Value of Time for Commuting Motorists

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The value of travel-time savings for commuting motorists is estimated from the behavior of motorists in eight areas of the country who faced a choice between a toll road and a free road in their trips to and from work. The value of travel time is calculated from the estimated coefficients of toll and travel-time variables in route-choice models for these motorists. The route-choice models are nonlinear and estimated by least squares techniques. Data on the characteristics of the alternate routes were collected by both motorist interviews and test-vehicle measurements, and each was used to estimate independently the value of travel time. This study recommends the use of $2.82 per person per hour as the value of travel-time savings for commuter trips of more than ten minutes and more than five miles in highway economy studies.

While the main objective of the study was to measure the value of travel time, the scope of the analysis included study of a wide variety of possible factors affecting route choice—for example, measures of route congestion or safety, family income, and sex of the motorist. In addition, special attention is given to a critique of both the methodology used in estimating the value of travel time and the use of the estimates in highway economy studies.

•INCREASED use of private automobiles makes economic analysis of highway improvement proposals an area of vital concern. Highway planners, faced with heavy demands for highway facilities and constrained by limitations on funds available for construction, are adopting the techniques of economic analysis to assist them in making better decisions on the expenditure of these funds. Economic analysis justifies highway improvement projects, develops priorities for the construction of highway projects within a political jurisdiction, and determines features of engineering design and layout for projects.

Economic analysis considers the effects of highway improvements both on the highway agency, in terms of increased costs for construction and maintenance of improved highways, and on the highway users, in terms of reduction in accidents and congestion and savings in travel time and vehicle operating costs. To include these effects in economic analysis, all benefits must be stated in dollar values.

One of the most important benefits is savings in travel time. A significant portion of proposed highway projects is directed toward savings in time, rather than savings in motor vehicle operating costs. Consequently, converting time savings from hours to dollars is critically important in both economic and engineering analyses of alternative highway locations and designs. The factor used to make this conversion is called the "value of time."

Even though a value-of-time factor has been used for years in highway economic analysis, relatively little reliance can be placed on the accuracy of the values chosen. The most common value—$0.86 per person per hour—can be justified only in that it

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represents current opinion of a logical and practical value. Research into the value of time has increased in recent years, but even the latest efforts are unsuccessful in determining values that can be used with confidence in a variety of situations.

In view of the widespread importance of the value of time to highway planning and design, an extensive program of studies was undertaken. The study described herein represents the most recent phase of a contract research program that has been conducted for the U. S. Bureau of Public Roads over a period of years by Stanford Research Institute. In studies completed earlier, the history of the value of time was first documented. This review contained not only a qualitative review of past writings, but also a quantitative review of the work of researchers who built models to measure the value of time and attempted to measure it. The problems encountered in previous studies vary, but in general they were caused either by inadequate theoretical specification of the model and its variables (such as the implied assumption that motorists have an accurate idea of operating costs) or by the necessity to use data already collected for other purposes (such as for origin-destination studies) instead of data generated specifically for use in estimating the value of travel time.

After this review, a number of theoretical analyses were undertaken in an attempt to develop a theory of the value of time. Several mathematical models were then constructed, and a series of behavorial science and route-choice prediction experiments were accomplished. These efforts prepared the way for the present study in which we attempted to establish the feasibility of measuring the value of time and the value of traffic impedances.

ESTIMATION OF THE VALUE OF TIME AND TRAFFIC IMPEDANCES

Theoretical analysis, supported by experience of others, led to the following requirements: First, because the research was focused on highway engineering economy, we believed that it was necessary to study choices made by highway users between alternative highways. This led to a determination to study route-choice decisions. Second, we needed to obtain good confidence limits on the calculated values of time and impedance. This required that the cost differences between alternative routes be accurately known by the motorist, which led to the selection of toll-road compared with free-road route choices. Third, to minimize the loss of information that results from aggregating data on different trips into groups of "average" trips, it was decided to study individual motorists, which implies a rather high-cost experiment. Fourth, we felt that we should study a decision situation that is important to motorists. Commute travel, which requires a significant expenditure for tolls or loss of travel time over a period of a year, satisfied this requirement. The next step in the research was to develop a mathematical model or estimation technique for route choice.

Route choice is estimated as a function of a linear combination of explanatory variables such as those indicating the differences between the routes in travel costs, travel times, and traffic impedances:

$$\text{Route choice} = f(a_0 + a_1\,\Delta\,\text{cost} + a_2\,\Delta\,\text{travel time} + a_3\,\Delta\,\text{traffic impedance})$$

where a_0, a_1, a_2, a_3 are the coefficients of the explanatory variables. The values of a_0, a_1, a_2, and a_3 are calculated to minimize the errors in estimating motorists' route choices.

This function provides the basis by which motorist' route choices can be "explained" by the characteristics of their alternative routes and the characteristics of the motorists themselves.

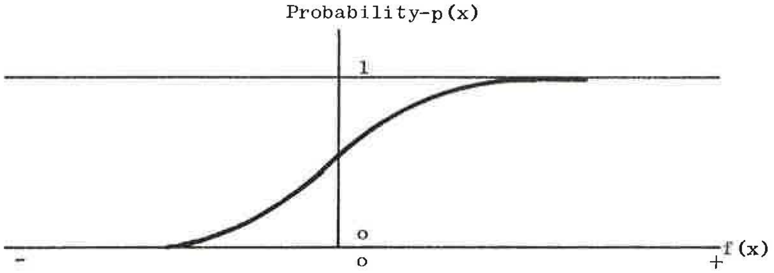
Next, the estimated coefficients are used to calculate the value of travel time and of traffic impedances. The value of travel time is defined as the ratio of a_2/a_1 and the value of traffic impedances as a_3/a_1. This definition implies that a motorist's route choice will not change when an increase in Δ cost by one unit is offset by an a_2/a_1 unit decreases in Δ travel time, or an a_3/a_1 unit decrease in Δ traffic impedance. Thus if Δ cost is in units of cents and Δ travel time is in units of minutes, a 1-cent increase in the cost of the road can be offset by an a_2/a_1-minute decrease in travel time.

The mathematical formulation of the functional relations between route choice and the linear combination of explanatory variables is based on the logit function, which can be expressed in the following form:

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

where p (x) = the probability of taking the free road, e = the base of the natural logarithms, and f (x) = a function of motorists and route characteristics.

A curve of the logit function is as follows:



In this curve, f (x) is plotted on the abscissa and p (x) is plotted on the ordinate and ranges from 0 to 1. The curve shows that when f (x) is large in the positive direction, the probability of taking the free road is close to 1, and when f (x) is large in the negative direction, the probability of taking the free road is close to zero. When f (x) = 0, the probability of taking the free road is 0.5 or 50 percent.

The route characteristics were used to form the x_is in f (x) in four ways: as the difference between routes, the difference multiplied by the magnitude of one characteristic, the ratio of the route characteristics, or the natural logarithm of the ratio of the route characteristics. Motorist characteristics such as income category and sex of driver were also included in the formulations of f (x).

