal, but because of the compelling need to evaluate time savings in transport projects, certain broad, generally accepted principles have emerged. Three basic approaches have been adopted: revealed behavior approach, willingness-to-pay approach, and housing prices approach.

Revealed Behavior Approach

The fixed origin-destination journey to and from work is a unique pattern of movement, amenable to sophisticated statistical techniques. Because of the habitual nature of such a trip, information on the revealed behavior of an individual faced with available alternative routes or modes is relatively easy to acquire and relatively more reliable than data on variable-destination trips. For this and other reasons, a disproportionate empirical emphasis has been placed on the study of the explanation of commuter trips and valuation of commuter travel time savings. With few exceptions (19, 26, 38, 40, 41, 52), the values of travel time have been a secondary output of these studies.

The key empirical assumptions underlying the stochastic disaggregate models used are as follows:

1. A real choice exists;
2. For studies in which automobile travel is an alternative, the individual must hold a current driver's license and have an automobile available for the journey to work; and
3. Sufficient variance must exist in the distribution of the modal and trip characteristics to enable a meaningful estimation of VTTS.

The time-cost trade-off concept for commuters was developed by Beesley (20), in a unimodal context, to derive an implied value of travel time by comparing travelers who choose a time savings at extra cost with travelers who choose a cost saving at extra time (Figure 1a). Commuters' behavior is revealed by their trade-off between time and cost in an attempt to save time or cost. Figure 1b shows superimposition of the two categories of traders. The linear function drawn from the origin to divide the groups is representative of some bound of minimum misclassification or minimization of bad choices, i.e., those commuters who, by choosing the alternative mode, could have either saved time by paying less money than the value of time implied by the slope of the line or saved money at the expense of a

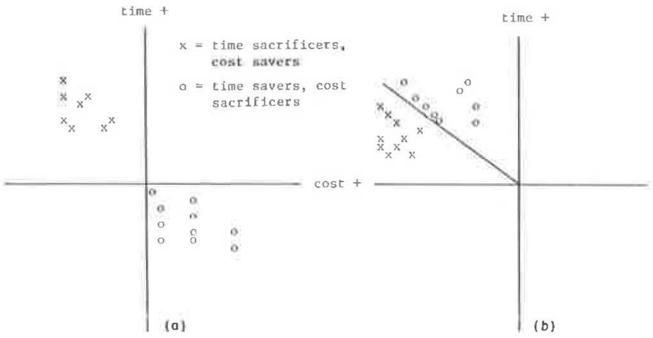

Figure 1. Two categories of commuters.

smaller time increase than the value of time implied.

This study provided a conceptual framework for all subsequent studies based on revealed behavior. This trade-off procedure has been the most useful for the empirical estimation of VTTS. However, Beesley's study suffered from a number of inadequacies, e.g., a biased small sample, a line of minimum misclassification emanating from the origin that implied equality between the average and the marginal value of travel time, and a consideration of time as a homogeneous entity.

More refined statistical techniques have subsequently been used, particularly discriminant analysis, probit analysis, and logit analysis. Discriminant analysis became popular in the United Kingdom because of its classification properties and its use in Quarmby's study (32). However, this statistical tool has recently been criticized as an effective mechanism for explaining modal choice and, hence, the value of time (26, 53, 58). A main criticism has been the assumption of knowledge of a priori probabilities, where variation in spatiotemporal stability makes interpretation of such probabilities difficult. In the studies using discriminant analysis, the unrealistic assumption of equal a priori probabilities of each group (the Bayesian hypothesis) or the assumption of equality of the ratio of a priori probabilities to the ratio of the group sizes is adopted.

Quarmby (32) provided the first attempt to unravel the argument between perceptual and manufactured measuring procedures for the two key determinants of the VTTS. Using the criterion that valuation should reflect the behavioral interpretation of a situation as seen by the individual, Quarmby recommended the perceptual process with certain important modifications. Believing that unedited, reported, and perceived data contained a high degree of error not indicative of the individual's true perception of a situation, Quarmby used a behaviorally perceived measurement process, expressed in terms of car-kilometer cost, that maximized the explanatory power of the discriminant function. The car-kilometer cost was selected as the sensitive parameter on the grounds that it is more open to misperception and guesstimation than any other component of the time or cost of travel. In addition to the incorrectly perceived costs, however, there appears to be a genuine variance in opportunity costs. For this reason, Beesley (19, 20) recommends deriving estimates of VTTS from public transport choices. Although this stand avoids the issue of car costs, it also eliminates a major circumstance under which such a value can exist. The other components were perceptual.

