Use of Two Concepts of the Value of Time

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•AS THE DEMANDS for highway facilities have increased with the years, it has become increasingly recognized that economic analyses of proposed highway improvement projects can provide valuable assistance in making rational decisions about the expenditure of public funds. In the very early days of highway construction, decisions were based, to a considerable extent on qualitative judgments; frequently, the only economic data available were estimates of highway construction costs.

In the 1920's, economic calculations began to take into account not only the expenditures of highway agencies (such as those for construction and maintenance of improved highways) but also the expenditures of the highway traveler (such as those for fuel, oil, and vehicle maintenance). When a highway improvement would result in reductions in user costs, these user benefits could be compared with the highway agency costs to obtain an evaluation of the total transportation costs that could be associated with the improvement.

Today, as then, one of the most important user benefits of new highway construction is savings in travel time for the occupants of passenger cars. To recognize the effect of these time savings in economic calculations, it is necessary to convert the savings in hours to a dollar amount. The factor used to make this conversion is called the value of time.

Thus, with the use of a value of time factor, benefit calculations include not only the out-of-pocket costs of vehicle operation, but a monetary evaluation of time savings as well.

This paper examines the meaning and the importance of the "willingness to pay" concept of the value of time; describes a newly developed concept of the economic worth of time savings, which is called the "cost of time"; and compares the use of the "willingness to pay" and "cost of time" concepts in making economic decisions on highway improvement projects. The primary intent is to demonstrate how the cost of time concept can be used to make better decisions in analyzing alternative highway designs and locations, and in formulating highway programs.

In this paper, the factors used in economic analysis have been combined into three parameters:

1. The annual highway cost, which includes the equivalent uniform annual capital or construction cost and the annual highway maintenance cost.
2. The annual user cost, which includes vehicle running costs, time costs for commercial vehicles, and accident costs.
3. The annual travel time for passenger cars.

Throughout the paper, it is assumed that the highway and user costs and the travel time have been accurately determined, and that the economic worth of savings in travel time is the variable factor of interest. The term "value of time" is used to describe the factor for converting hours to dollars in economic analyses. The terms "willingness to pay" and "cost of time" refer to two concepts or approaches to estimating a value of time.

WILLINGNESS TO PAY AS A VALUE OF TIME

For some three decades, highway engineers and economists have been concerned with the problem of measuring the economic value of savings in travel time to the oc-

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cupants of passenger cars. With few exceptions, studies of the economic worth of time have focused on the concept of value as opposed to the concept of cost. The most common concept of the value of time is defined as the maximum number of dollars that the potential users of an improved highway are willing to pay for an hour's saving in travel time. This user-oriented "willingness to pay" concept is similar to "opportunity cost" in economics, because both concepts depend on an evaluation of the alternative opportunities for the use of that time.

It is recognized that the willingness to pay is a variable quantity, dependent on the individual and the situation. Hereafter, the term "willingness to pay" will be used to describe a measure of the central tendency of the distribution of the maximum willingness to pay for time savings.

To illustrate the willingness to pay definition of the value of time, the benefit-cost ratio computation of economic worth of a highway improvement proposal is considered in simplified form (1) to be

$$R = \frac{V\,\Delta t + \Delta u}{\Delta h} \qquad (1)$$

in which

R = benefit-cost ratio;
V = value of time, in dollars per passenger car hour;
Δt = savings in annual travel time, in passenger car hours ($t_{existing} - t_{proposed}$);
Δu = savings in annual user costs, in dollars ($u_{existing} - u_{proposed}$); and
Δh = increase in annual highway costs, in dollars ($h_{proposed} - h_{existing}$).

A benefit-cost ratio of 1.0 indicates that the proposal is a break-even one — the benefits are equal to the costs. However, another way of viewing the 1.0 benefit-cost ratio is that passenger car occupants would, if the project were accomplished, be paying the maximum amount that they are willing to pay for the estimated time savings, assuming that the value of time used is a valid measure of maximum willingness.

The value of time is a highly important factor, for a significant proportion of highway improvement proposals cannot be economically justified without converting passenger car time savings to a dollar value. In doing so, the value of time chosen can have a major effect on total benefits.

The effect that the value of time has on benefit-cost ratios is shown in Figure 1. The benefit-cost ratios for three hypothetical improvement proposals (A, B, and C) are plotted as a function of the value of time used in calculating the ratio. Each proposal is represented by a straight line, with a higher benefit-cost ratio resulting from the use of a higher value of time. As an example, if a value of time less than V_1 is used in the calculation, proposal C will have a benefit-cost ratio less than 1.0; that is, it will not be economically justifiable. Figure 1 also shows another characteristic of many improvement proposals — with increases in the value of time, the benefit-cost ratio increases significantly.

