# The Value of Time for Commuting Motorists as a Function of Their Income Level and Amount of Time Saved

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The value of travel time saved for commuting motorists is established as a function of the motorist's income level and amount of time saved. The results are based on data previously collected by Stanford Research Institute and used to estimate a constant value of time per minute saved of $2.82 per person per hour. The data were collected for commuters with a choice between a toll route and a free route. It was found that the value of time is higher for motorists with higher incomes, e.g., in the income range of $4,000-$15,000 per year, the value of time increases at the rate of approximately $0.20 per person per hour for each thousand dollars per year ($0.50 per hour) increase in income. For very small amounts of time saved, the value of time per minute is quite low. It increases with the amount of time saved and then decreases again. As an example, the equivalent hourly values for a motorist with a family income of $9,000 per year are as follows: the first minute saved is $0.79 per person per hour, the 14th minute saved is $3.72 per person per hour, and the 25th minute saved is $1.26 per person per hour.

The paper includes a table that provides the value of the amount of time saved as a function of the motorists' income level and the amount of time saved. These results are limited to commuter trips with time savings of not more than 30 minutes per one-way trip. The value of time is estimated from motorists' route choices as a function of the motorists' characteristics and the characteristics of the routes. A route choice model, based on the logit function, is used to predict the motorists' route choices between the alternative toll and free roads. The coefficients of the discriminant function in this model are then statistically estimated by finding their maximum likelihood estimates. From these estimates the indifference curve between toll per person and travel time saved is determined, the slope of which yields the desired value of time function.

•HIGHWAY PLANNERS, faced with heavy demands for improving highway facilities and constrained by limitations on funds available for construction, utilize the techniques of economic analysis to assist them in making better decisions on the expenditure of these funds. Economic analysis provides information for the evaluation of highway improvement projects, the development of priorities for the construction of highway projects within a political jurisdiction, and the assessment of alternative features of engineering design and layout for projects.

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

Paper sponsored by Committee on Highway Engineering Economy and presented at the 49th Annual Meeting.

The reduction in motorists' travel times is often a major benefit of proposed highway improvement projects; lesser benefits result from the reduction in motor vehicle operating and accident costs. Consequently, converting time saved from hours to dollars is critically important in analyses of alternative highway locations and designs. The factor used to make this conversion is called the value of time.

Even though value-of-time factors have been used for years in highway economic analysis, relatively little reliance could be placed on the accuracy of these values. The commonly accepted value of $0.86 per person per hour used in the 1965 AASHO Handbook represents only the opinion at that time on a logical and practical value. Research into establishing the value of time has increased in recent years, but until 1967 the efforts failed to determine values that could be used with confidence in specific situations.

In 1967 two empirical studies of the value of time for commuters appeared. One study, a doctoral dissertation (1), used data on commuter choices between the Skokie-Swift rail transit south of Chicago and automobile transportation to estimate the value of time as between $2.50 and $2.70 per person per hour. The Stanford Research Institute (SRI) report (3) sampled commuters' choices between a toll road and free road in their home-to-work and work-to-home trips from eight areas of the country and estimated a constant value of time as $2.82 per person per hour.

This paper presents the results of further analyses of the SRI data. The main objective of the paper is to estimate a value of time that is a function of other variables such as income or the amount of time saved. This paper is written so that knowledge of previous SRI studies is not necessary. However, other information (2, 3) is recommended to the reader who wishes a deeper understanding of the theoretical, methodological, and empirical bases for estimating a value of travel time saved.

## APPROACH TO PROBLEM

The value of time saved is conceptualized in terms of a commuting motorist's indifference curve for a choice between two alternative routes. In microeconomic terminology, the value of time is the slope of the motorists' indifference curve for alternative trip cost and trip time saved; i.e., it is the rate at which the motorist is willing to trade more money for less travel time. In the real-life situation in which many motorists each face a different route choice, the money versus time-saved trade-off cannot be directly observed. Rather it must be inferred from the relationships that emerge when route choices of motorists are estimated from data on alternative trip costs and time saved and from other data on route and motorist characteristics that affect route choice. The coefficients of the route and motorist variables in the route choice estimator specify the relative importance of each variable to the motorist's choice and therefore can be used to calculate the trade-off between cost and time saved, i.e., the value of time.

In the previous SRI study (3), data were collected on commuters and their routes in situations where the commuter had a choice between saving travel time on a toll route and saving money (the toll) on a free route. Eight toll-route and free-route pairs in different areas of the country were studied.

Two types of on-route characteristics were collected. The first type, referred to as measured data, was recorded by a test vehicle that drove the routes, "floating" with the average traffic flow. The vehicle was equipped with a fifth wheel and associated electronics that measured and recorded the car's velocity every second. The second type, referred to as reported data, came from interviews with each motorist who was identified in the study as having a choice between the toll road and the free road. The interviewers collected information on the motorist's perceptions of the alternative routes, e.g., travel time, safety, and scenic beauty. Both measured and reported data provided estimates of such quantities as travel time and distance. The measured data yielded profiles of physical characteristics not obtainable by interview, such as number and size of speed change units on each route, whereas the reported data provided psychological measurements of their perceptions of safety, comfort, and "safe" speeds. The interviews were the sole source of the motorist data. Measured and reported data for route characteristics were combined separately with the motorist data to determine two different estimates of motorist route choices between the toll road and the free road.

The mathematical formulation of the route-choice model treated each driver as a separate data point with a binary choice, i.e., toll road or free road. The analysis estimated the route choice by using a logit function that 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 natural logarithms, and
$f(x)$ = a function of the characteristics of the route and motorist.

When a motorist chose the toll road, the observed $p(x)$ was assigned a value of zero; when he chose the free road, the observed $p(x)$ was assigned a value of one. The $f(x)$ was restricted to a linear function of the characteristics of the route and motorist, i.e.,

$$f(x) = a_0 + a_1x_1 + a_2x_2 + \ldots + a_nx_n$$

where the $a_i$ units are coefficients to be estimated, and the $x_i$ units are characteristics of the motorist, such as income or sex, or of the routes, such as travel time, toll cost, or number of speed change units.

The $p(x)$ can be interpreted in two ways: (a) as a probability estimate of the individual motorist's choice or (b) as the percentage split of a group of motorists all with the same characteristics (the same values) of the independent variables. When the estimated $p(x)$ is equal to or greater than 0.5, an individual motorist would be assumed to use the free road; when the estimated $p(x)$ is less than 0.5, he would be assumed to use the toll road. For a group of motorists, the $p(x)$ can be interpreted as the percentage split between routes.

Once the parameters of the route-choice model have been estimated, it is a simple calculation to estimate the value of travel time saved from the function $f(x)$. The motorist is estimated to be indifferent to the choice of alternative routes when $p(x)$ equals 0.50. For $p(x) = \frac{1}{2}$, $f(x) = 0$, or

$$0 = a_0 + a_1x_1 + a_2x_2 + \ldots + a_nx_n$$

This equation can be solved for the toll charge (one of the $x_i$ units) that the motorist will pay in terms of his psychological characteristics and the characteristics of the alternative routes. The derivative of the toll charge with respect to travel time saved is inferred to be the traveler's value of time, i.e., the trading ratio between toll and time saved at the indifference point.

In the case of the $f(x)$ used in the previous study (3), in which both toll and the difference in travel time appeared only to the first power, the value of time is simply the ratio of the coefficients of the difference in travel times and toll estimated in the route choice model. That is,

$$\text{value of travel time saved} = \frac{\text{coefficient of travel time saved}}{\text{coefficient of toll costs}}$$

The "best" model using the measured route data estimated a value of commuter travel time saved of \$1.82 per hour with a standard error of \$0.40 per hour. The value of time based on reported route data was considerably higher at \$3.82 per hour with a standard error of \$0.85 per hour. These values of time are for the 50th percentile or median motorist.