The research by Lisco (30) in the United States; by Quarmby (32), Rogers, Townsend, and Metcalf (34), and Watson (53) in the United Kingdom; and by Hensher (26) in Australia has provided sufficient evidence to suggest that individuals are able to provide sufficiently reliable information on the perceived times and costs of their usual means of travel, except for car costs. However, over all individuals, a sufficiently reliable global average car cost can be obtained. Reliability is interpreted in terms of the deviation of the reported perceived costs from the true values compared with the deviation of the manufactured values from the true values. For the alternative mode, however, the agreement is not so evident. Because of the habitual nature of the journey to work, reported information on the alternative mode tends to be biased against the alternative. For example, Quarmby found that car users compared with bus users tend to overestimate the times of bus travel by about 10 percent. One argument used to substantiate this state of affairs is that it is a means of rationalizing the individual's present mode choice.

Two studies (24, 26) have independently adopted a procedure for valuing the times and costs of the alternative mode, based on the criterion that the perceived values placed on a usual mode represent the best estimates of the values associated with this mode by the individual who currently travels by another mode and sees this mode as an alternative. If the individual was required to use the alternative mode, his or her evaluation process would conform with that of present users of the alternative mode. The resulting values of travel time appear to conform to other values, derived independently.

In the research of Hensher and Merlin and Barbier, the estimated value of waiting time is higher than that for walking and transfer time; in the work of Rogers, Townsend, and Metcalf, the opposite generally exists. If there is a disproportionate amount of walking and transferring in the British transport situation, then the latter relationship might be justified. The safest conclusion is that one is unable to compare directly results from different countries and different towns within a country and under different circumstances. Hensher (21, 23) found that the VTTS based on the overall travel time differences did not equal the weighted mean VTTS based on the linear addition of the heterogeneous components of time differences.

Stopher (36) also contributed to the debate on empirical valuation in the United Kingdom. His basic methodology was similar to other studies mentioned. The main difference was that Stopher initially divided his sample of London commuters into groups, each group corresponding to a certain time difference and cost difference bracket. He then measured the proportion using one mode in each group and treated this as the probability of using that mode for these time and cost conditions. This is a type of stratification process. For each of a range of values of time λ, a linear regression of probability of choosing the car, on the individual values of $[(c_1 - c_2) + \lambda(t_1 - t_2)]$, was conducted. The value of λ giving the largest correlation coefficient was chosen. The main criticisms of his study are the implicit assumption of homogeneous disutility of travel time, which in effect biased upward the value of in-vehicle travel time, and the initial use of a linear estimation procedure for an S-shaped behavioral relationship. Stopher subsequently reanalyzed his data by using the logit transformation (37).

Other U.K. studies (18, 59) used new data sets and existing techniques, and other studies confirm that the U.K. value of commuter travel time tends toward 25 percent of the average wage rate.

Although discriminant analysis gained a degree of respect in the United Kingdom, the improved techniques of probit and logit, designed specifically to handle a binary dependent variable (choice of mode), were becoming more popular in the United States. Lisco (30) and Lave

(29) derived values of time from the probit model (the cumulative normal probability function) by using existing and somewhat inadequate data.

Lisco is the main defender of manufactured measures of time and cost. He takes the stand that assumptions are not necessarily important provided that the model predicts satisfactorily. Hence, perceived data are inappropriate, since manufactured information gives as good an explanation of behavior. Although this might apply to Lisco's findings, Thomas (38) and Quarmby (32) indicate that their perceived data gave a much smaller percentage of misclassified choices than the manufactured data.

Limited sensitivity testing, however, did prevent Lisco from asserting any stability conditions on each measurement procedure. The opposite was the case for Quarmby and Thomas, who conducted extensive sensitivity testing on the model. Lisco's study (30) is one of a few (24, 34, 38) to consider the standard errors associated with a mean value of travel time derived from the ratio of the time and cost coefficients. Although the statistical significance of the separate coefficients might be acceptable, the statistical significance of the ratio might be implausible. Apart from the internal structure of the variables and the limited sample of pure traders (159), Lisco better explains and estimates the value of commuter time. Pure traders in this context refers to travelers who face a trade-off situation between a quicker, more expensive mode and a slower, less expensive mode.