Not only does the value of time that is chosen have a significant effect on the justification of a single proposal, it also can affect the relative ranking of competing proposals. In Figure 1, proposal C will have the highest benefit-cost ratio if a value of time less than V_2 is used. If a value between V_2 and V_3 is used, pro-

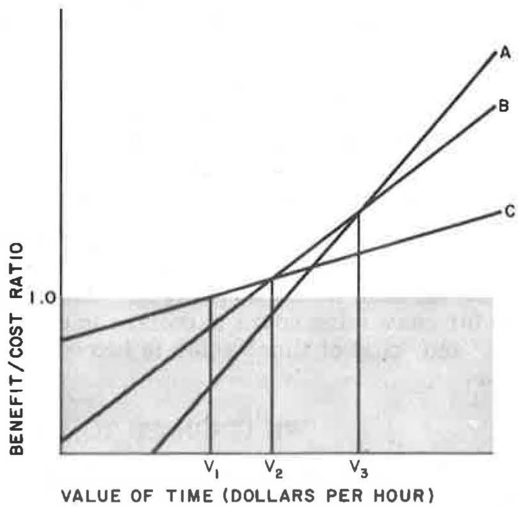

Figure 1. Benefit-cost ratios vs the value of time.

posal B will be favored, and if a value of time greater than V_3 is used, proposal A will be favored. In many situations, the lines that can be plotted for alternative proposals do not cross each other as shown in the figure, and thus different values of time will have no effect in determining the most desirable project. However, in many other situations, the lines do cross. To select the best project in these situations, the value of time must be accurately determined if there is any reason to believe that it may lie somewhere in the vicinity of the crossover values.

Present knowledge about the numerical value that should be associated with time savings is relatively poor. As a matter of fact, the most commonly used value of time ($1.55 per hr) is recommended in the Red Book (1, p. 126) as that value that is "representative of current opinion for a logical and practical value." The inadequate basis for the values now used is clearly recognized, and the number of investigations into this problem have increased in recent years.

COST OF TIME CONCEPT

The willingness to pay concept is not the only way of viewing the worth of time. Just as any commodity has a utility and a cost — and the commodity is desirable if its utility is greater than its cost — time savings also have a utility (a maximum willingness to pay) and a cost.

Although a single willingness to pay might be used to evaluate all projects of a certain class, the costs of specific projects may differ. Each project will have its own cost of time.

The cost of time concept is defined as the actual cost of providing time savings on a specific project. For each project, the cost of time, C, may be computed as

$$C = \frac{\Delta h - \Delta u}{\Delta t} \qquad (2)$$

The difference ($\Delta h - \Delta u$) may be considered as the "net change in annual transportation costs" of a given project or an aggregation of projects. This transportation cost concept allows the total dollar expenditures from two sources (highway agencies and highway users) to be considered together.

If the benefit-cost ratio for a certain project is 1.0, the cost of time is equal to the willingness to pay for time savings. The project will "break even." In symbolic terms, if

$$R = 1 = \frac{V\,\Delta t + \Delta u}{\Delta h}$$

then

$$V = \frac{\Delta h - \Delta u}{\Delta t}$$

or

$$V = C$$

In relatively few cases, however, are the benefit-cost ratios of selected highway improvement projects equal to one. The ratios are frequently substantially greater than one. Therefore, the actual cost of time savings for specific projects is generally some substantial amount less per hour than the willingness to pay value used in analyzing the improvement; i. e., if

$$R = \frac{V\,\Delta t + \Delta u}{\Delta h} > 1$$

then

$$V\,\Delta t + \Delta u > \Delta h$$

and from Eq. 2,

$$\Delta h = C\,\Delta t + \Delta u$$

then

$$V\,\Delta t + \Delta u > C\,\Delta t + \Delta u$$

or

$$C < V$$

Thus, with a benefit-cost ratio greater than 1.0, the estimates, in effect, indicate that the highway user would actually be paying somewhat less for time savings than the estimated value that he is willing to pay. To illustrate this point, the benefit-cost ratio and the cost of time were computed from data available on a number of projects (Table 1).

Most highway projects result in time savings and in increased highway cost. Therefore, in the computation of benefit-cost ratios, Δt is normally positive and Δh is normally positive. These restrictions are not necessary for the concepts presented in this paper. However, for simplicity of the immediate algebra, it is assumed that $\Delta h > 0$ and $\Delta t > 0$; i. e., that both highway costs and time savings are greater than zero.

OBJECTIVES OF HIGHWAY ECONOMIC ANALYSIS

Next, the usefulness of the concepts of the willingness to pay and the cost of time in meeting three objectives of highway economic analysis are examined. These objectives can be stated as follows:

1. Justifying highway improvement projects (comparing benefits with costs);
2. Formulating highway programs; and
3. Establishing tax rates and budget levels.

The justification of highway projects involves a comparison of the economic features of a proposed project with some predetermined standard. The formulation of highway programs is concerned with the fitting of economically justifiable proposals into a construction program. The establishment of tax rates and budget levels can be thought of as providing the amount of improvement that the highway users demand — a simple statement of an extremely complex problem.

First, a hypothetical world is considered — a world in which all considerations are expressible in economic terms, in which there are no irreducibles or "political" considerations, in which highway decisions are based purely on known economic data. In this world, it is assumed that the willingness to pay is a known constant, and, for each project under consideration, all other economic values would have been accurately determined.

A highway district is considered in this hypothetical world. The net dollar costs (Δh - Δu) and time savings (Δt) for proposed improvement projects can be shown graphically. Figure 2 shows the net change in annual transportation costs for various

TABLE 1

COMPARISON OF VALUE AND COST OF TIME FOR SELECTED PROJECTS[1]

Location of Project		Assumed Value of Time ($ per hr)	Resulting Benefit-Cost Ratio	Actual Cost of Time[2] ($ per hr)
State	Place			
Calif.	Baxter Creek	1.56	1.18	+1.21
	Butte County	1.56	1.59	+0.41
	King City	1.56	5.532	-1.45
	Sacramento	1.56	1.42	+0.76
	Salinas	1.56	1.176	+1.085
	Vacaville	1.20	4.6	-0.65
Conn.	Bridgeport	0.82	3.73	+0.16
	Norwalk	0.80	2.49	+0.38
Idaho	Idaho Forest	0.60	1.60	+0.08
	Moxie River	1.35	7.79	-0.33
Ky.	Louisville	1.35	9.60	-0.89
La.	Baton Rouge	1.35	2.43	-0.89
Mont.	Reas Pass	0.60	0.87	+1.10

[1] Value of time savings, plus user cost savings, minus highway cost increase.
[2] Source: Stanford Research Institute.