The definition of the value of time in terms of the motorist's indifference curve makes his perceptions of route characteristics at the time of his route-choice decision the correct variables (2) to place in the model. In general, neither the measured nor the reported data fully meet the requirements for perceived data (see Appendix for further discussion). However, in the previous report (3) it was shown that the value of time based on measured route characteristics would be less than the motorist's true value of time, whereas that based on the reported route characteristics would be greater than the motorist's true value of time. Therefore, the average of these two values, $2.82 per hour, was selected in the previous study as a reasonable approximation of the true value of travel time saved for the mean commuter. The $2.82 per person per hour is a constant value of time, i.e., it is independent of income level, amount of time saved, and other route and motorist characteristics.

## THE REANALYSIS—AN OVERVIEW

The main objective of this study is to estimate a value of time that is not a constant, but rather a value that is a statistically significant function of other variables such as income or the amount of time saved.

Two main obstacles stood in the path of this objective. The first, and less formidable, was the divergence of the constant value of time based on measured data from the constant value of time based on reported data. This divergence raised questions about the validity of the data and analysis approach. The divergence problem was resolved mainly through "corrections" to the time saved as measured by the test vehicle. The result was a sizable increase in the value of time based on the measured data. By one approach, that of adjustment, the gap between the measured and reported value of time was cut in half. The other approach, filtering, resulted in the two estimates becoming approximately equal. The details of the analysis are given in the Appendix. Both approaches increased the confidence in the use of the reported route data to estimate the value of time rather than the use of the measured route data, given the limitations faced in collecting measured data in different geographic areas of the country.

The second, and more formidable, obstacle was the problem of the constant value of time estimated in the previous report. At the very least, the "true" value of time can be expected to vary with the motorists' income level and the amount of time saved. The specific relationships are as follows:

1. The hypothesized relationship between the value of time and income is simply the higher the motorist's income, the higher his expected value of time if trip characteristics and other motorist characteristics are held constant. In the original formulations of the logit model, in which the variables of time saved, income level, and toll appear only to the first power in f(x), the value of time is functionally independent of income. However, the toll charge that the motorist is willing to pay to save travel time is a function of income. A contradiction thus arises when the value of time is estimated to be independent of income while the toll a motorist is willing to pay to save time is a function of income. This conflict must be resolved.

2. The hypothesized relationship between the value of time and the amount of time saved for a particular type of trip results in an S-shaped benefits curve in the total benefits (i.e., toll charge the motorist is willing to pay) versus time-saved plane as shown in Figure 1. For very small amounts of time saved, empirical evidence indicates that motorists are insensitive to reductions in trip time, while economic theory suggests an eventual diminishing marginal utility of time saved as the amount of time saved continues to increase (2). This relationship yields a value of time that is a function of the time saved. The marginal value of time is the slope of the total benefits versus the time-saved relationship, i.e.,

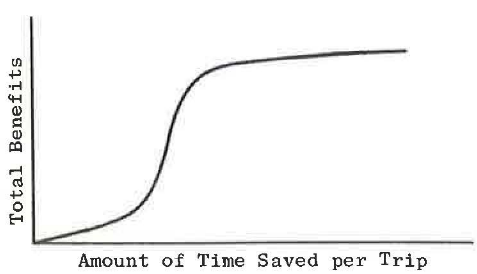


Figure 1. Total benefits function.

$$V_T = \frac{d(T.B.)}{d\Delta t}$$

where

$V_T$ = marginal value of time;
T.B. = the total benefits function, i.e., willingness to pay this level of toll; and
$\Delta t$ = the time saved.

The linear f(x) that provides the constant value of time is viewed as an approximation to the hypothesized curve in the 5- to 20-minute range of time saved, where nearly all the relevant data points are located.

Figure 2 shows the fit of a constant value of time to the hypothesized curve. This linear approximation has the undesirable characteristic of showing negative willingness to pay a toll (i.e., total benefits) for small positive time saved; that is, it intersects the time-saved axis at some positive amount of time saved.

The linear function provides a reasonable approximation for total benefits versus the amount of time saved per trip. However, the definition of the value of time as the slope of the linear approximation can result in a large estimate of the benefits of time savings even when the total benefits or willingness to pay a toll is estimated to be zero. For example, if the value of time is 5 cents per minute, then a 4-minute time savings is valued at 20 cents, but total benefits would be estimated to be zero (or negative).

The previous reports (2, 3) discussed the possible errors in estimating benefits that could result from using the constant value of time. However, it was not possible within the limitations of that contract to statistically estimate a variable value of time, i.e., one that varied as a function of income level and amount of time saved; this limitation needed to be corrected.

This report describes the results that were obtained in the present contract by using two techniques to estimate a variable value of time: (a) using higher order terms in f(x) in the logit model, and (b) making piecewise linear estimates of the value of time.

## HIGHER ORDER TERMS IN f(x)

Several polynomial forms for the discriminant functions were considered that involved first-, second-, and third-order terms in the three variables where c = toll per person, I = income level of the motorist, and $\Delta t$ = travel time saved. The higher order terms in the discriminant function can potentially improve the "fit" of the estimated total benefits function to the hypothesized curvilinear model. Preliminary analyses reduced the number of higher order terms worthy of further study to six that contained the variables for income level and travel time saved.

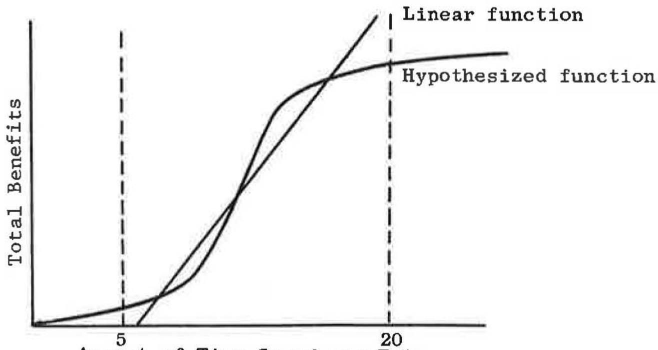


Figure 2. A linearly estimated total benefits function.

An example of an estimated f(x) with higher order terms in I and $\Delta t$ is

$$f(x) = a_0 + a_c c + a_I I + a_{\Delta t} \Delta t + a_{I\Delta t} I \Delta t + a_{\Delta t^2} \Delta t^2$$

The total benefits of the toll road, defined as the maximum toll charge the average motorist is willing to pay, can be found by setting p(x) = 0.5. Then f(x) = 0, and the total benefits can be solved for as follows:

$$T.B. = c = \frac{-1}{a_c} \left(a_0 + a_I \cdot I + a_{\Delta t} \cdot \Delta t + a_{I\Delta t} \cdot I \cdot \Delta t + a_{\Delta t^2} \cdot \Delta t^2\right)$$

The value of time is

$$V_T = \frac{d(T.B.)}{d\Delta t}$$

$$= - \left(\frac{a_{\Delta t}}{a_c} + \frac{a_{I\Delta t}}{a_c} \cdot I + \frac{2a_{\Delta t^2}}{a_c} \cdot \Delta t\right)$$

or

$$V_T = \beta_0 + \beta_1 I + \beta_2 \Delta t$$

where $\beta_i$ units are the coefficients determined by differentiating the total benefits function.