Two basic sources of data were used in the study: route measurements by a test vehicle and motorist interviews. The test vehicle measured the traffic flow of the motorist's route. This vehicle was equipped with a fifth wheel to measure velocity and trip distance and a control panel containing switches and buttons to record descriptive data on the trip, such as the cause of acceleration, deceleration, or turn, the speed limit, type of road, type of traffic flow, nature of roadside construction, and special characteristics coded to the instructions and maps that specified the trip.

Data recording was automated to the extent that data for each second of the trip could be directly processed by computer. A ¼-inch tape recorder was used in the car, and the data recorded on this tape were later converted to standard computer tape. Recordings by the second provided a description of the alternative routes from which a large number of variables could be formed. The data were used to create common measures of route characteristics, such as travel time and distance; a number of impedance measures, such as number and size of speed changes; the portion of the trip spent at various fractions of the speed limit; and time spent at speeds less than 10 mph.

The interviews determined the principal and alternative routes each commuter used in driving to and from work. They measured motorists' perceptions of the characteristics of the toll road and the free road, such as time and cost, and their reactions to driving in general. They also provided data on motorists' personal characteristics, such as family income, age, sex, and model year of the car.

The objective in designing the questionnaire was to obtain the "richest" possible set of descriptors of the motorist and his route. Therefore, not only was a variety of

TABLE 1

CHARACTERISTICS OF THE SAMPLE

Area	Employer	Number of Route Choices[a]	Questionnaire Data	Test-Vehicle Data	Toll Road	Free Roads (Major Roads Only)
Farthest Point—Work Location						
Saco, Me.—Kittery, Me.	Portsmouth Naval Shipyard	116	Yes	Yes	Maine Tpk.	US 1
Newburyport, Mass.—Kittery, Me.	Portsmouth Naval Shipyard	83	Yes	No	N.H. Tpk.	US 1
Milford, Conn.—Bridgeport, Conn.	General Electric Housewares and Wire and Cable Divisions	98	Yes	No	Conn. Tpk.	US 1 Conn. 122
Norristown, Pa.—Valley Forge, Pa.	General Electric Missiles and Space Center	127	Yes	Yes	Penn. Tpk.	US 202 Alt. Penn. 23 Penn. 363 Alt. US 422
Downingtown, Pa.—Valley Forge, Pa.	General Electric Missiles and Space Center	52	Yes	Yes	Penn. Tpk.	US 30 Penn. 113 Swedesford Rd. Penn. 23
Baltimore, Md.—Aberdeen, Md.	U.S. Army Proving Grounds	102	Yes	No	J.F.K. Memorial Tpk.	US 40 I-83 Md. 7 I-695
Dallas, Tex.—Arlington, Tex.	Six Flags Over Texas Industrial Park	110	Yes	Yes	Dallas-Fort Worth Tpk.	US 80 Jefferson Blvd. Texas 183 Loop 12
Fort Worth, Tex.—Arlington, Tex.	Six Flags Over Texas Industrial Park	124	Yes	Yes	Dallas-Fort Worth Tpk.	US 80 I-820 US 20 I-35W

Note: Average characteristics of commuters in sample—No. of passengers per car, 1.6; family income level, $9,200; model year of car, about 1961; sex of driver, 90 percent male, 10 percent female.

[a] Most, though not all, motorists provided both a morning and evening route choice.

questions included, but also two measurement techniques—line-scale ratings and forced-choice comparisons—were used for motorists' perceptions of route characteristics, such as the comparative safety of the alternative routes. A number of questions were eliminated during pretesting because of the low reliability of answers. In its final form, the interview took 40 to 60 minutes per commuter.

Commuters in eight areas were chosen for the route-choice sample. The characteristics of the sample are shown in Table 1. In three of the areas, interview data only were collected.

A conflict arose between the requirement to estimate the decisions of individual motorists and the resources needed to make test-vehicle measurements of travel time and traffic impedance of each motorist's alternative routes. Because both travel time and traffic impedance vary with the season, the day of the week, and the time of day, too many test-vehicle measurements on each route would be required if motorists were selected randomly. However, by selecting groups of commuters who work at the same location and have overlapping routes, it was possible to achieve major economies in the required number of test vehicle trips to create the physical measurements by combining overlapping segments of the trips. While this technique made the study feasible, it eliminated the possibility of a random sample. In all, 812 commute trips were analyzed.

The coefficients of the route-choice models were estimated from the data using maximum likelihood techniques. Since several hundred variables could have been formed from the available data, the number of variables used in any one model had to be restricted. It was decided that route variables based on questionnaire responses and test-vehicle measurements would not be combined in one route-choice model. These two approaches to route measurements were considered as distinct and independent and were used to provide separate estimates of the value of travel time and traffic impedance. Within each of these two sets of route characteristics, correlations were run between the motorists' route choices and the route variables—singly and in combination. This provided an indication of the empirical importance of the route variable that was then matched against its theoretical importance to select a subset of variables. Motorist characteristics were treated the same way. From the subsets of motorist and route-explanatory variables, route-choice models were specified and estimated.

Thirty-seven models were estimated that used route variables based on the test-vehicle data. The best route-choice model of the 37 models had an f(x) as follows:

	Coefficient	Variable
$f(x) = 9.15$	-0.236 (0.066)	Income category of motorist—categories 1 to 8
	-0.105	Model year of car—'58, '59, '60, . . .
	-1.29 (0.36)	Sex of driver—1 equals male and 2 equals female
	+0.0554 (0.012)	Toll per person—in cents
	+0.0028 (0.0003)	Difference in travel time—in sec

Numbers in parentheses beneath the coefficients are the standard errors of the coefficients. This model correctly estimated route choice for individual motorists 75.8 percent of the time. The percentage was calculated from the estimated p (x) for each motorist. If p (x) turned out to be greater than 0.5 the motorist was estimated to take the free road, and if it was less than 0.5, the toll road. The estimates were then compared with the actual choices.

Twelve models based on route characteristics taken from interview data were estimated. The best route-choice model based on the five-area interview data for which test vehicle measurements were also available had an f (x) as follows:

	Coefficient	Variable
f (x) = 3.48	-0.410 (0.089)	Income category of motorist—categories 1 to 8
	+0.025 (0.033)	Model year of car—'58, '59, '60, . . .
	-1.12 (0.44)	Sex of driver—1 equals male and 2 equals female
	+0.0488 (0.014)	Toll per person—in cents
	+0.00522 (0.00048)	Difference in travel time—in sec

This model correctly estimated route choice for individual motorists 84.5 percent of the time.

The best route-choice model based on the full eight-area interview data had an f (x) as follows:

	Coefficient	Variable
f (x) = 3.86	-0.432 (0.077)	Income category of motorist—categories 1 to 8
	+0.0499 (0.011)	Toll per person—in cents
	+0.0053 (0.0004)	Difference in travel time—in sec

This model correctly estimated route choice for individual motorists 85. 6 percent of the time.

Two criteria were used to select the best model in each set:

1. The coefficients of income, toll per person, and all the route-characteristic variables, such as difference in travel time, had to be significant at the 95 percent confidence level when compared to their standard errors.
2. The higher the percentage of correct predictions, given criterion 1, the better the model.