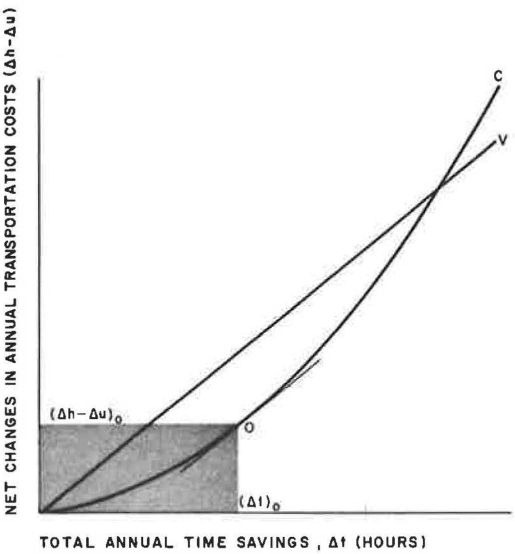

Figure 2. Net change in annual transportation costs vs total annual time savings.

amounts of highway improvements on the ordinate, and the resulting annual time savings on the abscissa. Individual projects or sets of projects could be plotted as points on this graph. Two curves are shown to indicate the willingness to pay value of time and the cost of time. The willingness to pay curve, V, for the district is plotted as a straight line, which indicates that the willingness to pay for time savings is independent of the amount of time saved. Those points plotted for projects or for sets of projects that lie below this curve would be considered desirable; those above, undesirable. (In reality, the willingness to pay time curve may be more complex, but its exact shape is not of great importance to this argument.) The cost-of-time curve, C, is a cumulative curve of the costs of time for various combinations of the available highway projects. If projects are arrayed in order of increasing cost of time, and cumulative values are plotted, the resulting curve will be concave from the top of the graph, and the incremental cost of time will increase as more time is saved. This curve, then, is the locus of the best available project sets. No points plotted for project sets lie below the curve. (Another cost of time curve for a hypothetical set of discrete projects will be shown in Fig. 3.)

The graphical solution to this hypothetical world problem is simple: time savings should be purchased until the last increment of time savings is equal to the willingness to pay for time savings. At this point, which is shown at 0 on the graph, the slopes of the willingness to pay value of time curve and the cost of time curve are equal. Further savings of time would cost more than highway users are willing to pay; i. e., the incremental cost of time would be greater than the maximum willingness. The total annual time savings that should be provided are $(\Delta t)_0$. The net change in transportation costs that is indicated is $(\Delta h - \Delta u)_0$. This dollar cost is a composite of increased highway costs and savings in user costs. The correct budget for new construction in this hypothetical district would be equal to the highway cost component (converted to a present worth) of the total dollar costs. (If maintenance costs are included in the highway cost estimates, the budget would be computed by converting the annual capital (construction) cost component of Δh to a present worth, and adding the annual increased maintenance costs.)

Thus, in this hypothetical world, projects would be justifiable if their cost of time were less than the willingness to pay; the correct program would consist of all projects that are justifiable; and the tax rates would be adjusted to provide the amount of funds required to complete the program comprised of all justifiable projects.

The real world is far different from this hypothetical (and superficially described) world. In the first place, decisions of justification, program formulation, and taxation are based in part on considerations that cannot be reduced to economic terms. Secondly, the economic calculations may be in error because of errors in input data. Of specific interest to this paper are two problems:

1. It is difficult to establish tax rates and budget levels solely on economic grounds.
2. The willingness to pay is not known with precision.

Tax Rates and Budget Levels Difficult to Establish

In the legislative process of fixing taxes and in the resulting administrative process of establishing budgets, many complex and nonquantifiable considerations apply.

(The term "budget" in this report refers not to the estimated or approved expenditure for a single project, but to the total amount of funds that is allocated to an agency for allocation to many projects.) Tax rates are frequently established on the basis of detailed highway needs studies, but these studies are based to a considerable degree on engineering judgment, because accurate economic data are not available. Once the tax rates are fixed, legislative apportionments of funds to highway types and to geographical areas cannot be justified by indisputable economic data. Finally, the allocation of the total estimated revenue to various activities within a highway agency is similarly based at least in part on nonquantitative considerations. It may be utopian to hope that the "correct" taxes and budgets can ever be fixed with accuracy.

Nevertheless, tax rates and budgets are economic realities that most highway planners must face. Highway programs must be formulated within the expectation of total revenues. No matter how properly or improperly the tax rates and budget levels are established, they must be recognized. The highway planner must therefore concern himself with developing the best possible procedures for selecting among alternative construction proposals within this constraint.

Willingness to Pay Not Accurately Known

Highway agencies, in the process of analyzing the economics of improvement proposals, may estimate many traffic and cost factors for the alternatives being considered. The estimate of each factor is subject to some error, and errors in the estimates may result in errors in the conclusions drawn from economic calculations. Some of the factors that are commonly estimated for such calculations are listed in approximate order of accuracy from most to least.