The potential importance of the higher order terms can be seen in this last equation; the value of time would be a function of the income level of the motorist (I) and the exact increment of time saved ($\Delta t$). The result is that the statement "the value of time is $3.30 per hour" is no longer valid for all income levels and amounts of time saved.

In general, the results of the use of the higher order terms were quite disappointing for the following reasons:

1. Many of the coefficients were not significant at the 95 percent confidence level.
2. In several instances, the maximum likelihood estimate had a sign opposite to that predicted theoretically.
3. The improved models had no greater success in predicting route choice decisions than the linear models.
4. Differences in the value of time and in the total benefits made by the higher order terms were quite small for most of the models over the range of time savings covered by the majority of the data, i.e., 5 to 20 minutes.

The only higher order f(x) with 95 percent confidence level for all coefficients was

$$f(x) = a_0 + a_c \cdot c + (a_{\Delta t} + a_{I\Delta t} \cdot I) \cdot \Delta t$$

The value of time for this f(x) is

$$V_T = - \left(\frac{a_{\Delta t}}{a_c} + \frac{a_{I\Delta t}}{a_c} \cdot I\right)$$

or

$$V_T = \beta_0 + \beta_I \cdot I$$

The value of time is then estimated as a linear function of the income level of the motorist. The coefficients $\beta_0$ and $\beta_I$ were estimated by using the adjusted reported and adjusted measured data. They are given in Table 1.

TABLE 1

INCOME-DEPENDENT VALUE OF TIME ESTIMATES

| Data Set | Sample Size | Value of Time (dollars per hour) | Value of 1 Hour of Time Saved | | |
|---|---|---|---|---|---|
| | | | I = 2 | I = 4 | I = 6 |
| Reported-adjusted | 807 | 1.803 + 0.461·I<br>(0.628) (0.174) | \$2.73 | \$3.64 | \$4.57 |
| Measured-adjusted | 510 | 1.850 + 0.181·I<br>(0.735) (0.127) | \$2.31 | \$2.57 | \$2.94 |

Note: The figures in parentheses are the standard errors of the estimates.

Income (I) level 1 is under \$4,000 per year;
2 is \$4,000-\$5,999 per year;
3 is \$6,000-\$7,999 per year;
4 is \$8,000-\$9,999 per year;
5 is \$10,000-\$11,999 per year;
6 is \$12,000-\$14,999 per year;
7 is \$15,000-\$20,000 per year; and
8 is over \$20,000 per year.

The relative magnitudes of the constant term and the coefficient of income level indicate a major dependence of the value of time on the income level of the motorist, particularly for the reported-adjusted data. The confidence in this dependence is reflected in the small standard errors; all coefficient estimates are significant at the 95 percent confidence level. An average of the two estimates based on adjusted data gives a $V_T = 1.83 + 0.32 \cdot I$.

Therefore, using higher order terms in f(x), it has been possible to establish the value of time as a function of income. However, the dependence of the value of time on the amount of time saved could not be estimated at a statistically significant level by using higher order terms in f(x).

## PIECEWISE LINEAR ESTIMATES

A second approach to estimating a value of time that is a function of the amount of time saved was to make estimates using subsets of the data limited to different ranges of time saved. The result is that different values of time can be estimated for each range of time saved, e.g., 0 to 5 minutes, 5 to 15 minutes, and more than 15 minutes, which provides a value of time dependent on the (range of) time saved. In making these estimates the f(x) that gave a value of time dependent on income level was used, i.e.,

$$f(x) = a_0 + a_C \cdot c + (a_{\Delta t} + a_{\Delta t} \cdot I)\Delta t$$

Considerable effort was expended in testing alternative definitions for the data subsets. The boundaries and numbers of data subsets were varied; both overlapping and nonoverlapping subsets were tried. Variations in f(x) using $\Delta t^2$ or $\Delta t^3$ were also tested to see if a better fit could be obtained for a limited range of time saved.

Many of the estimates, particularly for the more constrained ranges of Δt, did not yield good standard errors. However, when all the estimates were plotted together they generally fell on top of each other. As a result, an overall picture of total benefits versus time saved was built up in which we have considerable confidence.

The resultant graph of benefits versus time saved for adjusted reported data is shown in Figure 3. Less desirable statistical properties occurred for the measured adjusted data and filtered data.

Two of the more important estimates on which Figure 3 is based are

5 to 15 minutes: $T.B. = -40.86 + 3.06\Delta t + 0.811 I \cdot \Delta t$
(15.35) (1.12) (0.298)

15 or more minutes: $T.B. = 8.25 + 0.16\Delta t + 0.47 I \cdot \Delta t$
(20.60)(1.41) (0.24)

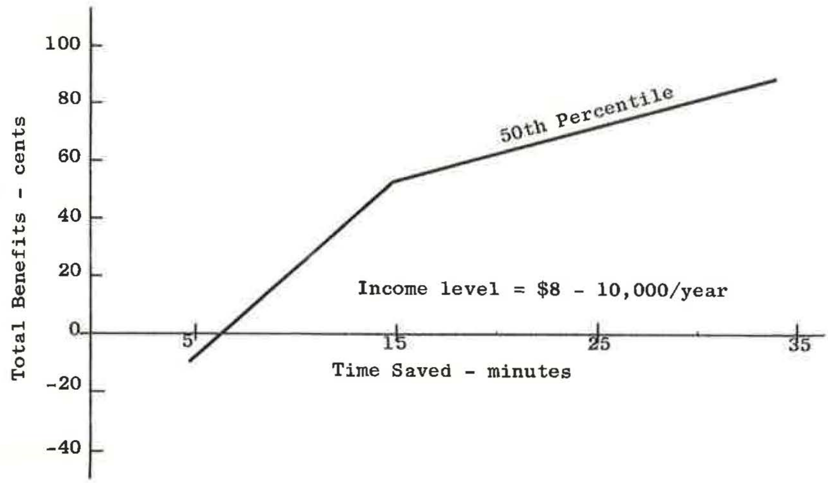


Figure 3. Estimated 50th percentile total benefits function.

In the second estimate, the I · Δt term predominates over the Δt term (which is not significantly different from zero) to dictate the slope of the value of time for a time saving of more than 15 minutes. The intercept is not statistically significant and was adjusted slightly in fitting the curves together. All coefficients in the first equation are statistically significant. However, as previously stated, these are only two of a number of different estimates that give approximately the same results.

Therefore, when using estimators that are piecewise linear in the amount of time saved (but a function of income level), the marginal value of time is found to decrease for time saved of greater than 15 minutes. However, the nature of the data precluded statistical estimates of the value for the 0- to 5- minute range. For time saved of less than 5 minutes and more than 0 minutes there are very few reported data points because of the motorist's tendency to report in multiples of 5 minutes. The measured data also have problems in this range of time saved because a small perceptual error by the driver can turn a positive time saved into a negative time saved. Therefore it is hard to focus the empirical analysis on a small amount of time saved. Another approach had to be taken.

One property of the route choice estimators was that, in the final form of the model, the only route characteristic used was the time difference between the two routes. This was a result of extensive analysis, not an assumption of the analysis. Route choice models were built using as variables the differences in distance, several alternative measures of differences in amount of speed changes on the routes, measures of differences in waiting times, differences in perceived safety, differences in perceived driving pleasure, and other variables. The estimators using these additional route-characteristic variables all suffered from some combination of (a) the wrong sign on their coefficients, (b) large standard errors of estimate, and (c) no improvement in route choice prediction. Thus, only the time difference and toll plus motorist characteristics are included in the final models. The time difference between routes was found to be the only route variable for which motorists perceived a benefit and would be willing to pay.