The unique characteristic of all three best route-choice models is that none contains a route characteristic variable other than difference in travel time. This is despite the fact that models were developed with a wide variety of traffic impedance variables in a number of combinations. The exclusion of traffic impedance variables from the route-choice model can be interpreted as (a) assigning little importance to a reduction in traffic impedance, independent of travel time, or (b) stating that nearly all the important reductions in travel impedances are included in the associated reductions in travel time. The second interpretation assumes that the difference in travel-time variable is highly correlated with the traffic-impedance variables, so that a separate coefficient cannot be reliably estimated. However, if this were true, the coefficient of the difference in travel-time variable should change, and the ratio of its coefficient to its standard error should decrease as travel-impedance variables are added to the route-choice model. This does not happen. Therefore, the first interpretation appears to be correct. According to this interpretation, a reduction in a traffic-impedance variable such as Δ deviation from speed limit is important only for the reduction in travel time it may bring. If it does not result in lower travel time, it has little or no importance to the motorist and does not affect route choice in a statistically significant manner.

Value of Travel Time

The value of travel time is calculated as the ratio of the coefficients of difference in travel time and toll per person. For the units in which the coefficients are expressed, the ratio must be multiplied by 36 to obtain an answer in dollars per hour. Initially, attention is directed at the values of time calculated from two best route-choice models for the five areas to facilitate comparisons.

From the best model based on test-vehicle data, the value of travel time was estimated to be $1.82 per person per hour (0.0028 × 36÷0.0554). The 95 percent confidence limits of the value of time range from $1.04 to $2.60 per person per hour.

From the best model based on motorists' reported route characteristics covering the same areas as the test-vehicle data, the value of travel time was estimated to be $3.84 per person per hour (0.00522 × 36÷0.0488). The 95 percent confidence limits of the value of time range from $2.82 to $4.86 per person per hour.

Standard errors of the calculated values provide confidence limits on their magnitude for each model, that is, for the particular set of explanatory variables for which the coefficients were estimated. However, these confidence limits apply only to values calculated from data from the same population using the same model. They provide no information on the changes in the calculated values (and hence the value of time that might occur) as other explanatory variables are added or subtracted from the route-choice model. Since large changes in the coefficients are possible when there is intercorrelation between the potential explanatory variables, the stability of the coefficients (and hence their ratios) will be analyzed as explanatory variables are introduced or removed from the discriminant function. This provides a clue to whether a consistent effect of the variable is being measured or whether only an unstable best fit has been determined that changes with the particular set of variables used to construct the model.

For the two best models that estimate the value of time from the five-area data, the test of stability takes on a special interpretation. The other variables to be introduced are all different formulations of the traffic-impedance variable. Therefore, the test can be rephrased: Is the value of time that is estimated when the value of traffic impedance is set at zero changed when the route-choice model is also formulated to estimate a value of traffic impedances, that is, when traffic impedance variables are included in the model?

For the model using test vehicle road measurements, the ratio of the coefficients of Δtravel time to the coefficient of toll per person is 0.05. The ratios of the coefficients for the models are the value of time in cents per person per second. Examination of the variations in this ratio when one additional variable is added (either in the form of a delta or a total variable) shows that the ratio of the two coefficients varies from a low of 0.04 to a high of 0.053. Thus, with the introduction of one additional variable, the variation in the value of Δtravel time stays well within the 95 percent confidence limit.

For the model using interview data for road measurements, the ratio of the coefficients of Δtravel time to the coefficient of toll per person is 0.107. Introduction of other variables into the discriminant function—not only singly but in groups of up to five additional variables—causes the ratio of coefficients to vary from 0.113 to 0.0866. Thus, the maximum variation with the introduction of other explanatory variables is well within the 95 percent confidence limit for the value of Δ travel time.

In summary, both the best model using test-vehicle data and the best model using interview data to measure road characteristics provide stable estimates of the value of travel time that significantly differs at the 95 percent confidence level from the $0.86 per person per hour value most commonly used in highway economy studies. In addition, the two estimates are significantly different from each other at the 95 percent confidence level.

Before analyzing the deviations of both estimates from a hypothesized true value of time, one argument will be considered for summarily rejecting the perceptual estimate without further analysis. This argument asserts that the value of travel time based on physical data must be used, since highway economy studies are based on physical data.

Nature of Value of Δ Travel Time and Its Use in Highway Economy Studies—The theoretical framework for the value of travel time is the motorist's indifference curve. Within this framework, the value of time to a motorist is the slope of the indifference map in the plane formed by the money-used and time-used axes. This slope of the indifference map can be interpreted as a value of travel time that the motorist holds only if the variables of money used and time used are the ones he perceived, that is, if it is his indifference map. Specifically, in this analysis the toll per person and Δ travel time quantities used should be the quantities the motorist perceived when he made his route-choice decision. Therefore, the only question is: Does the test vehicle or interview data on road characteristics better represent the motorist's perceived quantities when he made the decision? There is only one value of time—the motorist's. The best model is determined by how well it estimates the value of time, not its data source.

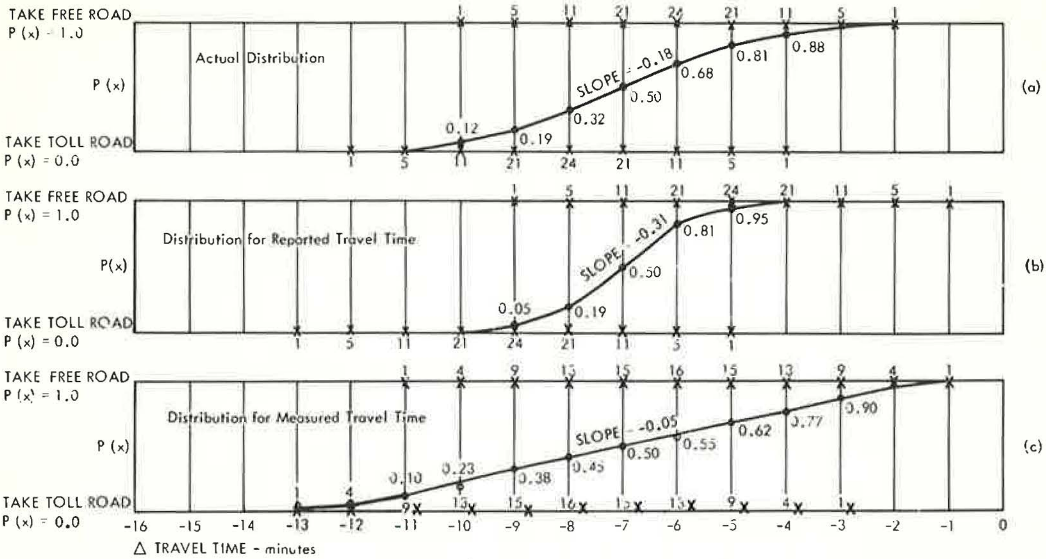
However, after the value of time has been estimated, there may be some question about how properly to estimate the difference in travel-time variable for use with the value of time. If motorists consistently perceive Δ travel time as higher or lower than is actually the case, they will estimate their benefits higher or lower than the product of their value of time and their actual time savings. However, given that the motorist's values are used, it seems appropriate for a public official to base benefits on the best available estimates of travel-time changes. This is the same benefit the motorist would calculate if he were informed of the "true" travel time difference.