1. Project length.
2. Per mile running costs for both passenger cars and trucks.
3. Travel time for both passenger cars and trucks.
4. Average daily traffic.
5. Capital (construction) cost.
6. Annual highway maintenance cost.
7. Annual accident rate.
8. Minimum attractive rate of return.
9. Rate of traffic growth.
10. Study period (number of years for analysis).
11. Personal injury cost.
12. Willingness to pay value of time.
13. Cost of a human life.

Because of the errors inherent in estimates of these factors, an economic analysis must be concerned with more than the simple combination of all the factors into some formulation of economic worth. It is also necessary to evaluate the effect of possible errors on the calculation; in other words, to perform a sensitivity analysis. This consideration is basic to the principles of engineering economy and has been discussed in detail by Grant and Oglesby (2).

In some methods of analysis (e. g., benefit-cost ratio, equivalent annual cost, present worth), all factors must be known before the calculation can be made. In another method used to calculate break-even point or rate of return, all factors except a rate of return must be known, and the calculation is made to determine the rate of return.

It is possible to design a method of analysis, similar to a rate of return calculation, in which all factors except the willingness to pay must be known. This calculation is made in terms of the cost of time.

If the calculation of the economic worth of a particular project were made in terms of the cost of time, it appears that significantly increased insight could be gained as to the importance of this factor, and that project priority lists could be prepared which do not depend so heavily on a willingness to pay value of time on which little confidence can be placed. Even though some value of time has been used for years in economic analysis, the fact remains that relatively little confidence can be placed on the willingness to pay value which is chosen for the calculations. At least, most other factors (including a minimum attractive rate of return) can be estimated with more precision than the willingness to pay.

The remainder of this paper compares use of the willingness to pay value of time with use of the cost of time for identification of project priorities within the context of a budgetary constraint.

SELECTION OF HIGHWAY PROJECTS USING WILLINGNESS TO PAY VALUE OF TIME

The concept of the willingness to pay is almost universally used to evaluate the economic consequences of highway improvements. After compiling the basic project data (such as highway cost, user cost, and travel time) and separately estimating or assuming a willingness to pay, the analytical methods used to evaluate feasible alternatives include computation of benefit-cost ratios, equivalent annual costs, or rates of return.

As discussed previously, errors in input data may cause errors in the project selection process in spite of the validity of the analytical methods used. In this section, the effect of various willingness to pay values on the project selection process are examined in detail.

Current methods of analysis can best be illustrated by an example. Table 2 gives a number of hypothetical highway improvement proposals. At each of four different locations within the highway district, either three or four mutually exclusive improvement proposals are presented for consideration (14 in all). It is assumed that the total budget which is allocated to the district for the year for construction of new projects is \$11.7 million. The equivalent annual capital cost of this \$11.7 million budget, based on 7 percent interest and 20 years, is \$1.1 million. All subsequent comparisons are made on the basis of this \$1.1 million equivalent annual capital cost.

TABLE 2

HYPOTHETICAL HIGHWAY IMPROVEMENT PROPOSALS, CHANGE OVER EXISTING CONDITION[a]

Location Number	Cost and Time Factors	Proposals[b]			
		1	2	3	4
1	Increase in annual highway cost (\$)	+0.2	+0.7	+1.5	+2.3
	Savings in annual user cost (\$)	-0.1	-0.2	+0.7	+1.7
	Savings in annual travel time (hr)	+1.1	+1.4	+2.0	+1.9
2	Increase in annual highway cost (\$)	+2.6	+4.7	+9.5	+12.0
	Savings in annual user cost (\$)	+0.2	+0.3	+0.3	+0.8
	Savings in annual travel time (hr)	+5.3	+7.7	+9.2	+9.9
3	Increase in annual highway cost (\$)	+2.1	+3.5	+6.2	--
	Savings in annual user cost (\$)	+3.7	+2.8	+0.1	--
	Savings in annual travel time (hr)	+0.5	+3.3	+6.1	--
4	Increase in annual highway cost (\$)	+1.1	+2.1	+3.8	--
	Savings in annual user cost (\$)	+1.6	-0.5	-4.5	--
	Savings in annual travel time (hr)	+2.6	+8.1	+12.2	--

[a]Estimates of highway and user costs are stated in terms of equivalent uniform annual series. Changes of travel times are also corrected to an equivalent uniform annual series.

[b]Estimates of dollars and hours in hundreds of thousands.

For each proposal, estimates of economic factors have been summarized in Table 2 in the three categories defined previously. The highway cost is the estimate for capital expenditures, and includes costs of detailed design, land acquisition, and construction, converted to an equivalent annual basis using 7 percent interest and a 20-yr life. (Throughout these examples, it is assumed that the highway cost is composed only of capital (or construction) costs, and that highway maintenance costs are estimated in a separate budget. Thus, annual highway costs in these examples can be directly converted to a present year's budget simply by converting the annual series to a present worth.)

The savings in annual user costs is the difference between the existing user costs and the estimated user costs if the improvement were accomplished. User costs include such items as vehicle running costs, accident costs, and time costs for commercial vehicles (it is assumed that information is available to permit estimating a value of time for commercial vehicles independently). An increase in user costs is indicated by a minus sign. The savings in annual travel time is for passenger cars only. Both user costs and travel times are expressed in equivalent annual figures using the same rate of interest as used to reduce the capital cost to its equivalent annual amount.

An alternative method of handling commercial vehicle time would be to establish an arbitrary weighting factor to convert saving of commercial time to an equivalent number of hours for passenger cars. An equivalent amount of total hours saved could then be computed and converted to dollars by using a value of time for passenger cars.