The empirical evidence from the body of data under analysis gives scant weight to suppositions about "other reasons" for taking the toll or free road other than the toll and time difference. Thus, in the case where the same vehicle would be used on either route, it appears appropriate to impose the boundary condition that the relationship between the total benefits of taking the toll road and the amount of time saved must be non-negative and go to zero as the time difference goes to zero. This is a crucial assumption. However, a 1- or 2-cent positive or negative vertical intercept would not

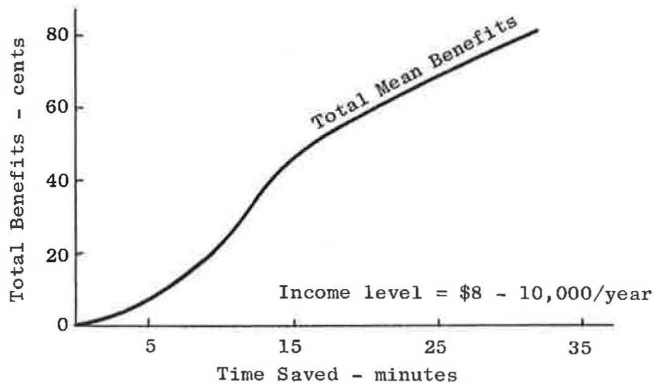


Figure 4. Total mean benefits function.

change the results appreciably. By contrast, the intercept of the linear estimator implied the requirement of a negative toll, i.e., a payment to the motorist, of some 40 cents for the average motorist (earning $8,000 to $10,000 per year) to take the toll road when there was no time difference.

The other reasonable (and less important) assumptions are that (a) the relationship is continuous and smoothly joins the empirically estimated curves, and (b) the motorist tends to be insensitive to time differences of less than a minute so that the relationship approaches the origin along the time-saved axis. The application of these assumptions results in a constraint on the total benefits curve. When a benefit line (relationship) reaches the time-saved axis (i.e., zero total benefits), it must be constrained from going lower. Thus, in Figure 3 the benefits relationship for the 50th percentile motorist (i.e., for $p(x) = 0.5$) would be altered so that after it reaches zero benefits for a time saving of 6.5 minutes it would go along the time-saved axis and not cross it. However, this does not mean that all motorists at this income level have ceased to be willing to pay for a time saving of 6.5 minutes. The 25th percentile motorist has zero benefits starting at 9.7 minutes, whereas the 75th percentile motorist has zero benefits starting at 3.2 minutes.

Therefore, constraining benefits to be greater than or equal to zero results in the distribution of motorists' benefits no longer being symmetrical about the 50th percentile motorist for small time saved. The mean is no longer equal to the median. The mean benefits are now above the 50th percentile benefits and thus the mean-benefits line departs from the 50th percentile line and must be recalculated as the distribution changes. The total (mean) benefits versus the time-saved graph that was calculated is shown in Figure 4.

A similar but higher curve is estimated for income levels above $10,000, and a similarly shaped but lower curve is estimated for income levels below $8,000. The value of time is now estimated as a function of both income level and amount of time saved. The empirical form of the relationship agrees with the hypothesized form.

Table 2 gives total values of time for from 1 to 30 minutes time saved per commuter trip for each of the eight basic income levels studied. These are not incremental values for the specific minute saved, but reflect the total value for the full time savings indicated.

For example, consider a commuter whose income places him in income level 4. He will value 4 minutes of time saved at 5.2 cents, 8 minutes of time saved at 15.0 cents, and 16 minutes of time saved at 51.4 cents. Note that the 16-minute time saving is not valued at twice the 8-minute time saving, nor a 4-minute time saving at half the value of an 8-minute time saving. The marginal value of time for 1 minute of time saved first increases as the time saved increases up to approximately 14 minutes, and then decreases thereafter.

To aid the reader in seeing the changes in the value of time, Table 3 has been calculated from Table 2 to show the equivalent hourly values of time saved, e.g., the value

TABLE 2

TOTAL VALUE OF TIME SAVED IN DOLLARS

| Time Saved in Minutes | Income Level of Motorist[a] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 1.00 | 0.007 | 0.009 | 0.011 | 0.013 | 0.016 | 0.019 | 0.023 | 0.027 |
| 2.00 | 0.014 | 0.018 | 0.022 | 0.026 | 0.032 | 0.038 | 0.045 | 0.054 |
| 3.00 | 0.022 | 0.027 | 0.032 | 0.039 | 0.048 | 0.057 | 0.068 | 0.081 |
| 4.00 | 0.029 | 0.035 | 0.043 | 0.052 | 0.063 | 0.076 | 0.091 | 0.108 |
| 5.00 | 0.036 | 0.044 | 0.054 | 0.066 | 0.079 | 0.095 | 0.114 | 0.135 |
| 6.00 | 0.044 | 0.056 | 0.070 | 0.088 | 0.109 | 0.134 | 0.162 | 0.194 |
| 7.00 | 0.053 | 0.070 | 0.090 | 0.116 | 0.146 | 0.182 | 0.222 | 0.267 |
| 8.00 | 0.064 | 0.086 | 0.115 | 0.150 | 0.192 | 0.240 | 0.293 | 0.351 |
| 9.00 | 0.077 | 0.106 | 0.144 | 0.190 | 0.245 | 0.306 | 0.372 | 0.442 |
| 10.00 | 0.091 | 0.130 | 0.178 | 0.237 | 0.304 | 0.378 | 0.456 | 0.537 |
| 11.00 | 0.108 | 0.156 | 0.217 | 0.289 | 0.369 | 0.454 | 0.543 | 0.633 |
| 12.00 | 0.128 | 0.187 | 0.260 | 0.344 | 0.437 | 0.533 | 0.632 | 0.731 |
| 13.00 | 0.149 | 0.220 | 0.306 | 0.403 | 0.507 | 0.613 | 0.721 | 0.828 |
| 14.00 | 0.173 | 0.257 | 0.356 | 0.465 | 0.579 | 0.694 | 0.810 | 0.925 |
| 15.00 | 0.180 | 0.271 | 0.373 | 0.493 | 0.612 | 0.731 | 0.849 | 0.967 |
| 16.00 | 0.188 | 0.283 | 0.389 | 0.514 | 0.637 | 0.761 | 0.884 | 1.007 |
| 17.00 | 0.196 | 0.295 | 0.405 | 0.534 | 0.662 | 0.790 | 0.918 | 1.046 |
| 18.00 | 0.203 | 0.307 | 0.421 | 0.555 | 0.688 | 0.820 | 0.953 | 1.085 |
| 19.00 | 0.212 | 0.319 | 0.437 | 0.575 | 0.713 | 0.850 | 0.987 | 1.124 |
| 20.00 | 0.220 | 0.331 | 0.453 | 0.596 | 0.738 | 0.880 | 1.022 | 1.163 |
| 21.00 | 0.228 | 0.345 | 0.468 | 0.616 | 0.763 | 0.910 | 1.056 | 1.202 |
| 22.00 | 0.236 | 0.357 | 0.484 | 0.637 | 0.788 | 0.939 | 1.090 | 1.242 |
| 23.00 | 0.245 | 0.369 | 0.500 | 0.657 | 0.813 | 0.969 | 1.125 | 1.281 |
| 24.00 | 0.253 | 0.381 | 0.516 | 0.677 | 0.838 | 0.999 | 1.159 | 1.320 |
| 25.00 | 0.262 | 0.393 | 0.532 | 0.698 | 0.863 | 1.029 | 1.194 | 1.359 |
| 26.00 | 0.270 | 0.405 | 0.548 | 0.718 | 0.888 | 1.058 | 1.228 | 1.398 |
| 27.00 | 0.279 | 0.419 | 0.563 | 0.739 | 0.914 | 1.088 | 1.263 | 1.437 |
| 28.00 | 0.287 | 0.431 | 0.579 | 0.759 | 0.939 | 1.118 | 1.297 | 1.477 |
| 29.00 | 0.296 | 0.443 | 0.595 | 0.780 | 0.964 | 1.148 | 1.332 | 1.516 |
| 30.00 | 0.304 | 0.455 | 0.611 | 0.800 | 0.989 | 1.178 | 1.366 | 1.555 |

[a]Income levels as given in Table 1.