Therefore, returning to the question, Can either value of Δ travel time be rejected based on the nature of the data used in its estimation?, the conclusion is that neither estimate can be rejected. Both must be analyzed.

Comparison of Test-Vehicle and Interview-Based Estimates—Neither the test-vehicle nor interview data provide a precise estimate of the travel time perceived at the point of the route-choice decision. Interview data have a bias toward the road taken, that is, the motorist consciously or unconsciously tends to make the road appear better in response to a question than it was previously perceived to be. Analysis of the data indicates that the magnitude of this bias is about 1 to 2 minutes upward in Δ travel time if the free road is taken and about 1 to 2 minutes downward if the toll road is taken. It is easy for this level of bias to be incorporated into the reported magnitudes of Δ travel time because motorists tend to report travel-time differences in multiples of 5 minutes. About 92 percent of the estimates were rounded to multiples of 5 minutes.

The measured data are in error, if for no other reason than that the motorist's perceptions do not always correspond to the actual travel time. Thus, even if the measurement were exact—which is unlikely, given the small number of measurements—they would still be in error in estimating the Δ travel time perceived at the point of decision. Analysis of the data indicates that the measured data probably are equal to the perceived Δ travel time at the time of decision on the average, that is, the measured data are unbiased. However, the effect of the differences between perceptions and measurements is to increase the variance of the travel time distribution from what it would otherwise be.

The effect of the bias in interview data and the errors in measured data on the coefficient of travel time in the route-choice model is shown in Figure 1. The effect of the bias and errors is compared to the coefficient that would hypothetically be estimated without bias or errors in the data. In each of three examples, the explanatory variables other than Δ travel time are assumed to be held fixed. It is assumed that 200 motorists have faced different Δ travel times and made a decision between the toll and free roads.



NOTE ONE: All explanatory variables except Δ TRAVEL TIME are assumed to be held constant. Therefore Δ TRAVEL TIME is linearly related to F (x).

NOTE TWO: Sign of Δ TRAVEL TIME is negative because Δ TRAVEL TIME = toll road travel time - free road travel time.

X Indicates number of motorists observed

Figure 1. Effect of biases and errors on the coefficient of Δ travel time.

Of these, 100 chose the toll road. They are shown by X's on the toll-road choice line, indicating the Δ travel time they faced. The other 100 motorists are shown in the same way on the free-road choice line. The number above the X's indicates the number of X's—the number of motorists that faced that level of Δ travel time and made the indicated decision.

For comparative purposes, the analysis concentrates on the slope of the S-shaped curve in its midrange. Since all explanatory variables except Δ travel time are assumed to be held constant, changes in Δ travel time are linearly related to changes in f(x). Therefore, the larger the absolute magnitude of the slope in the midrange (which is common to each graph), the larger the absolute magnitude of the coefficient of Δ travel time; the smaller the absolute magnitude of the slope, the smaller the absolute magnitude of the coefficient of Δ travel time. Since toll per person is known without error, its estimated coefficient is nearly uniform for all models; therefore, the larger the coefficient of Δ travel time in absolute magnitude, the larger the value of Δ travel time, and vice versa.

Figure 1a shows a hypothesized distribution for the Δ travel time perceived at the time of the route choice The approximate slope of the S-shaped curve between -6 and -8 min is -0.18, that is, a change in p(x) of -0.18 for each 1-min change in travel time. The coefficient of Δ travel time from these data is assumed by definition to provide the true coefficient of time. The S-shaped curve is pictured as trying to minimize the sum of the squares of the deviations for each integral Δ travel time. This would require that the curve go through the mean of the observations at each integer (shown on the graph). While the actual S-shaped curve fitted to the data will not go through the mean for each integer, it will be close to these means in the midrange, where the largest number of observations were made.

Figure 1b shows a hypothesized distribution of travel time reported in the interviews. This is the same distribution used in Figure 1a, except 1 min is subtracted from the Δ travel time of each toll-road user and 1 min is added to each free-road user. The effect of this bias on the estimating of an S-shaped curve is to raise its approximate slope in the -6 to -8 min range to -0.31. This increase in the absolute magnitude of the slope is due to the additional separation in the toll-road and free-road motorist distributions caused by the biases. This bias makes discrimination between toll-road and free-road users easier. Better discrimination corresponds to a higher slope of the S-shaped curve, which provides a quicker change in p (x) from the toll road to the free road as Δ travel time increases. Therefore, the value of time based on interview data is estimated to be higher than the true value of time.

Figure 1c shows a hypothesized distribution of travel time measured at the time of the survey. The mean of each distribution is kept the same as in Figure 1a—at -6 min for the free road and -8 min for the toll road. The only change is an increase in the variance of each distribution, that is, a spread due to errors between the perceived Δ travel time at the point of decision and the measured Δ travel time. The effect of the increase in the variance is to lower the approximate slope of the S-shaped curve between -6 and -8 min to -0.05. The larger variance has increased the overlap of the two distributions and made the discrimination task more difficult. This corresponds to a lower slope in the midrange of the S-shaped curve, which provides a slower change in p (x) from the toll road to the free road as travel time increases. Therefore, the test-vehicle-based value of time is estimated to be lower than the true value of time.

The analysis shown in Figure 1 leads to the conclusion that the value of Δ travel time based on the test-vehicle data of $1.82 per person per hour is low and that the corresponding estimate of $3.84 per person per hour based on interview data is too high. The correct value of time lies between these two values.

It was not possible to derive estimates of the relative magnitude by which each type of estimate was in error. However, both simulation and analysis hold some promise. At this point in time, a simple average of the two values of time would appear to provide the most reasonable compromise estimate based on the five-area data.

Additional Evidence on the Value of Time—Additional interview data on commuters' route choices were available for three areas. Despite the dissimilarities between the route choices in these three additional areas and the original five areas, there was no significant difference between the two sets of data in the commuters' decision structure (as approximated by the model). Specifically, the coefficients of toll per person and Δ travel time estimated from the two sets of data were different by less than a single standard error of each coefficient. Therefore, the difference in the value of time calculated for both areas is not statistically significant.

The two sets of data were combined, and a route choice model estimated for the eight areas. Results were as follows:

1. Using the same variables as in the best five-area model using interview data, the value of the difference in travel time was estimated to be $3.72 per person per hour with a standard error of $0.84 At the 95 percent confidence level, the value of the difference in travel time ranges from $2.07 to $5.37 per person per hour.
2. If the two explanatory variables—sex of the driver and model year of the car—are eliminated (as was indicated by their lack of statistical significance) and the route choice model is reestimated, the value of the difference in travel time is estimated as $3.82 per person per hour with a standard error of $0.84. At the 95 percent confidence level, the value of Δ travel time ranges from $2.17 to $5.47 per person per hour.

These results are very close to the calculated value of the difference in travel time from the best five-area model with some widening of the confidence limits. The additional evidence of the three new areas strongly supports the existence of a uniform value of Δ travel time based on interview data. Also, the highly favorable nature of these results lends implicit support to the hypothesis that the value of travel time based on test-vehicle data for the three additional areas also would correspond closely to that of the other five areas.