To demonstrate the possible results of using an inaccurate value of time, the proposals are analyzed with three alternative willingness to pay values of $1.00, $1.50, and $2.00 per hour.

Incremental Procedure

With the data on highway costs, user costs, and travel time thus defined, and willingness to pay values assumed for the analyses, it is now necessary to describe the analytical technique used to select proposals within the limit of the budget. Because of its wide acceptance, the benefit-cost ratio method is used for analyzing these 14 proposals. As pointed out by Winfrey (3) and by Grant and Oglesby (2), incremental investments are justified when the incremental benefits are greater than the incremental costs; the incremental benefit-cost ratio is appropriate for the analysis.

To choose a set of projects using the incremental benefit-cost ratio method, it is necessary to consider all 14 proposals simultaneously. When the alternative proposals must be considered within the context of a budgetary constraint, the incremental analysis must consider all alternatives at all locations in a single analysis. Separate evaluations at separate locations may indicate which proposal will result in the greatest benefit-cost ratio at each location, but cannot provide a basis for selection of improvements at different locations to arrive at maximum gain within the budget constraint. The result of separate analyses is that some locations may receive relatively costly time savings because only costly alternatives were proposed, whereas other locations receive relatively inexpensive time savings because only inexpensive alternatives were proposed.

In many highway agencies, economic analysis frequently affects two stages in highway planning, the two stages being performed by separate organizations. The first stage is frequently called economic analysis in location and design; the second, programing. If there is a budgetary constraint which affects the programing process, the analyses by separate organizations may lead to selection of sets of projects which are not optimal.

The method presented here would result in optimal gain (maximum total benefits), if the actual willingness to pay were known, but the point of the example is to show the effect of various values of the willingness to pay.

An iterative procedure is used, in which the best incremental benefit-cost ratio is chosen among all alternatives at all locations at each iteration. The iterative procedure continues until no further investment opportunities exist that will permit the total expenditure to remain within the budget, with the additional criterion that no proposal will be accepted which has an incremental benefit-cost ratio less than 1.0.

The iterative procedure as described is somewhat cumbersome numerically. The hypothetical highway improvement proposals in Table 2 are considered in Appendix A according to this iterative procedure. At each iteration, the following steps are required:

1. Given the existing situation at the end of the previous iteration, the incremental investment opportunities not yet chosen or rejected are considered. The measure of each alternative is the incremental benefit-cost ratio.
2. From all incremental benefit-cost ratios at all locations, the most attractive alternative (that with the greatest benefit-cost ratio) is selected.
3. The highway cost of the alternative selected is added to a cumulative total highway expenditure schedule. If the alternative selected replaces one at the same location chosen in a previous iteration, the highway cost of the previously chosen alternative is dropped from the highway expenditure schedule.
4. If the revised highway expenditure total is less than the budget, the alternative chosen at this iteration is added to the list of alternatives previously selected, and any previous selection at that location is removed from the schedule.
5. If the revised highway expenditure total exceeds the budget, the alternative selected is rejected at this iteration. The list of alternatives remains the same as at the beginning of the iteration.

Using this procedure with the three values of the willingness to pay, three sets of projects are chosen (Table 3), along with the resulting total change in highway cost, in user cost, and in travel time. Also, at the bottom of the table are the net benefits (value of travel time savings, plus user cost savings, less highway cost).

Using three willingness to pay values to analyze the 14 improvement proposals results in the selection of three different sets of projects to be constructed. Thus, if little confidence is held for the actual willingness to pay, little can be said about the comparative economy of the three sets. Computations of the net benefits, given at the bottom of Table 3, are meaningless because the benefits depend to a considerable extent on the willingness to pay value used in the calculations.

TABLE 3

PROJECTS CHOSEN USING INCREMENTAL BENEFIT-COST RATIOS

Property	Willingness to Pay = $1.00/Hr	Willingness to Pay = $1.50/Hr	Willingness to Pay = $2.00/Hr
Project identification[1]	(1, 4), (2, 1), (3, 2), (4, 2)	(1, 2), (2, 2), (3, 2), (4, 2)	(1, 2), (2, 1), (3, 2), (4, 3)
Savings in travel time (hr)	1,860,000	2,050,000	2,220,000
Value of time saved ($)	1,860,000	2,075,000	4,440,000
Savings in user cost ($)	420,000	240,000	-170,000
Total user savings ($)	2,280,000	3,315,000	4,270,000
Total increase in highway cost ($)	1,050,000	1,100,000	1,060,000
Net benefits (including travel time) ($)	1,230,000	2,215,000	3,210,000

[1] First number in parentheses is location number; second is proposal number.

SELECTION OF HIGHWAY PROJECTS USING COST OF TIME

If little is known about the willingness to pay, errors in project selection may result, as illustrated in the previous section. How, then, can this difficulty be surmounted? The answer lies in a solution for the cost of time. Rather than performing calculations of benefit-cost ratios, equivalent annual costs, or rates of return, a procedure can be devised to evaluate projects in terms of the dollar cost of providing time savings — the cost of time.

The Budget

The cost-of-time procedure would function within a specific budget and would apply to all projects that fall within the scope of that budget. The total money available to a State highway department is apportioned to various uses; for example, to administration of the department and to highway maintenance activities. The remainder of the funds is sometimes distributed (as subbudgets) to geographic divisions within the State. The procedure would apply to a subbudget.