TABLE 3

HOURLY EQUIVALENTS OF THE TOTAL VALUE OF TIME SAVED IN DOLLARS

| Time Saved in Minutes | Income Level of Motorist[a] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 1.00 | 0.43 | 0.53 | 0.65 | 0.79 | 0.95 | 1.14 | 1.36 | 1.62 |
| 2.00 | 0.43 | 0.53 | 0.65 | 0.79 | 0.95 | 1.14 | 1.36 | 1.62 |
| 3.00 | 0.43 | 0.53 | 0.65 | 0.79 | 0.95 | 1.14 | 1.36 | 1.62 |
| 4.00 | 0.43 | 0.53 | 0.65 | 0.79 | 0.95 | 1.14 | 1.36 | 1.62 |
| 5.00 | 0.43 | 0.53 | 0.65 | 0.79 | 0.95 | 1.14 | 1.36 | 1.62 |
| 6.00 | 0.44 | 0.56 | 0.70 | 0.88 | 1.09 | 1.34 | 1.62 | 1.94 |
| 7.00 | 0.45 | 0.60 | 0.77 | 0.99 | 1.25 | 1.56 | 1.91 | 2.29 |
| 8.00 | 0.48 | 0.65 | 0.86 | 1.12 | 1.44 | 1.80 | 2.20 | 2.63 |
| 9.00 | 0.51 | 0.71 | 0.96 | 1.27 | 1.63 | 2.04 | 2.48 | 2.95 |
| 10.00 | 0.55 | 0.78 | 1.07 | 1.42 | 1.82 | 2.27 | 2.74 | 3.22 |
| 11.00 | 0.59 | 0.85 | 1.18 | 1.57 | 2.01 | 2.48 | 2.96 | 3.46 |
| 12.00 | 0.64 | 0.93 | 1.30 | 1.72 | 2.18 | 2.67 | 3.16 | 3.65 |
| 13.00 | 0.69 | 1.02 | 1.41 | 1.86 | 2.34 | 2.83 | 3.33 | 3.82 |
| 14.00 | 0.74 | 1.10 | 1.53 | 1.99 | 2.48 | 2.97 | 3.47 | 3.96 |
| 15.00 | 0.72 | 1.08 | 1.49 | 1.97 | 2.45 | 2.92 | 3.40 | 3.87 |
| 16.00 | 0.70 | 1.06 | 1.46 | 1.93 | 2.39 | 2.85 | 3.31 | 3.77 |
| 17.00 | 0.69 | 1.04 | 1.43 | 1.89 | 2.34 | 2.79 | 3.24 | 3.69 |
| 18.00 | 0.68 | 1.02 | 1.40 | 1.85 | 2.29 | 2.73 | 3.18 | 3.62 |
| 19.00 | 0.67 | 1.01 | 1.38 | 1.82 | 2.25 | 2.68 | 3.12 | 3.55 |
| 20.00 | 0.66 | 1.00 | 1.36 | 1.79 | 2.21 | 2.64 | 3.06 | 3.49 |
| 21.00 | 0.65 | 0.98 | 1.34 | 1.76 | 2.18 | 2.60 | 3.02 | 3.44 |
| 22.00 | 0.64 | 0.97 | 1.32 | 1.74 | 2.15 | 2.56 | 2.97 | 3.39 |
| 23.00 | 0.64 | 0.96 | 1.30 | 1.71 | 2.12 | 2.53 | 2.93 | 3.34 |
| 24.00 | 0.63 | 0.95 | 1.29 | 1.69 | 2.10 | 2.50 | 2.90 | 3.30 |
| 25.00 | 0.63 | 0.94 | 1.28 | 1.67 | 2.07 | 2.47 | 2.87 | 3.26 |
| 26.00 | 0.62 | 0.94 | 1.26 | 1.66 | 2.05 | 2.44 | 2.83 | 3.23 |
| 27.00 | 0.62 | 0.93 | 1.25 | 1.64 | 2.03 | 2.42 | 2.81 | 3.19 |
| 28.00 | 0.61 | 0.92 | 1.24 | 1.63 | 2.01 | 2.40 | 2.78 | 3.16 |
| 29.00 | 0.61 | 0.92 | 1.23 | 1.61 | 1.99 | 2.37 | 2.76 | 3.14 |
| 30.00 | 0.61 | 0.91 | 1.22 | 1.60 | 1.98 | 2.36 | 2.73 | 3.11 |

[a]Income levels as given in Table 1.

of six 10-minute periods of time saved or twelve 5-minute periods of time saved. Note that, although the equivalent hourly value of an 8-minute period of time saved at income level 4 is $1.12, the equivalent hourly value of the 8th minute itself, i.e., $d(T.B.)/d\Delta t$ at 8 minutes, is approximately $2.04 (the value in Table 2 of 8 minutes minus the value of 7 minutes times 60).

## CONCLUSIONS

The most striking result of estimating a value of time as a function of both income level and the amount of time saved is the large drop in the value of time compared to either the constant value of time or the value of time as a function of income level. This change is clearly the result of the modification of the total benefits function to keep total benefits non-negative. The total value of time saved as a function of income level and amount of time saved is given in Table 2.

However, the analyst who attempts to use Table 2 will quickly find out that more has changed than merely the value of time. A whole new set of requirements for data on highway improvements results from the use of any value of time that is a function of the amount of time saved.

Once the value of time is a function of the time saved, however, then clearly the total amount of time saved must be known. The average value of 1 minute of time saved is dependent on whether it is the only time saved (value of 1.3 cents), part of a total of 10 minutes of time saved (average value of 23.7/10 = 2.4 cents), or part of a total of 20 minutes of time saved (average value of 59.6/20 = 3.0 cents). (These numbers are taken from Table 2.) Because motorists on short trips can be expected to have less total time saved by highway improvements than motorists on longer trips, the motorists using a highway improvement would need to be segregated by their total trip length (and perhaps ultimately even by origin and destination). Similar problems exist for spot improvements in intersections, stop signs, or pavement quality.

All at once the highway economist needs more information than just information on the amount of time saved by the highway improvement and the volume of motorists who will use it and their income levels. He needs cross-tabulated information on the motorists' income, trip length, and all improvements (actual and possibly planned) on their different trips.

Thus, the use of Table 2 imposes data requirements far in excess of those presently available for highway economy studies. Yet at times even accurate estimates of the volume of motorists using an improvement are difficult to obtain. The result is certain to present highway economists with a challenge. Our function has been to estimate the value of time implied in the behavior of urban commuter motorists. The highway economist must now develop and test for himself how to best make use of this behavioral information in furthering rational highway planning, design, and development. Subsequent reports will describe research on the value of time for trip purposes other than commuting.