Lave's research (29) is conceptually similar to Lisco's work (30). His major contribution is the direct estimation of the VTTS as a percentage of the average wage rate. This is determined by weighting the relative travel time by the average wage rate and a random variable k whose value depends on the individual's preference for more work time income versus more leisure time. If the commuter prefers more leisure and less work, k is greater than 1.0; if the commuter prefers more work and less leisure, k is less than 1.0. Gronau's model (4, 5, 6) also gives a direct estimate of k; the VTTS is slightly lower than that of Lisco. Like Lisco, Lave devotes a considerable amount of time to careful examination of the internal and external structure of variables to ensure that the best behavioral specifications are used. It was unfortunate that the data were poor and, thus, negated the impact of some of the precise model formulation.

Hansen's research (24) evolved from a need to explain how people choose their means of transport under special conditions, e.g., various levels of car density and varying distances from Oslo. Unlike the other studies, the zonal requirement is introduced, but in a way that enables mode and trip characteristics to be initial behavioral measures based on individual behavior. Hansen found from a sample biased toward the higher income groups, older persons, and high car densities that, for the healthy Norwegians who "do enjoy walking" (24, p. 25), a marginal reduction in travel time is valued four times higher for a reduction in in-vehicle travel time than for a reduction in walking and waiting times. This opposite finding from that in the United Kingdom and the United States might be explained by the tight housing market in the Oslo area and the housing cost structure, which tend to push up the value of in-vehicle travel time in relation to areas where there is a properly functioning housing market.

The Hansen study seems to indicate that it is difficult to suggest that the VTTS can be generalized within a country, let alone between countries. Given the similarity in physical and socioeconomic characteristics among certain communities in different countries, the VTTS for certain groups in different countries might be closer (as a percentage of the wage rate) than that among groups within one country.

Thomas (38) offers the only important route choice contribution in the area of revealed commuter behavior [the Dawson and Everall study (2) followed similar lines]. Using the time-cost trade-off approach for the individual facing a choice between a tolled and a nontolled route, the study considered the sensitivity of the value of time to differing internal structures of the relative time variable. Cost differences were calculated directly from the toll rate, and no consideration was given to any differences in in-vehicle trip costs. The outcome of the discriminant function (with a logit transformation) indicated a market difference between the value of time based on the perceptual measures ($3.82) and that based on manufactured measures ($1.82). Values were estimated for reasonably small differences in the two sets of time measures. A mean of $2.82 was recommended because "an analysis of errors and biases in the motorist-perceived and test vehicle data shows that the true value of time lies somewhere between the two midpoint values" (38, p. vii). Even though the true value could be expected to be within the bounds of the two estimated values, the sensitivity of this model depends almost exclusively on the assignment of a journey time. In general, there is limited scope outside the United States to use techniques of route choice, time-cost, and trade-off, and the situations that do exist usually provide too little variation in the variables for reliable parameter estimation.

Thomas (38) concluded that time savings were income elastic. In an attempt to unravel a relationship among income, the amount of time saved, and the value of time, Thomas and Thompson (52) collected a new set of route choice data. Using the same procedure, they tested a number of polynomial variable structures to relate the value of time directly to income. The only significant relationship of major dependence for the reported perceived data was value of time = $b_0 + b_1$(income). Although the model satisfied significance tests and standard error requirements, the high intercorrelation between straight time differences and income-adjusted time differences places some reservations on the actual VTTS estimated as a function of income. This direct method also assumes that the impact is the same for all states of the modal variables. Hence, any increase in income proportionally increases the VTTS without any consideration of possible structural changes of the modal variables.

Stratification of the large data set into three ranges of amount of time saved was adopted to estimate a different value of time for each range of time saved. The direct functional relationship between income and the value of time was maintained:

$$f(x) = a_0 + a_1(\text{toll}) + [b_0 + b_1(\text{income})](\text{time difference}) \qquad (3)$$

Stratification is preferred to the direct method because it avoids any double inference stemming from the ex post inclusion of a variable (e.g., income), which is also an ex ante perceptual influence on the internal structure of relative times and relative costs. The inclusion of income as a higher order term gave a poor statistical fit. The final model dropped this direct functional relationship and used time differences between routes as the only route variable for which commuters perceived a benefit and would be willing to pay.