Furthermore, the procedure would apply only to those proposals that are evaluated in economic terms. Some projects are undertaken without an economic justification, because they cannot be evaluated on economic terms, or because they are deemed desirable to provide continuity within the highway system, or for other reasons. The cost of time procedure would apply to the subbudget or budgets that remain: to the specific geographical area and class of budgetary expenditure to which a set of proposals and their costs may be associated, all requiring economic justification.

The determination of the budget to be analyzed also involves the time-phasing of the design and construction process. Major projects frequently take a number of years to complete, from the time that the original go-ahead decision is made. Construction engineering, right-of-way acquisition, and construction phases are not easily telescoped. Thus, the approval of a highway project is a decision that affects capital expenditures not only in the current year, but in subsequent years as well. Thus, in any given budget period, a certain portion of the total available funds may be allocated to projects whose approval decision has been made in past periods. The remaining amount after deducting the funds for these projects becomes the "effective" budget. Furthermore, in using the technique described in this paper, it will be necessary to recognize that the year's budgetary constraint does not apply to the total project cost, but only to that part of the cost that must be funded in the current year.

It may be appropriate to consider the budgetary constraint in terms of a longer period than a year. Highway revenues are generally predictable into the future with good precision, for they depend primarily on the relatively predictable amount of automobile travel. If revenues (and therefore, budgets) can be predicted two, three, or five years hence, and if sufficient project economic data are available to cover the maximum construction level over the same period, the more lengthy time frame has appeal. The reason is that the one-year budget level may, in some cases, just barely exclude a project, not because its cost of time is significantly higher than others selected, but because the total highway cost, when added to the cumulative highway costs of proposals previously chosen, would cause the single year budget to be exceeded. Analysis over a longer period would tend to introduce a "leveling" effect.

The Incremental Procedure

The most obvious procedure for selecting the set of proposals that will lead to the greatest average saving in time per budget dollar expended would be simply (a) to enumerate the total highway cost, user cost, and time savings for all possible sets of proposals, (b) to exclude those sets whose total highway expenditure exceeds the budget, and (c) to select the remaining set that has the greatest time savings. This procedure, though simple in concept, is likely to be very lengthy. In the example used in this paper, which has many fewer alternatives than many real situations, there are 400 possible sets of proposals. With a larger number of locations, the total number of possible sets becomes very large. It would be desirable to find a procedure that would ease this computational burden.

TABLE 4

PROJECTS CHOSEN USING INCREMENTAL COST OF TIME

Property	Value
Project identification	(1, 4), (2, 1), (3, 2), (4, 2)
Total increase in highway cost ($)	1,050,000
Total savings in user cost ($)	420,000
Total savings in travel time (hr)	1,860,000

The incremental analysis used in the previous section can be adapted to the cost of time solution. The procedure used is exactly the same, except that incremental costs of time are computed, instead of incremental benefit-cost ratios, and proposals are selected by the criterion of the smallest incremental cost of time.

The computations using the cost of time are again lengthy, and therefore the selection of an optimal set from the 14 hypothetical proposals is shown in detail in Appendix B.

For the cost of time procedure, the set of projects chosen is given in Table 4, along with the total change in highway cost, user cost, and time savings. The set chosen is the same as that chosen by the incremental benefit-cost ratio method using a value of time of $1.00 per hour.

The two procedures are compared in Table 5, in terms of their average cost of time. The set chosen using the cost of time procedure and the benefit-cost ratio procedure with V = $1.00 per hr provides significantly lower average cost of time than those selected using $1.50 per hr and $2.00 per hr in a benefit-cost ratio procedure.

The set derived using a willingness to pay of $1.50 per hr would result in greater time savings than the set chosen by the cost of time, but to attain these additional time savings, the incremental cost of time would be about $1.21 per hr. If this incremental cost of $1.21 could be justified on the basis of willingness to pay, then the $1.50 set should be accomplished. But it has already been admitted (in this example) that the value of time may be as low as $1.00 per hr; therefore, it is not possible to state with confidence that the willingness to pay is at least $1.21. If this is representative of the real situation, it is a good illustration of the fact that the willingness to pay cannot be completely ignored, and it also indicates the economic advantage of choosing projects by the cost of time procedure. (If some proposals were admitted whose cost of time was higher than the lowest estimated willingness to pay, then other factors than the cost of time savings would be necessary to justify these projects. Otherwise, it could be concluded that the budget may simply be larger than necessary for the number of available projects.)

TABLE 5

COMPARISON OF THE TWO PROCEDURES

Property	Cost of Time Procedure	Benefit-Cost Ratio Procedure		
		V = $1.00/Hr	V = $1.50/Hr	V = $2.00/Hr
Project Identification	(1, 4), (2, 1) (3, 2), (4, 2)	(1, 4), (2, 1) (3, 2), (4, 2)	(1, 2), (2, 2) (3, 2), (4, 2)	(1, 2), (2, 1) (3, 2), (4, 3)
Net change in dollar costs ($)	630,000	630,000	860,000	1,230,000
Change in travel time (hr)	1,860,000	1,860,000	2,050,000	2,220,000
Average cost of time ($/hr)	0.339	0.339	0.420	0.554