## REFERENCES

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# *Appendix*

## REFINEMENT OF THE ROUTE-CHARACTERISTIC DATA

In the study cited previously (3), it was argued that the amount of time saved as measured by the test vehicle differed from the amount of time saved perceived by the motorist in making his route-choice decision (and thus from the proper variable for an indifference curve analysis) by randomly distributed perceptual errors. An analysis of the effect of the type of error distribution showed that the estimated value of travel time saved was lowered from the one perceived by the motorist, i.e., the "true" value of time. Unfortunately, there is no scientific way to eliminate truly random perceptual errors from the data.

On the other hand, certain measurement errors that potentially could be eliminated and have the same effect as the perceptual errors were thought to exist in the measured data. Therefore, an extensive reanalysis of the data was instituted to try to eliminate or to reduce the magnitude of these measurement errors. Because measurement errors could also occur in the reported data, they were studied further.

The technique for refining the data started by identifying a subset of the data on which the analysis would be concentrated through a comparison of the measured travel time with the reported travel time. The data points for which there were important deviations between the measured and reported travel times were identified for further analysis. The subsets of the data points that were identified by these comparisons were then refined in two ways. First, the data were researched and if a reason could be documented for changing either the reported or measured data, a change was made. However, if no reason existed, the data were not altered but were kept in the data base as before. This analysis resulted in the "adjusted" data base. Second, in the adjusted data set, those data points were eliminated where large discrepancies still existed between the measured and reported time saved. The resulting data became the "filtered" data base.

After the errors had been analyzed, possible biases in the reported travel times were studied. Biases are hypothesized to occur because motorists tend to "improve" the route they choose in reporting travel times. The effect of the bias is to increase the estimated value of time.

### Adjusted Data

The criteria used to identify deviant data for adjustment were as follows:

1. Instances where the reported and measured driving times for a motorist differed by 10 or more minutes in at least three out of four possible comparisons, i.e., the toll road in the morning and evening and the free road in the morning and evening.
2. Instances where the time saved on the toll route (sometimes negative) estimated by the measured data differed by at least 10 minutes from those estimated by the reported data. The morning and evening trips for each commuter were treated separately.

These data points were placed into a subset for further examination. Intuitively it is felt that these data points are the ones most likely to contain errors and biases.

After the data points in this special set had been identified by either criterion, each point was reexamined for errors that might have been introduced during the data collection and processing phases. Four basic sources of error were identified in this manner (the first three occurred for both reported and measured data and the fourth occurred only with the measured data set); they can be listed as (a) respondent misunderstood questionnaire; (b) interviewer error; (c) coding errors, e.g., keypunch errors; and (d) measurement errors caused by driving incorrect route, driving at incorrect time of day, or other measurement functions.

Although most of these error sources had been corrected in the original analysis of the data, the current reanalysis of these errors resulted in adjustments for approximately 12 percent of the measured data points and 4 percent of the reported data.

Next, the deviant data points were examined to see if the measured rush hour travel times might have been atypical. Variations in measured traffic flow from typical traffic flow conditions could result from fluctuations in the daily rush hour conditions. Because

TABLE 4

ESTIMATES FOR ORIGINAL AND ADJUSTED DATA SETS BASED ON LINEAR MODEL[a]

| Model | Sample Size | Percentage Correct Predictions | Value of Time Saved (dollars per hour) | Standard Error (dollars per hour) |
|---|---|---|---|---|
| Original reported data | 812 | 85.6 | 3.82 | 0.82 |
| Adjusted reported data | 807 | 85.3 | 3.78 | 0.92 |
| Original measured data | 529 | 75.8 | 1.82 | 0.40 |
| Adjusted measured data | 510 | 78.0 | 2.83 | 0.87 |

[a]The linear model contains the three basic variables (toll per person, income level, and incremental time saved for the reported data) plus the variables of sex of driver and model year of car for the measured data.

only two measurements of traffic flow for a particular route at a single time of day were taken, these variations might not have yielded representative average flows.

Analysis revealed that many of the large deviations between measured and reported time saved were bunched in the same area of a city and were all based on the same test-vehicle measurements. Therefore, when a number of commuters in a specific local area reported travel time savings that had large (more than 10 minutes) and consistent differences from measured travel time saved, all in the same direction, it was decided to adjust all the measured points from that specific locale by the average difference. Individual differences between reported and measured time were not eliminated. The average measured time saved was made to equal the average reported time saved only for the sum of estimated times morning and evening, toll and free routes, for all drivers in that section of the city.

An additional 12 percent of the measured data points were affected by these adjustments. In total, then, approximately 24 percent of the measured data and only 4 percent of the reported data were adjusted. The model was run with these adjusted data sets and new coefficients were estimated. The results are given in Table 4. The estimates based on the adjusted reported data are affected only slightly by the adjustments. This result was expected because of the small percentage (4 percent) of adjustments to that data set.

Both the estimated value of time and its standard error increased considerably for the adjusted measured data, from $1.82 per hour to $2.83 per hour and from $0.40 per hour to $0.87 per hour respectively. As a result, the difference between the measured and reported values of time decreased approximately in half.

## Filtered Data

The identification of a data point for possible adjustment did not automatically mean that the point would be adjusted. Adjustment was made only if specific evidence supporting an adjustment was found. Consequently, a number of data points that could be classified as extreme or apparently inconsistent points were left in the adjusted data base. The filtering process identified these points and eliminated them to test their effect on the value of time estimates. Two filtering criteria were used as alternative approaches.

The first filtering criterion (method 1) was the removal of both estimated and reported data points where there was more than 10 minutes difference between the measured and reported amount of time saved by use of the toll road. The morning and evening data were treated separately. The justification for this criterion is purely intuitive. A difference between the measured and reported amount of time saved of more than 10 minutes is probably not due to normal perceptual or measurement variations; it is probably the result of an error in some part of the data collection and analysis tasks.

The second filtering criterion (method 2) was removal of those data points where the free-road travel time was less than the toll-road travel time. With travel time the only route characteristic (other than toll) in the estimator, presumably there is no "reason" for a commuter to pay the toll except to reduce driving time. [In the previous study (3), possible reasons were examined by including such variables as distance, congestion,

TABLE 5

FILTERING RESULTS

| Data | Filtering Method | Value of Time Saved (dollars per hour) | Standard Error (dollars per hour) | Sample Size |
|---|---|---|---|---|
| Reported | None | 3.78 | 0.92 | 807 |
| | No. 1 | 4.13 | 1.06 | 709 |
| | No. 2 | 3.87 | 1.02 | 436 |
| Measured | None | 2.83 | 0.87 | 510 |
| | No. 1 | 5.78 | 2.76 | 412 |
| | No. 2 | 4.04 | 1.55 | 394 |

and perceived safety in the models, but they had unsatisfactory standard errors or signs on their coefficients and were therefore excluded from the final models.]

The estimates of the value of time using the filtered (and adjusted) data are given in Table 5. The table shows that the value of time based on reported data changes only slightly under either filtering technique. However, the value of time estimated from the filtered measured data significantly increases under either filtering criterion. In both cases the value of time based on measured data exceeds the value of time based on reported data.

In analyzing the effects of filtering on the measured data base, it was evident that method 1 served mainly to eliminate data points that showed large amounts of time saved. Large amounts of time saved have a lower value of time per hour than medium (5 to 15 minutes) amounts of time saved. The results given in Table 5 are consistent with the elimination of lower value-of-time data points by method 1.

In method 2 the filtering served to eliminate "negative" values of time, i.e., commuters measured as paying to increase their travel time. The elimination of such points resulted in increased values of time.