Thomas and Thompson (52) have shown the difficulties in using higher order terms and the problem of generating a table of values of time over various ranges of income and amounts of time saved. It appears that such an approach expects too much from the data. The failure to allow for the relationship between trip length and the amount of time saved makes the usefulness of stratification questionable. The main contribution seems to be the support for the assertion that the VTTS is a direct function of income.

In general, most studies emphasize the estimation of a unique VTTS with little satisfactory consideration of the variations in the value with respect to income, trip length, and amount of time saved. A word of warning is given to the planner who might use the unique values in an economic evaluation model: He or she should be informed of the large variations observed in the few studies with data that are capable of eliciting such variations. A unique value could be as misleading as no value.

Willingness-to-Pay Approach

Lee and Dalvi (40, 41) use the notion of a diversion price to determine the VTTS for each individual, at the point of modal indifference, with respect to total travel time and travel cost. The diversion price is the increase in travel cost on the preferred mode that would make the individual indifferent about modes.

Variations in VTTS were calculated by separately analyzing commuters who travel by a faster, more expensive mode (minimum set) and commuters who travel by a slower, less expensive mode (maximum set). These variations were related by regression to various factors, such as journey length, walking and waiting time, income, and age. The initial study (41), involving choices between public transport modes, concluded that time savers (cost sacrificers) apparently value time savings three times as much as the time losers (cost savers) but warns that the value of time is the product of the situation in which it is determined. The later study (40), using data on choices involving car use, found the VTTS to be higher for the car than for public transport but quite consistent with findings elsewhere. The mean values within the minimum set greatly exceed those within the maximum set. A comparison of the mean diversion price time values with the average value that best discriminates between car and public transport users (based on discriminant analysis) was considerably consistent (40, p. 200).

This novel approach has been criticized for using a diversion price obtained from a statement of intended consumer behavior, a hypothetical situation. Although the criticism is fair, it can be argued that the error associated with the diversion price approach (potential behavior) might be no greater than the error commonly associated with the derivation of a value of time from revealed actual behavior models as a quotient of two coefficients. A testable hypothesis is that, under habitual conditions commonly associated with commuter travel, the error associated with measurement of the times and costs of the alternative mode is high because the individual's revealed habitual behavior does not include the alternative mode in the choice process. Only when a change in time or cost actually occurs (or is predicted) do the alternative mode attributes appear to be actively considered. It has also been indicated that scanning is neither a continual nor a frequent process for most people. If people have not had recent experiences with the alternatives, their preferences will tend to be biased. However, if we have a diversion price that is related to alternatives, then no matter how the alternative is perceived, the interpretation will be conceptually valid.

Housing Price Approach

Wabe (42) attempted to value travel time by using a linear model concerned with the influence of demand (at a microlevel) on the determination of individual house prices during the first 3 months of 1968 for the London metropolitan region. Becker (44) and Mohring (43) also looked at the trade-off between lower house costs and lower travel costs in the United States.

In the Wabe model, a decrease of 1 new pence (p) in the cost of the journey to Central London was associated with an increase of £18.74 in the level of house prices. Similarly, a 1-min reduction in journey time to the center is reflected in house prices to be worth £20.38. The ratio of time and price coefficients indicates that 1 min is being valued at 1.0875 p or 65.25 p/h. This is quite similar to the 61-p car value of time estimated by Lee and Dalvi. An implicit assumption of Wabe's model is that, over large numbers, behavior is continuous, i.e., there is a gradual transition from one position to another (a trend from inner to outer areas). Problems of multicollinearity and crude specification of some of the variables reduce the reliability of this result, despite its consistency with other studies. Whereas the behavioral models discussed provide a trade-off mechanism between modes for a fixed residential location, Wabe is extending the consideration of valuation to include variable residential locations.

A potential criticism of this approach is the extent to which transport decisions are functionally ex ante or ex post to locational decisions, with respect to both residence and employment location. If the transport decision (i.e., mode choice) is a residual process, then is a derivation from residential-employment location trade-off necessarily indicative of the individual's value of travel time savings? Even if the transport mode decision is residual, there is no reason why consistent values of time should not be revealed by location choice and mode choice studies. Biases may be introduced into mode choice studies if the residential location decision is neglected. Wabe's approach appears to be a useful alternative for understanding the valuation of travel time savings (for a constant time difference between existing modes), in a somewhat more realistic context. Despite the doubts, this is the only study to have considered the relationship between transport and location decisions at the level of the individual traveler and to have made allowances for environmental and amenity circumstances.