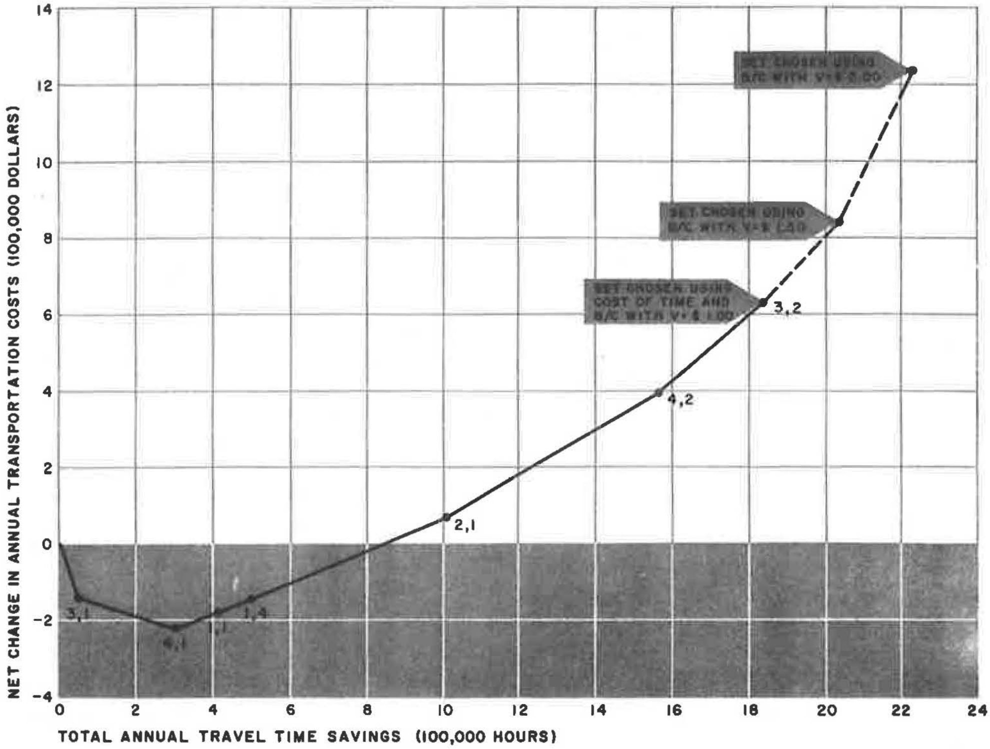

Figure 3. Comparison of the two procedures.

The set chosen using a willingness to pay value of $2.00 per hr would have an incremental cost of time of $2.18 per hr over the set chosen with V = $1.50. Thus, using the incremental benefit-cost ratio procedure, it is possible to attain a final increment of time savings that is greater than the assumed willingness to pay value used in the calculations.

The results of the two methods are shown in Figure 3, which plots total highway-plus-user costs vs time savings. It also indicates the iterative steps taken in the cost of time procedure, with lines connecting the successive proposals chosen at each iteration — (3, 1) first, then (4, 1), (1, 1), etc. This illustrates the iterative procedure — that each proposal chosen is more costly (cost per hour saved) than the proposal chosen in the previous iteration.

USE OF COST OF TIME CONCEPT IN PRACTICE

The monetary worth of time is one of the most important factors, if not the most important factor, in determining the total user benefits of highway improvements. Therefore, if little confidence can be placed on an estimate of a willingness to pay, it is desirable that the analysis of proposals be carried out by considering the cost of time as a primary variable.

Up to this point in the paper, the discussion has centered around a somewhat theoretical development of a new procedure for economic analysis. This section considers the practical problems associated with the adoption of the procedure and suggests an alternative use of the cost of time concept.

The procedure might be used just as described by a governmental body administering highway improvement expenditures. So used, economic decisions involving design, location, and programing would be made simultaneously. (It is recognized that the programing function is very complex. In addition to economic considerations, programing must take into account the present status of construction projects, land acquisition, analysis of proposals in the design stages, the availability of contractors to perform the work, and other considerations that are not readily reduced to economic data. These considerations are important, so important that they frequently take precedence over the economic calculations. Nevertheless, this technique could improve the economic portion of the total programing process.)

However, to use the entire cost of time procedure as outlined would entail a substantial change in the methods of economic analysis now used by highway agencies. In addition, this procedure seems to throw time savings into an all-important position. Clearly, many highway projects are justified on bases other than time savings. Vehicle running cost savings and safety are but two of many other important reasons for constructing improved highways. For such reasons, the cost of time procedure as described does not answer all the questions that need to be raised about proposed highway projects.

What is really of interest is not a new procedure, but a value of time that can justifiably be used to convert time savings to dollar savings. The willingness to pay is such a figure, but another figure may prove equally useful in many cases in which economic analysis is used. This figure is the maximum allowable cost of time, as determined from a budget constraint.

It appears far more simple to estimate a maximum allowable cost of time than to estimate a willingness to pay. Determining a maximum allowable cost of time would entail analysis of past years' histories to aid future decisions. In this use it is recognized that funds available for highway purposes do not change radically from year to year (for example. fuel tax revenues remain relatively constant, and, in general, increase gradually and relatively evenly as automobile travel grows), aside from relatively infrequent changes in fuel tax rates.

To estimate a maximum allowable cost of time, it would be necessary to examine all alternative highway proposals that were considered within a budgetary period in the past (including the alternatives of design, location, and programing), together with the budgetary allocation associated with that specific group. The costs of time could be calculated as previously outlined and could be used to indicate how, on economic grounds alone, projects should have been chosen and expenditures should have been made. Almost certainly the set of optimal projects so derived will not agree with the set actually accomplished. This disagreement might be due, in part, to the use of the "wrong" value of time in the calculations, wrong in relation to the budgetary constraint. (A useful by-product of analysis of a number of budget-proposal sets would be a comparison of the different costs of time that result. For example, if analysis of improvements to Federal-aid primary highways indicated a cost of time significantly different from that resulting from analysis of Federal-aid secondary highways (and there were no significant differences between budget categories because of irreducible considerations), one could conclude that the two budgets analyzed were incorrectly established in relation to each other. Conversely, if it were decided that two areas should have different degrees of improvements (e.g., a tourist area and a commuter area), the extent to which this objective was attained could be evaluated. These comparisons might justify reappraisal of the budget-establishing process or provide further basis for using different values of time in different situations.)