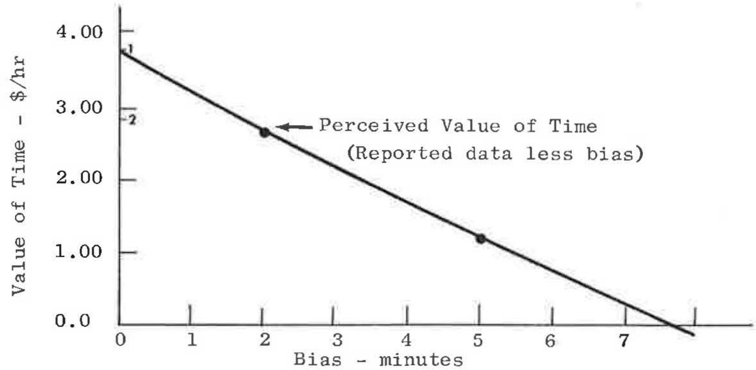
For both practical and theoretical reasons the filtered data base does not yield results appropriate for use in estimating the variable values of time. However, analysis of the filtered data serves to increase confidence in relying on estimates based on the reported data set rather than on those based on the measured route data set.

## The Effect of Biases in the Reported Data

The hypothesized biases in the reported data cause a shift in the data that raises the estimated value of time. The time saved on the toll roads is hypothesized to be reported as larger than the motorist originally perceived if the toll road is used, and is reported as smaller if the free road is used. This bias serves to justify or rationalize the motorist's choice in his own mind as he is interviewed. It is accentuated by his tendency to round reported times to multiples of 5 minutes. In the decision to round up or down, the motorist's route choice can easily influence his implicit decision on which way to round.

Although the bias is obvious from an overall comparison of reported and measured time saved, there is no evidence on the actual bias in each data point. However, the overall sensitivity of the estimates of the value of time to the hypothesized biases was tested as follows: The existence of a uniform bias was first hypothesized and then eliminated by subtracting a uniform amount of time from every toll-road time savings if the toll road had been taken and by adding to every toll-road time savings if the free road had been taken. Then a new route choice model and a new value of time were estimated from the revised data. Three estimates were made using 2, 5, and 8 minutes as the level of bias to be subtracted or added to each trip.

The estimated values of time are shown in Figure 5. The decreases in the value of time are exactly as had been predicted. As more bias is removed, the value of time decreases further, reaching zero between 7 and 8 minutes. This analysis also allowed an estimation of the maximum magnitude of the bias in the reported data, based on the assumption that the adjusted measured value of time of $2.83 per hour is a lower bound on the value of time. A uniform bias of only 1.6 minutes would decrease the reported




[1] Adjusted Reported Value of Time = $3.78/hr (includes assumed bias)
[2] Adjusted Measured Value of Time = $2.83/hr

Figure 5. Effect of bias on the value of time.

value of time to this value. The conclusion is that the level of bias in the reported data is relatively small, which is fortunate because the value of time appears to be very sensitive to bias, i.e., a uniform 2-minute bias decreases the value of time by $1.14 per hour.

Summary of Adjustments to Original Data

The previous study (3) had estimated a value of time based on measured time saved of $1.82 per person per hour and a value of time based on reported time saved of $3.82 per person per hour. In this section the measured and reported data were reanalyzed and "adjusted" and "filtered" to test the effect of measurement errors and to eliminate them when possible. New coefficients were estimated for each of these revised data sets, and new values of time were calculated. In addition, the sensitivity of the value of time to biases in the reported amount of time saved was analyzed.

The results of these analyses were minor changes in the constant value of time based on the reported route data but were major changes in the value of time based on the measured route data. The changes in the value of time based on the measured route data (adjusted or filtered) brought it roughly into line with the value of time based on the reported data.

The overall conclusion is that the reported adjusted data are the best single data set on which to estimate the value of time given the limitation in the collection of the measured route characteristics.

## *Discussion*

THOMAS E. LISCO, Chicago Area Transportation Study, and PETER R. STOPHER, Northwestern University—This paper documents some of the continuing research work being done by Stanford Research Institute in its program of determining time values for automobile travel. The work done by SRI on this subject has made exceedingly important and useful contributions to the field of transportation analysis. Perhaps first and foremost, this work has been an important contribution to the field of highway economy studies, because it has tended to make people more aware of the tremendous value of travel-time savings resulting from highway investments. In the past these savings, which are usually the greatest single benefit of highway investment, have tended to be badly underrated and, at worst, totally ignored. The SRI work has shown in convincing fashion that commuting motorists, certainly, put a very high value on travel-time savings.

This SRI research has also made important contributions, specifically to the field of travel-time evaluation studies and generally to travel-demand modeling. This has been done by analyzing situations and using statistical methods that represent the best of both that are presently being used in the field.

In choosing route-choice analysis for deriving travel-time value, SRI has chosen a subportion of the more general mode-choice analysis, which is now widely throught to be by far the most fruitful area for deriving accurate values of travel time. In addition, this research has used disaggregate behavioral analysis, rather than aggregate models, to reach its conclusions. There is also general agreement in the transportation-analysis field that the great advances in accuracy and dependability that we can expect in demand modeling in the coming years will be in just such disaggregate behavioral models. Finally, this work has used the statistical tool of logit analysis in fitting the models used. There is also general agreement developing among researchers that logit analysis is one of the most dependable and accurate statistical tools available to analyze route and modal choice situations.

In this particular paper, the authors have reanalyzed data that they originally analyzed and reported on elsewhere (3). In this reanalysis, the authors have done basically two things. First, they have reworked the data to try and eliminate some problems that were apparently unresolved by the original analysis. Second, they have extended their modeling efforts to try and yield not one given value of time, as had been done in the original study, but different values of time for different amounts of time savings and for motorists having different incomes. Both of these further analyses appear to require some comment.

## Reworking of Base Data

A basic problem of the original SRI analysis was that time values derived from the analysis of measured travel-time data differed from time values derived from the analysis of reported travel-time data. This problem was resolved in the original report by simply taking an average of the two results.

In the work reported in this paper, the authors tried to find out why there were differences. It seemed likely to them that the differences were caused by errors in the data. To try and eliminate such errors, the authors reworked the data in two ways. The first they called "adjustment" and the second, "filtering".

In the adjustment process, data were carefully examined, and changes were made either in the measured or in the reported data when a good reason could be documented for doing so. Such reasons included interviewer errors, coding errors, and errors where large numbers of persons in a given area of a city consistently disagreed in their reporting with the objectively measured data. In this last instance, the assumption was made that the measurement was wrong. We find no particular fault with this adjustment process. It raised the value of time for measured data from $1.82 per hour to $2.83.

The filtering process seems to have serious problems, however. In this process, the authors removed from the data set all instances where measured and reported route-choice travel-time differences differed by more than 10 minutes, and instances where use of the toll road represented no travel-time savings.

This procedure could have no result but to eliminate inappropriately the effect of a well-known and standard phenomenon whereby persons tend to bias their reporting of travel time between alternative routes in favor of the route that they use. This bias causes considerable differences between values of travel time inferred from route choices and driver reports of travel time as opposed to values inferred from route choices and empirically determined travel times.

Rather than try and resolve the implications of this perceptual problem, the authors have tried to resolve differences between data sets in order to be able to claim that the problem does not exist. They effectively changed the measured data until the measured data were essentially the same as the reported data. That the time-value results of the changed measured data then more closely approximated those of the reported data should have come as no surprise. Their conclusion that this result justifies using reported data is insupportable.