VALUE OF NONWORK, NONCOMMUTING TRAVEL TIME

The purposes and nature of nonwork, noncommuter trips are more diverse than the limited number of techniques adopted to specify models capable of generating empirical estimates of the VTTS. Existing empirical studies fall into two basic categories: trip distribution models (46, 49, 50, 51) and mode (or route) choice models structured along the lines of commuter studies (2, 27, 52, 53).

Trip Distribution Function

The trip distribution function is a useful mechanism for relating the number of trips between any two areas within a network to the inherent characteristics of those areas and to a behavioral generalized cost function (BGCF) that explains why the expected number of trips between the areas should diminish as they become geographically more remote from each other. The VTTS can be inferred from the BGCF, which includes combinations of money price and journey times facing the would-be traveler between two areas. Most of these studies were primarily concerned with estimating the value of recreational services.

Data and model specification limitations have resulted in the restriction of empirical studies to situations involving trips from origin i to a single destination J. A typical distribution function is

$$T_{ij} = kO_i e^{-\lambda f(c_{ij})} \qquad (4)$$

where

T_{ij} = demand for trips,
k = trips to other zones, and
c_{ij} = generalized behavioral cost.

In all the empirical studies, substitutability between trips to zone J and trips to other zones k is assumed to be trivial.

The general absence of information on money costs of travel on an individual basis has resulted in the inclusion of distance (kilometers) as a mechanism for relating time and cost. This intervening approach is most appropriate for recreation trips where there is evidence to suggest a high degree of multicollinearity between time and cost for unique destination-based trips. Colenutt (46) found r to vary between 0.966 and 0.989. The approach adopted by Smith, Mansfield, and Colenutt involved directly estimating the collinearity between journey cost and journey time by including in the behavioral cost equation only those parts of time differences unexplained by the relation between distance and journey time. The empirical requirements for such an approach are as follows:

1. The recreation area is homogeneous; i.e., it is attracting a single trip purpose (to a point destination). The test of homogeneity would be whether travelers to these destinations possess different attitudes about travel. This assumption is required to avoid the simultaneous equation bias associated with discarding the normal trip generation assumption that the number of trips is a function of all the opportunities in the transport sector and competing opportunities elsewhere.
2. A trade-off situation exists. This assumption requires the existence of distinguishable route speeds in the road network and a distribution of route choices so that travelers can take advantage of route choices by trading off time and cost. This also helps to reduce the collinearity between time and cost. This implies a nonlinearity between time and distance; otherwise, the pattern of individual responses to the distinguishable trip times will reflect random factors and not the value placed on time.
3. Travelers are aware of the route choices implied by the trade-off; i.e., choices are neither strongly independent of time nor random.

The exposition by Smith is the most concise. Smith (51) selected a sample to include all individuals who do and do not use a particular recreational facility (for trout fishing). An objective was to compare areas that were equidistant from the facility but that differ with respect to the alternative route facilities available and to the time taken to reach the recreation site. Multicollinearity between time and distance was avoided by use of an indirect method to estimate the impact on trip rates of a unit change in time. The procedure was as follows:

1. Estimate the general relationship between the time taken and distance traveled;
2. Based on the estimate, calculate an expected time for any distance and thus for an aggregation of zones; and
3. Introduce a variable, the deviation from the expected time to the time actually taken for the journey to the facility for each aggregation of zones.

Smith, using manufactured time estimates, calculated a VTTS of 50 p/h. One probable explanation of this high value compared with Mansfield's value of 13 p/h is the nonfulfillment of one of the basic assumptions of the trip distribution function, namely, that behavioral costs are independent of the demand for trips. Trout fishers may be more sensitive to an increase in time caused by having to travel on a longer route free of delays. In both studies by Mansfield and Colenutt, the trips from any zone were not numerous enough to affect traffic congestion significantly on any road that the zone residents use in common with those travelers from other zones.