Use of the Estimated Value of Δ Travel Time

The value of Δ travel time for the sample has been placed within the limits of $1.82 per person per hour (best five-area model based on test-vehicle data) to $3.82 per person per hour (best eight-area model based on interview data). There is no evidence for narrowing these limits further or placing the value of the difference in travel time (that is, the value of Δtravel time) closer to one limit or the other. Therefore, the simple average of the two values, or $2.82 per person per hour, is selected as the value of Δtravel time.

It is obvious that $2.82 per person per hour is not the value of Δtravel time for all motorists under all circumstances. In analyzing the subpopulation of motorists for whom this value is appropriate, one is limited because the sample was not random. Consequently, statistical confidence limits cannot be placed on the expected value of Δ travel time for motorists—not even for commuters facing a toll road-free road choice. In a statistical sense, knowledge is limited to the observations in the sample. Nevertheless, the value of Δtravel time of $2.82 per person per hour is based on the actual preferences displayed by commuters. Alternative values of time are based on judgment and current opinion. In these circumstances, it is our judgment that the value of time of $2.82 per person per hour should be used for all commuter trips greater than 10 min and longer than 5 miles.

The reason for restricting the recommendations to commuters is obvious: all the motorists in the sample were commuters. Likewise, the shortest trips in the sample took over 10 min and were longer than 5 miles. Another characteristic of the sample is that all the route choices involved toll road-free road alternatives. However, this does not appear to present a limitation to increasing the value of travel time to at least $2.82 per person per hour. If there is a bias against paying a toll just because it is a toll, the bias would operate to decrease the estimated value of Δtravel time from its true free road-free road value. The value of the time savings would have to be greater than the toll by the amount of the bias. This decreases the amount of toll that a motorist would otherwise be willing to pay and results in a lower value of Δtravel time for the motorist. Consequently, because of this bias, the value of $2.82 per person per hour may be too low. However, from other evidence developed in the study, the magnitude of this bias in the decisions studied is believed to be small.

The data have other peculiarities. The average income per family is high compared to all commuters, being approximately $9,200 compared with the overall average of $6,500. However, income is a variable in the route-choice model and its influence is estimated separately. Professional and blue collar workers are overrepresented and clerical workers are underrepresented. Metropolitan areas predominate. Government and defense industry workers are overrepresented. The possible effect of these and other characteristics of the data appears to be negligible in light of the magnitude of the difference between the currently used values of time and $2.82 per person per hour.

It is therefore recommended that the value of time for commuter trips of over 5 miles and 10 min be adjusted upward to the estimated value of $2.82 per person per hour.

CRITIQUE AND EXTENSION OF THE METHODOLOGY

The value of time is shown to have a number of desirable statistical characteristics for an estimated value. In addition, the number ($2.82 per person per hour) can be used in present procedures for calculating highway benefits. However, it is just this characteristic of the estimate—that it is a single number—that makes it most undesirable on theoretical grounds.

This section analyzes the characteristics of this estimate of the value of time that are independent of the amount of time saved, of the income level of the motorist, or of any other variable except type of trip, which is limited to commuters.

The linear form of f(x) used to estimate route choice makes the value of Δtravel time constant for all levels of time savings. However, both theoretical and empirical work in earlier Stanford Research Institute studies indicate that motorists are less sensitive to an incremental unit of time savings when total time savings are either very small or very large (1).

Figure 2a shows the theoretical relationship that is hypothesized. The slope of the relationship is low for both small time savings (labeled insensitive) and large time savings (labeled diminishing marginal returns) and is high in the midrange. Therefore, the linear approximation is low for some amounts of time savings and high for others.

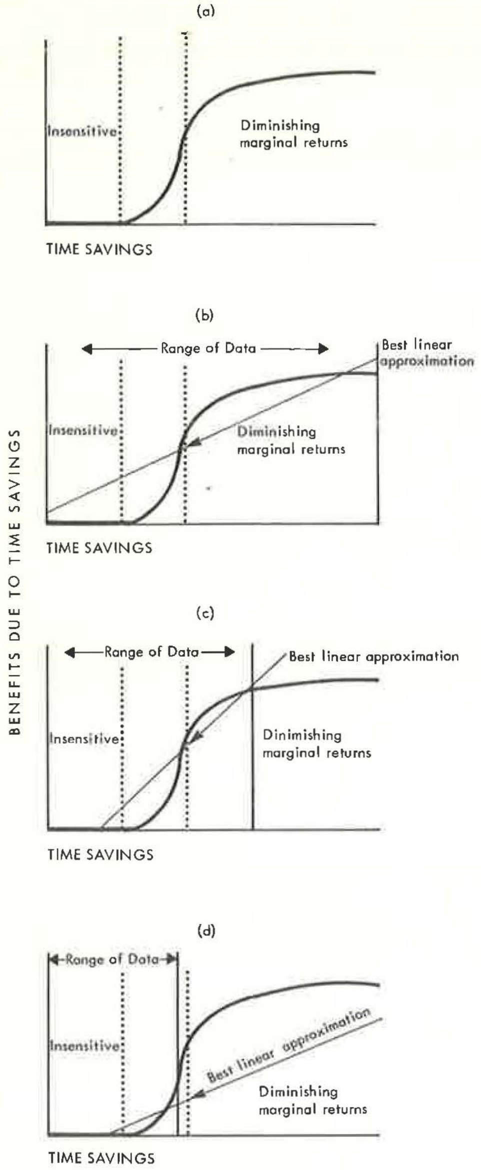


Figure 2. Relationships of benefits due to time savings.

Furthermore, the estimate of benefits obtained from multiplying time savings by the value of time is not necessarily equal to even the linear approximation. It is equal only if the intercept of the linear approximation on the benefits axis is zero.

Figures 2b, 2c, and 2d illustrate how the slope and intercept of the linear approximation may change as the range of data changes. The slope is low and the intercept positive when much of the data lie in the area of diminishing marginal returns (Fig. 2b). The slope increases and intercept decreases (to a negative value) as data become more evenly distributed over the three areas (Fig. 2c). Finally, the slope of the linear approximation decreases and the vertical intercept remains negative as the range of data excludes all diminishing marginal returns and part of the midrange (Fig. 2d). In Figure 2b, the linear approximation of benefits from time savings is higher by the amount of vertical intercept than that estimated from multiplying the value of Δtravel time by Δtravel time. In Figure 2c and 2d, the linear approximation of benefits from time savings is lower by the magnitude of the vertical intercept.

There are reasons to believe that Figure 2c or 2d portrays the actual situation in the sample. It was selected to provide a split in route choices and approximately one-third of the motorists reporting that the toll road is faster do not take it. Since motorists appear much more sensitive in their route choice to the level of time savings than to any other variable including toll per person, it appears that benefits due to time savings cannot be too high, or they would outweigh all other considerations and result in a higher proportion of motorists taking the toll road. It is likely, therefore, that few if any motorists are in the region of diminishing marginal returns.

Therefore, the use of the product of the value of travel time and travel time savings as an estimate of benefits may overstate the benefits compared with the linear approximation, which itself has over- and under-approximation errors.