Value of Time by Amount of Time Saved and by Income Class of Driver

It appears as though the authors have caused themselves some unnecessary problems because of the complexity of the argument used to obtain a value of time. The simplest way of obtain the value of time from a mode or route-choice model is to determine the coefficient of the time difference that will allow cost and time to be added together as a single parameter. Such a coefficient is the necessary scale or equivalence value between cost and time, i.e., the value of time. Thus, in the original model obtained by the authors,

$$f(x) = a_0 + a_1c + a_2(t_2 - t_1) + a_3I \tag{1}$$

the value of time is obtained by reexpressing this as

$$f(x) = a_0 + a_1\left[c + \frac{a_2}{a_1}(t_2 - t_1)\right] + a_3I \tag{2}$$

where $a_2/a_1$ is the value of time.

To illustrate this, the changes in f(x) resulting from a unit change in either cost or time difference can be investigated. A unit change in time difference will make a change of $a_2$ units of f(x). This change could be produced by a change of $a_2/a_1$ units of cost. Thus, the value of time may be inferred as $a_2/a_1$.

It is the greater complexity of the authors' derivation that led to the abortive effort of attempting to incorporate polynomial terms in income and time difference. Given the original hypothesis of the value of time, the polynomial model is a logical step. Unfortunately, high intercorrelations between the variables [e.g., between I and $I(t_2 - t_1)$] and the use of five instead of three variables both lead to the estimation of a less reliable model than the original one. These two factors are probably largely at the root of the four reasons given by the authors for a disappointing model.

The hypothesis of the form of the variation of total benefits with time saved is only one of several possible hypotheses. It poses some serious problems in the evaluation of alternative plans. The S-shaped benefits curve suggests that benefits accrue over only a restricted range of time savings. Both small and large time savings apparently yield no increased benefits. One immediate question that is raised by this is how to treat a series of improvements on a particular link. If each is evaluated separately, then total benefits for each may come from the first part of the curve, and may sum to a relatively insignificant value. However, taken together they may produce significantly higher total benefits, because total time savings may then occur in the second, steeper portion of the curve.

The piecewise estimation does not appear to vindicate the hypothesis. In the equations derived there are both $\Delta t$ and $I\Delta t$ terms, and it would be useful to know how high the intercorrelations are between these terms. To interpret the weight of each of the terms, the $\beta$-coefficients ideally should be used, and these would give a more reliable basis for interpreting the equations. The unacceptable results of the piecewise estimates for both the 0 to 5 and 5 to 15 minute time savings are probably due to the paucity of data on these small time savings and to the comparatively large size of minimum toll charges. Because the minimum toll that can be paid is 10 cents, it is extremely dangerous to try to extrapolate data back beyond this point.

To avoid problems of collinearity in the estimating equations, an alternative method of model calibration could be used to determine variations in value of time with income. This method would be a stratification of the data by income groups. Separate models could be constructed for each income group and the variations in the resulting cost and time coefficients could be analyzed across all income groups. This approach has been successfully used in previous research (4). Then the results of attempting to determine variations of the value of time with time saved may well be markedly different.

In general, it appears that the authors have adopted an overly complex method of dubious validity to determine their final values of time. This method has brought with it several further problems in terms of attempts to value time with respect to time saved and trip-maker's income. Finally, some highly sophisticated statistical manipulations have been attempted that are probably well beyond the sophistication of the data base. It was not unreasonable that the authors found the results of these manipulations to be untenable, and subsequently discarded them. The hypothesis of the variation of value of time (total benefits) with time savings was not validated by the empirical results until considerable further assumptions and adjustments had been made to these results.

The basic requirements of model-building are accuracy and simplicity. It does not seem as though the models of total benefits presented in this paper are simple, and their accuracy is not proved. The difficulties of use of these values may alone render them of little practical use. Our abilities to predict travel movements to the degree of precision where we can identify each user and his exact time saving, as required by this model, do not currently exist. Furthermore, it is not obvious that they should be developed for the foreseeable future.

Reference

4. Stopher, P. R. A Probability Model of Travel Mode Choice for the Work Journey. Highway Research Record 283, 1969, pp. 57-65.

THOMAS C. THOMAS and GORDON I. THOMPSON, Closure—Two research groups studying the value of travel-time savings to commuters used data on individual traveler's transportation choice. Both arrived at a constant (marginal) value of time within a few cents of each other. Both had a large intercept term favoring one route when there was no difference in travel time between the different routes. One study found one route to be preferred over the other by about \$2.00, while the other found a preference of about \$0.40.

The first study (Lisco) used mode-choice data. It concluded that it was reasonable to assume that the full estimated \$2.00 preference of an average motorist for the automobile over rail rapid transit could be explained by convenience, scheduling, and other factors. The second study (SRI) used route-choice data. It could not see any reason why the average motorist would have to be paid \$0.40 to use the toll route given no time difference between routes, because the engineering quality of the toll route was higher than the free route.

SRI had previously developed (and reported in the literature) theoretical and empirical data that showed the value of travel time was not constant for different amounts of time saved. Therefore, the constant (marginal) value of travel time was seen as only a first approximation to an S-shaped function. Because the route-choice data showed a \$0.40 intercept, it is clear that the use of this first approximation could cause substantial errors in estimates of the true value of travel-time savings.

It is "unfortunate" that both SRI's theoretical work and its selection of a route-choice model makes the holding of the assumption of a constant value of travel time impossible. As the discussion points out, "The difficulties of use of these values may alone render them of little practical use." However, as our paper points out, we took as our task exploring the determinants of the value of travel time, not the making of assumptions on the capabilities of transportation economists to use them.

On the specific question of the ways the estimates were made, the following is offered:

1. The dependence of the value of travel time on income was estimated by the use of polynomial terms and also (as the discussion suggests) by the breaking of the data base into income categories. Only the results of the former analysis were reported

because of their superior statistical characteristic (considerably smaller standard errors). However, there was little difference in the maximum likelihood estimates.

2. The discussion suggests that simple models are the best—they were used first. The simplyfying assumptions were removed (such as linearity) only when the result showed the assumptions to result in large errors. Simplicity and accuracy is highly desirable; simplicity at the expense of accuracy is not desirable.

3. The discussion objects to the process of filtering the data, but accepts the process of adjustment. We agree with this and for this reason the adjusted data, not the filtered data, were used in the analysis. The filtered data are used in the Appendix only to highlight certain characteristics of the data.

4. The difference between the value of travel time based on different data sources is not seen as a "problem". Rather it confirms the theoretical analysis and serves to highlight underlying issues in the analysis of values. The two estimates operate to bracket the true value of travel time and greatly increase the confidence that can be placed in the estimate.

5. The discussion incorrectly states that, in the paper, "Both small and large time savings apparently yield no increased benefits." As is clearly shown in Table 3, we only argued that time savings less than 5 minutes or greater than 15 minutes have a smaller value per minute than those between 5 and 15 minutes; i.e., the relationship between the value of travel time and the amount of time saved is S-shaped.

6. It is also stated in the discussion that the results of the piecewise estimates between 5 and 15 minutes are unacceptable. Statistically we see them as highly acceptable, and we can find no basis for such a statement.

However, these are minor points. As stated initially, the major difference is that Lisco and Stopher do not accept what to us is a demonstrated empirical fact: that the value of travel-time savings is not a constant, but is dependent on the actual amount of time saved. The assumption of a constant (marginal) value of travel time leads to a large error in pricing time savings, especially for small amounts of time saving, i.e., less than 5 minutes. This is the primary issue that the reader will have to judge for himself.