The empirical results of Smith's study are generally inconclusive (51, p. 99). The main difficulty arose when an attempt was made to estimate empirically the coefficient of money cost. In many cases the influence of time was so strong that the calculated cost coefficient was apparently positive. In only two equations was the cost coefficient negative (from which the value of 50 p/h was calculated). Mansfield and Colenutt avoided this issue by using a variant on Smith's basic model. Mansfield defined the second variable in Smith's initial equation as the nonlinear piece of the time-distance relationship expressed as the difference between the actual and calculated journey time for a zone and called it "excess time." When speed variations exist, it is possible to describe journey times per kilometer from particular zones as higher than or below average for the complete sample. In the initial equation, distance includes the basic effect of journey time as well as vehicle operating cost. Using a function relating journey time to distance ($t = b_0 + b_1 d$), Mansfield and Colenutt obtain the marginal time element in distance. Hence the effect of a 1-min change in excess time becomes $(a_2/a_1) \times (C + b_1 t)$, where $(C + b_1 t)$ is the total cost per kilometer of the journey. It takes b_1 min to travel a marginal kilometer. The solution of the equation, for a selected car-kilometer cost, will produce an estimate of the value of travel time.

Colenutt (46, p. 184) gave values from which he concluded that "a strong case has been presented for considering the time values . . . to be spurious." He attributes this to the data.

1. Trip population is composed mainly of short-distance travelers [62 percent of trips were less than 64 km (40 miles)], who may not be so sensitive to small changes in travel time as long-distance travelers are.
2. Relative uniformity of the road network around the area may have obscured the time-saving behavior of some of the travelers. The motorways available do not offer any special travel time privilege to any particular market area. Hence, there is a close association between time and distance throughout the road network.

This discussion has served to illustrate the general direction in which the limited amount of research into nonwork, noncommuter time valuation using the trip distribution function is heading. Although many studies (2, 21, 27, 45, 46, 47, 48, 50, 51, 53, 55, 59, 66) have been calculated for such travel time values that confirm the tendency for recreation trip time savings to be valued less than commuting travel time, the limited evidence is somewhat diverse. So that the findings of most of these recreation studies can be understood, estimations of recreational values require much assistance from independent estimates of time values. This only serves to emphasize the difficulties of valuing such time savings under so many varied circumstances. Leisure trips may be useful in themselves and as inputs to other activities.

Mode and Route Choice Studies

Watson's medium range intercity mode choice study (53), Thomas and Thompson's route choice study (52), and Hensher's interurban choice of route study (54) provide the most reliable attempts to value nonwork, noncommuter travel time. Other studies, although estimating time values, have not contributed to the methodology but have applied well-tested techniques in the valuation of commuter travel time to other journey purposes.

Watson used the basic methodology of revealed behavior to study the importance of time and cost elements in determining the choice of mode in the Edinburgh-Glasgow corridor. The main data set emphasized social-recreational trips. From 12 models, the most satisfactory was as follows:

$$\text{Choice of mode} = a_0 + a_1 + a_2 + a_3 + a_4 \qquad (5)$$

where

a_1 = walk-wait time,
a_2 = time by car,
a_3 = train journey units, and
a_4 = non-line-haul transit cost.

To allow for the convenience of travel by each mode, Watson developed a simple variable measured in terms of the number of phases of a trip. The best model implies that, for a longer journey (such as recreational), the traveler compares the absolute speed of the car with the sum of the inconveniences resulting from the journey by train. Unable to estimate a value of travel time from this model, Watson used a suboptimal model:

$$\text{Choice of mode} = a_0 + a_1 \frac{(t_1 - t_2)}{\frac{1}{2}(t_1 + t_2)} + a_2 \frac{(c_1 - c_2)}{\frac{1}{2}(c_1 + c_2)} \qquad (6)$$

where

t_1 = time by train,
t_2 = time by car,
c_1 = train cost, and
c_2 = car cost.