Total Benefits

A quantitative estimate of the magnitude of the intercept of the linear approximation (as well as the effect of income on the value of time) requires an analysis of the motorist's total benefits from his route selection. This is necessary because the route choice is the observed event to which benefits can be related. The calculation of the benefit from time savings involves an allocation of part of the total benefits from the route choice to time savings and clouds the analysis.

The method of calculating the difference in total benefits for two alternative free roads can be conceptualized as follows: Assume that the characteristics of one road are better. On the better road, however, there is a toll booth with an operator that adjusts the amount of toll required from each motorist until the motorist becomes indifferent to the route he takes. Then the toll is lowered just enough for each motorist to take the better road. This toll, individualized for each motorist, equals the money value of the benefits he would have received if there were no toll—his benefits on the better free road.

The median benefit to the group of motorists is the toll that would make the median motorist indifferent. This toll can be obtained in a straightforward manner from route-choice model. The median motorist is indifferent to differences in the two roads when the probability of taking the free road is 0.5. But the probability of taking the free road is p (x) where

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

where $p(x) = 0.5$ and $f(x) = 0.0$.

If the route-choice model uses as explanatory variables toll per person plus motorist and route explanatory variables, then:

$$f(x) = 0 = k + a_T x_T + a_{1m} x_{1m} + a_{2m} x_{2m} + \cdots + a_{1r} x_{1r} + a_{2r} x_{2r} + \cdots$$

where

a_T is the coefficient of toll per person,
x_T is toll per person,
a_{im} is the coefficient of the ith motorist explanatory variable,
x_{im} is the ith motorist explanatory variable,
a_{ir} is the coefficient of the ith route explanatory variable,
x_{ir} is the ith route explanatory variable, and
k is the estimated constant term.

Therefore, the total benefits—x_T, or the toll per person required to make the median motorist indifferent—are

$$x_T = -\frac{k}{a_T} - \frac{a_{1m}}{a_T} x_{im} - \frac{a_{2m}}{a_T} x_{2m} - \cdots - \frac{a_{1r}}{a_T} x_{ir} - \frac{a_{2r}}{a_T} x_{2r} - \cdots$$

For the best model using test vehicle data, the total benefits become

$$\begin{aligned} \text{Total benefits per person} = {} & \frac{9.15}{0.0554} + \frac{0.236}{0.0554}\ \text{Income category} \\ & + \frac{1.29}{0.0554}\ \text{Sex of driver} \\ & - \frac{0.105}{0.0554}\ \text{Model year of car} \\ & - \frac{0.0028}{0.0554}\ \Delta\ \text{Travel time} \end{aligned}$$

Any mathematically equivalent expression for total benefits is permitted. A particularly appealing one, since Δ travel time is the only route variable describing the two free roads, is to use Δ travel time as the only explanatory variable with the other explanatory variables (based on motorist characteristics) operating as modifiers of the coefficient of Δ travel time. Stated mathematically,

$$\text{Total benefits per person} = (V^*)\ (\Delta\ \text{travel time})$$

For the best model using the vehicle data, the equality is preserved when:

$$V^* = -\frac{0.0028}{0.0554}\left[1 + \frac{9.15}{0.0028}\frac{1}{\Delta\text{ travel time}} - \frac{0.236}{0.0028}\frac{\text{income category}}{\Delta\text{ travel time}} - \frac{1.29}{0.0028}\frac{\text{sex of driver}}{\Delta\text{ travel time}} - \frac{0.105}{0.0028}\frac{\text{model year of car}}{\Delta\text{ travel time}}\right]$$

where 0.0028/0.0554 is the value of Δ travel time as previously defined, and the expression in brackets modifies it, based on the income category, sex of driver, and model year of car.

V* has the dimensions of total benefits per second saved. It not only incorporates the effects of the explanatory variables specifically in the model, but also the effect of the average of all other variables through the constant term. These other variables are not only the excluded variables, such as Δ distance and Δ speed changes, but also such variables as bias against the toll road for which no attempt was ever made to represent them explicitly in the route choice model. The multiplicity of factors involved in determining the magnitude of the constant term should be kept in mind as its effect is examined.

Estimates of Total Benefits to Motorists

Figure 3 shows total benefits vs Δ travel time for the model using test-vehicle data and the best area interview-data model. The relationships are for the median motorist. In the graph, explanatory variables other than toll per person and Δ travel time are held

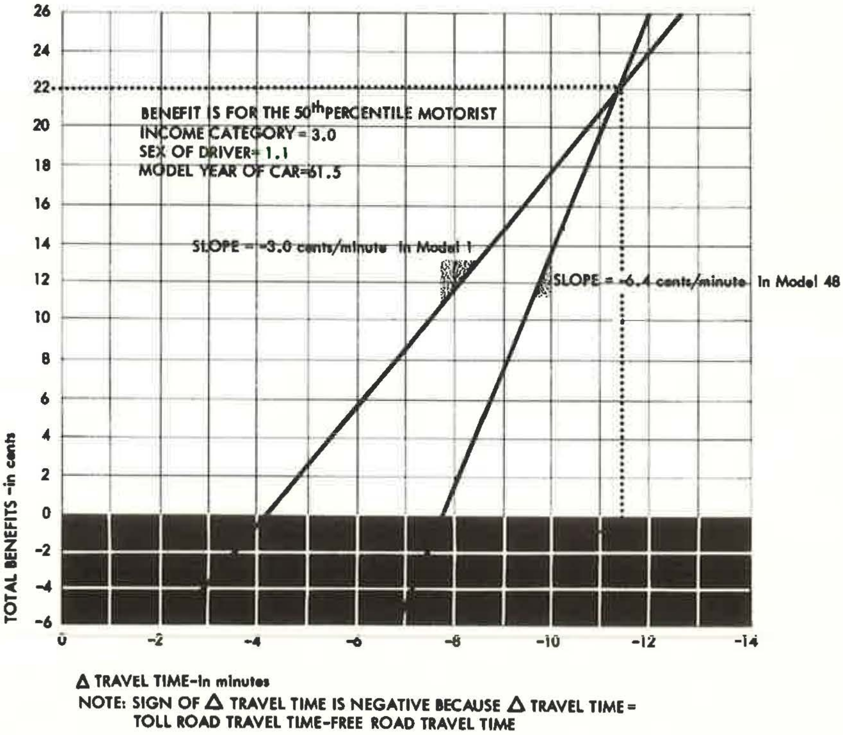


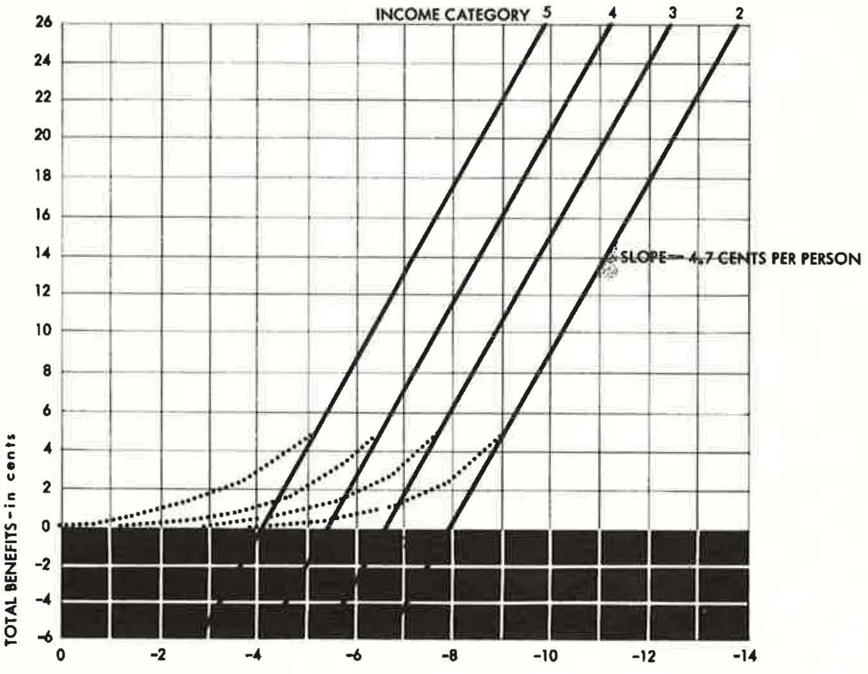
Figure 3. Total benefits vs Δ travel time for model 1 (best model using test-vehicle data) and model 3 (best area interview-data model).

constant. Income category is set at 3 ($6,000 to $8,000 a year), which includes the median for all automobile commuters. (The median value for all automobile commuters is about $6,500 as shown in Passenger Transportation Survey, 1963 Census of Transportation, Bureau of the Census, 1965.) The test-vehicle data model also uses the model year of the car and the sex of the driver as explanatory variables. These variables are fixed at their mean value in the sample, that is, a model year of 61.2 and a sex of 1.1 (10 percent females, 90 percent males). The slope of the lines in Figure 3 is the value of Δ travel time in units of cents per minute. Any point on the line relates travel-time savings to the equivalent total benefits to the motorist, given the fixed value of the other explanatory variables.

Figure 4 shows a different picture. The average model, which has a value of Δ travel time of $2.82 per person per hour, or 4.7 cents per person per minute, is shown by the solid lines for each income category from 2 through 5. The effect of an increase in family income of the motorist is to increase the total benefits equivalent to a fixed level of travel-time savings.

Total benefits are negative for some amounts of positive time savings (Figs. 3 and 4). For example, in Figure 4 the solid lines show that total benefits become negative for motorists in income category 3 when travel time savings are less than 6.7 min. This property—benefits dropping to zero before time savings—was depicted in Figure 2c and 2d as the most likely placement of the linear function used to approximate the theorized nonlinear relationship between benefits due to time savings and actual time savings.

The estimated relationship should not be used to calculate negative benefits. It is an approximation and should not be used outside the range of data in the sample. A toll of 5 cents per person is effectively the lower limit of the data. Therefore, the relationship should not be used to estimate total benefits of less than 5 cents. Similarly,



NOTE: SIGN OF Δ TRAVEL TIME IS NEGATIVE BECAUSE Δ TRAVEL TIME= TOLL ROAD TRAVEL TIME-FREE ROAD TRAVEL TIME

Figure 4. Total benefits vs Δtravel time, average model.

the relationship should not be extended above a toll of 30 cents per person, which is effectively the upper limit of the data. For total benefits less than 5 cents per person, a new relationship can be proposed,which theory suggests should eliminate negative benefits for positive time savings, intersect the origin, and have a monotonically increasing slope to the right of the origin. The dotted lines in Figure 3 indicate such a relationship. The required reduction in the slope to eliminate negative benefits for positive time savings makes total benefits less sensitive to time savings near the origin.

Once the slope of the linear portion of the relationship has been estimated, the range of reduced sensitivity is determined by its intercept. The magnitude of the intercept is determined by several factors. First, the income category of the motorist affects the placement and consequently the range of reduced sensitivity. For the model graphed in Figure 4, the range of reduced sensitivity for motorists in income category 5 is from the origin to time savings of approximately 5 min, and for motorists in income category 2, from the origin to time savings of approximately 9 min. Second, the placement is affected by the constant term in the route-choice model. The question therefore arises as to how accurately the constant term is known, that is, what the confidence limits on the constant are.

For both models, the standard error of the constant term is slightly larger than two units. But only a one-unit change in the constant term changes the intercept of the line with the Δ travel time axis by 6 min for the model based on test-vehicle data and 3.2 min for the model based on interview data. Therefore, the confidence limits on the placement of the line are very broad. The hypothesis that the intercept is actually zero—that there is no reduction in sensitivity—cannot be rejected at the 95 percent level. Thus the route choice models can provide statistically significant estimates of the marginal effect of both Δ travel time and the income category on total benefits, but not the intercept of the relationship. The wide confidence limits on the constant term may be due to the fact that the constant term reflects many factors, including the mean value of each explanatory variable, the mean value of the excluded explanatory variables of traffic impedances (to the extent that their mean affects route choice), and the mean value of other variables, such as toll road bias, that were never considered for inclusion in the route-choice model. The effects of the average magnitude of the excluded explanatory variables were analyzed, and the Δ distance in the models based on physical data had a noticeable effect. An adjustment for its average effect would lower the intercept of test-vehicle data model by about 0.5 min, but it has a negligible effect on the interview data model.

The estimated intercept based on toll road-free road choice data may be biased as an estimate of the intercept for a free road-free road choice. This bias if it exists is the negative effect on the motorist of the existence of a toll, independent of the level of the toll. Its existence could be tested by comparing the estimated relationship from a toll road-toll road choice. In this case, both roads would have a toll and any bias would cancel out. The difference in tolls would act as a measure of total benefits.

The only evidence available on the magnitude of the toll-road bias is inferential. In a hypothetical question, motorists were asked if they would pay a given amount for additional time savings. Most of them indicated thay they would not, even though the payment was considerably less per minute saved than what they were already paying. This discrepancy between word and deed is probably caused by the toll-road bias. It operates in a hypothetical question, where a verbal refusal to make the payment does not cost the motorist any actual benefits. However, when faced with real benefits, many more motorists pay the toll than their answers to the hypothetical question indicated. The inference can be drawn that the average toll-road bias in the actual situations may be quite small and exert only minor influence on the intercept.

Thus, while the total benefits approach is useful in examining the effect of the intercept and other variables in the route-choice model, the analysis is still based on a linearized estimator, that is, f(x). Within this study, the extent of the nonlinearity could not be determined. (A precise estimate of the intercept in the total benefits versus Δ travel time would have provided some insight.) However, the ramifications of a nonlinear relationship such as those shown in Figure 2 are quite striking and will be illustrated in a simple example.

Effect of Nonlinearity in the Relationships of Total Benefits to Time Savings

With a nonlinear relation, a reduction in the slope of the relationship between total benefits and Δ travel time compared with the linear portion will occur. If such a reduction occurs around the origin, the value of a minute saved depends on which minute it is—the first minute saved or the tenth. Stated another way, if the motorist has a reduced sensitivity to small savings in travel time, the average value of a minute is 1 minute or 10 minutes. In such a case, the accurate assessment of the benefits of time savings on a portion of the trip requires a knowledge of the travel-time savings for the entire trip.