This model (equation 6) replaces the urban commuter model and incorporates simple time and cost differences with a functional form that allows for the effect of the total length and total cost of the trip. This appears most plausible for the longer and more costly interurban trip. Because Watson considered it difficult to say whether a traveler would base his or her assessment on the faster or slower time, it was decided to use the mean of the two times and the two costs to indicate total journey time and journey cost respectively. A mean value of time of 53 p/h (equal to 67.5 percent of the average wage rate) was estimated. However, from Watson's study, it can be concluded that a value of time could not be estimated from the best model. This result is important since it indicates that the derivation of a time value from an apparent time-cost trade-off situation may not be universally valid, since, in some cases, what appears to be a trade-off situation may not be perceived as such by the travelers. This finding gives support to the perceived measurement of the relevant variables (rather than manufactured measurement). It was not possible to examine the behavior of value of time across income groups because time and cost variables do not appear together in any of the models calibrated for the separate income groups. Hensher (54) in a route choice study derived values of time for personal business, social-recreation, and work purposes. He used a direct valuation procedure that explicitly related the time and cost differences between two interurban routes by a parameter that was a direct estimate of the value of time in which the cost difference was a toll.

The existence of only one route choice situation in Australia limited the variance in the time and cost differences between the two routes required for successful measurement by the binary (logit) estimation procedure. A transfer payment, defined as the amount of change in cost that would have to occur for an individual to consider changing route, was introduced to analyze the point of potential substitution between routes with respect to cost and time, where time incorporated both the opportunity cost and disutility cost of time. Any criticism of this approach would be the same as that given to the willingness-to-pay approach discussed previously. Further theoretical and empirical assessment of the relationship between the opportunity and disutility costs of time has recently been undertaken and will be reported in due course. Only door-to-door values were derived. The absence of any information on income prevented an equivalent wage rate percentage from being provided.

CONCLUSIONS

This paper has attempted to emphasize the most important empirical contributions to the valuation of travel time under varying circumstances Nearly all the studies have estimated values of travel time as by-products of single or simultaneous travel choice and demand models in which the emphasis is on prediction rather than on capturing the conceptual essence of the notion of the value of travel time. Certain underlying requirements for mode choice, such as representation of all trading and nontrading situations, are not consistent with the valuation requirement of individuals who actually face a true time-cost trade-off situation.

Australian evidence for commuter trips indicates that, when the total mode choice sample is used to estimate the value of time, a somewhat lower value than the true value is obtained (26). Many of the studies (29, 32, 38) produced dubious values because of this procedure. With the exception of the work by Hensher (15, 26) on the valuation of business air travel time and commuter mode choice and the research by Hensen (24), there has been difficulty in isolating the true (or pure) value of travel time from a composite time-comfort (and convenience) value. The values derived from mode choice studies are a composite of the pure value of time (a mode abstract measure), any comfort and convenience differences that are a function of changes in activity time within a given mode, and comfort and convenience differences associated with mode switching where the disutility difference intensity is a function of the absolute amount of activity time. This composite value has led to difficulties and general confusion in the application of values to particular modes. As a working rule, the pure value of travel time should be mode abstract and only modified in the context of a particular mode to make allowance for comfort and convenience differences (assuming that there is no separate value of comfort or convenience differences).

A number of researchers are currently trying to identify, quantify, and value (in a relative sense) those nontime cost influences on various travel choices so that the relatively independent valuation components can eventually be isolated. Although early attempts to remove the value of comfort differences associated with mode switching from the value of time have been successful (26), no one has yet isolated the other nontime influences. The continuing research into preferences in nonmarket situations should be encouraged. This need is consistent with the requirement for efficient estimation of the value of time and the requirement to separate the opportunity cost of time and the disutility of time spent traveling.

The majority of the studies discussed have produced single total sample values of travel time savings due largely to the inadequate sample sizes required for stratifications and have resulted in insignificant income-related values. Seven studies found the VTTS to be directly related to income, two studies found the VTTS to be a constant proportion of income, two studies found the VTTS to be less than a constant proportion of income, one study found the VTTS to be greater than the constant proportion of income, and one found the VTTS to be an increasing function of income below mean income and a decreasing function above mean income. The general view is that the VTTS is a function of income, but more research on larger data bases is required to test this hypothesis. Even though there is a diversity of single values, they do tend to show some semblance of consistency when converted to international units (67). Even allowing for problems of international and interpersonal comparisons of values and utility, the studies discussed suggest that the VTTS tends to range in value from a high for working time through business travel time and commuting time to a low for nonwork, noncommuting time. A definite trend in technique is emerging.

Before improved (stratified) empirical estimates can be made, improvements to the procedures previously used to obtain estimates are required. For some journey purposes (e.g., commuter trips), these improvements are relatively small; for other trips (e.g., recreation trips), the improvements appear to be enormous (69).

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