By similar logic, the evaluation of the benefits of time savings from a highway improvement requires knowledge of whether it is a single isolated improvement or part of a series of improvements. In the latter case, the larger the total time savings of which the improvement is part, the greater the average value of a minute saved.

However, reduced sensitivity to small time savings would not only affect the data collection requirements for highway economy studies, but it would also create problems in specifying the proper methodology for the evaluation. The following example introduces some of the methodological complications:

Assume that the relationship between total benefits and Δ travel time is known. The question is then posed: What are the benefits to a motorist of the proposed improvement in the following example? The motorist must go from point 1 to point 2. At present, he has the choice of using either Route A or Route B. Route A is 10 minutes faster than Route B. The proposed improvement is to Route A. If the improvement is made, Route A will be 12 minutes faster than Route B. These conditions are shown in Figures 5 and 6.

Assume that the time savings of the proposed improvement are the only aspect of the improvement that affects the total benefits perceived by the motorist. Then one method of calculating the benefits (Method 1) would be:

Total Benefits of Improvement = f [travel time on Route A (improved) - travel time on Route A]

= f[2 min of travel time savings]

However, the relationship between total benefits and travel time was presumably estimated from data on the motorist's choices between two routes, both of which were available at that time. Therefore, it is equally logical to use the following method (Method 2) to calculate benefits: Total Benefits of Improvement = [total benefits of Route A (improved) compared with Route B] - [total benefits of Route A compared with Route B] = f [travel time on Route A (improved) - travel time on Route B] - f [travel time on Route A - travel time on Route B] = f (12 min of travel time savings) - f (10 min of travel time savings)

If the slope of the total benefits vs Δ travel time relationship were a constant for all amounts of Δ travel time, the two methods of calculating total benefits would produce the same estimate of total benefits. But if the slope is not constant because of reduced sensitivity to small time savings, for example, the results of the two methods will differ. For the modified relationship shown in Figure 4 (the dotted lines for benefits

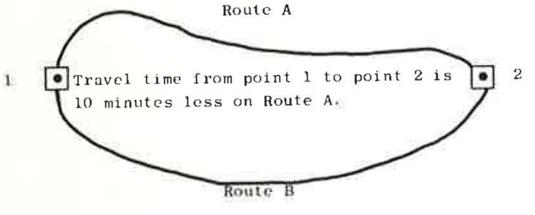


Figure 5. Present conditions.

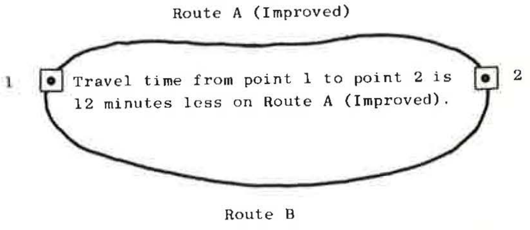


Figure 6. Conditions with proposed improvement to Route A.

of less than 5 cents), the first method of calculation would estimate total benefits of less than 1 cent. The second method of calculation would estimate total benefits of 9.4 cents. It is not just insensitivity to small time that will cause this result. The two methods will generally produce different answers when the slope varies. For example, if total benefits were a function of Δ travel time and $(\Delta \text{ travel time})^2$, the relationship would be curvilinear, and the method of estimating total benefits also would be important.

The choice between the two methods is difficult. Both methods of calculating total benefits can be logically defended and both produce anomalous results under some circumstances.

The recommended use of $2.82 per person per hour as the value of travel time is based on the use of Method 2 and the assumption that total benefits before and after the improvement lie on the linear portion of the relationship between total benefits and travel time. This is the case shown in the example.

Under these circumstances, only the slope of the relationship in its linear portion need be known. The placement of the relationship will not affect the results. Since the extent of the reduced sensitivity is not known, it is impossible to specify quantitatively the route choices for which the assumption of linearity is valid.

The use of $2.82 per person per hour is consistent with Method 1 only if the range of insensitivity is assumed negligible; that is, the graph of the total benefits vs travel time is approximately linear and passes through the origin. In this case, Methods 1 and 2 give the same results.

The recommended value of Δ travel time bypasses the problems of estimating total benefit in the face of reduced sensitivity through a plausible assumption on the method of estimating highway benefits. However, this problem will almost certainly become important as the empirical basis for the value of time expands.

By making a more precise estimate of the value of time than has previously been possible, this study has transformed the question, "What is the correct number of the value of time?" to "What is the functional form and parameters of the value of time?". The second question will be more difficult to answer, but being in a position to ask the mc sophisticated question indicates considerable progress.

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Discussion

DENNIS NEUZIL, Assistant Professor of Civil Engineering, University of Delaware—Because this report has presented rigorously derived values for the value of time to commuting motorists, and because similar information for other types of trips does not exist, the Stanford Research Institute values will probably be used for other trip purposes as well. When faced with a lack of information for certain phenomena, there is a tendency to use data from related phenomena that have been well substantiated. While this practice may not be desirable, it is not uncommon.

For example, one state highway department has already made use of the Stanford Research Institute travel-time values in the analysis of a proposed rural Interstate highway located in a scenic mountaninous area abounding in recreational activities. Citing the Stanford Research Institute study, the highway department used a value of $1.72 per person per hour—slightly less than the $1.82 per person per hour average value based on actual cost differences and time savings found in this report. Thus a value slightly reduced from that found for urban work trips is being used in the economic analysis of a highway for which work trips will not be the dominant trip type, and where the alternatives differ significantly in length, gradient, and cost.

At the risk of sounding redundant, then, it should be emphasized that the values of time reported in this study are for commuting motorists, that is, for urban work trips, and may not be valid for other types of trips. For rural highways, where the combination of recreational, tourist, and pleasure-drive trips is often the major component of average daily traffic, and where average trip length is greater than in urban areas, one would expect a lower overall value of time to apply.

During the discussion of this paper, a significant statement was made concerning the application of time values for non-toll road travel to the effect that, time costs should not be added to motor vehicle operating costs in order to arrive at a total road-user cost for benefit-cost ratio analyses, because these are not the same type of costs. Unlike operating costs, time costs do not represent an economic transaction: while there is a per-mile expenditure for fuel, oil, tires, etc., there is no actual expenditure for travel time. Although we may impute a time cost to the motorist, he does not actually pay this "cost" from his wallet. This position has, I believe, much merit.

Highway economy analysts typically report only a single benefit-cost ratio for a proposed improvement. Because time costs are becoming larger relative to operating costs for many highway improvement situations, the limitations of our knowledge and the above considerations indicate that a better procedure would be to present a series of road-user costs, savings, and consequent benefit-cost ratios using, for example, the following format: (a) all time costs excluded (operating costs only); (b) including truck time costs; (c) including truck time costs plus, say, one-half of the passenger car time costs; and (d) all time costs included. This presentation could also be made with more than one assumption for the value of travel time.

When the results of highway economy studies are presented in the above manner, those who will review and pass judgment on the several alternatives for a given highway improvement will have the opportunity to note the sensitivity of the economic feasibility of the alternatives to the assumptions regarding travel-time costs, as well as to make their own judgment as to the proper handling of time costs. This format would add little to the cost or effort of conducting the economic analysis but would ignificantly increase its utility.