In any event, the maximum incremental cost of time can be computed. This maximum cost of time would be the incremental cost for the last project selected by the iterative procedure. This is the value that could be considered for future economic analyses as a value of time. (With this method of solution, it may be that the final selection made is much more costly than the previous selection. This possibility could exist, if, when considering the last selection, many appealing alternatives are rejected because their selection would cause the total highway expenditure to exceed the budget, and it is still possible to select a poor improvement of low highway cost. In theory, the budget has been considered fixed and it has been assumed that as much of the budget will be expended as is possible. In practice, the budget amount is somewhat flexible, so that it may be a sufficiently practical rule to look no further once the next most attractive alternative would exceed the budget. The maximum allowable cost of

TABLE 6

EQUIVALENT ANNUAL TRANSPORTATION COST SAVINGS[1] WITH V = $0.822 PER HR

Location	Cost Savings ($)			
	Proposal 1	Proposal 2	Proposal 3	Proposal 4
1	60,200	24,800	84,000	95,800
2	194,600	191,400	-165,600	-308,200
3	201,200	201,200	-310,400	--
4	263,200	404,200	170,400	--

[1] Source: Stanford Research Institute.
[2] A negative cost of time indicates that increase in highway costs is less than savings in user costs.

time, for use in future evaluations, would be the cost for the project selected just prior to rejection of the first project for budget reasons. Vaswani (4) used the cost of time principle, in which the highway administrator would choose a maximum allowable cost of time on the basis of local "considerations," for a "reference" highway. In this paper, the cost of time would be computed from a budgetary constraint.)

In the example, the final proposal selected by the cost of time procedure (3, 2) has an incremental cost of time of just over $0.82. This final incremental cost is, for this budget and set of proposals, the maximum allowable cost of time, and can be used as a value of time to compute equivalent annual costs of all these 14 proposals. If this value is used, the set of projects chosen in the iterative cost of time procedure will have the greatest equivalent annual cost savings, as given in Table 6. Thus, the optimal set of projects could have been selected by computing equivalent annual costs with V = $0.82, and selecting those with the greatest savings. (Actually, at the location where the last selection is made (location 3), two proposals would have the same (most negative) equivalent annual costs (3, 1 and 3, 2) (Table 6). If among these two, the proposal is chosen with the greatest total time savings, the optimal set will be identified.) The same set would be selected by the incremental benefit-cost ratio approach with V = $0.82. This is the major conclusion of this paper: By use of a maximum allowable cost of time, the optimal set of projects would be automatically derived and the budgetary constraint would be nearly met by the sum of all the individual highway costs.

Thus, the maximum allowable cost of time is the correct value of time for those economic analyses concerned with evaluation of alternatives when the incoming revenue or budget must be treated as a fixed amount. The maximum allowable cost of time is appropriate when evaluating alternative designs or alternative locations; it is appropriate in programing analyses. In these analyses, it will provide (as much as possible within the discrete nature of highway proposals) equally costly time savings at all locations that fall within the particular budget.

On the other hand, the maximum allowable cost of time is not appropriate for economic analyses in connection with highway needs studies, or for any other analyses in which the objective of the analysis is to influence the setting of tax rates or the establishing of budget levels. In these cases, the maximum willingness to pay is the appropriate conversion figure, for it is the standard of comparison which reflects highway users' desires.

But until a maximum willingness to pay value of time can be estimated with accuracy, no method of economic calculation can accurately influence the tax rate and budget allocation process, and no method of calculation can justify a project on absolute grounds.

CONCLUSIONS

A maximum willingness value of time is commonly used in economic analyses to convert travel time savings in hours to dollar values. However, little confidence can be placed on the results of these analyses, because little is known about the actual willingness to pay. It is demonstrated in this paper that the projects selected are dependent on the value of time chosen, and that, if the actual willingness to pay value differs much from the chosen value, the projects selected may not be the most desirable projects.

The cost of time procedure presented in this paper allows projects to be selected within a budget constraint without dependence on an estimated willingness to pay, which may be inaccurate. When time savings play an important part in the total benefits associated with an improvement proposal, it is appropriate to direct attention in their direction by computing the cost of time.

The most immediately practical use of the cost of time procedure would be to estimate the maximum allowable cost of time, using data on the past year's proposals and past year's budgets. This cost of time could then be used as a value of time to evaluate alternatives of design or of location and to formulate highway programs. In this way, time savings over the entire highway district will be attained at minimum cost.

ACKNOWLEDGMENTS

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Appendix A

SELECTION OF PROPOSALS USING INCREMENTAL BENEFIT-COST RATIOS

This appendix describes the detailed procedure of the use of benefit-cost ratios to select a set of highway improvement proposals. The data presented in the main body of the paper on hypothetical proposals at four locations are used as an example to display the numerical calculations involved. The computation is shown for an assumed willingness to pay value of $1.00 per hr. The procedure for other values is the same.

The first step is to order the alternatives in terms of increasing highway cost and compute the incremental benefit-cost ratios for all alternatives over all other alternatives at each location separately. At location one, the incremental ratios are computed for

(1, 1), (1, 2), (1, 3) and (1, 4) vs (1, 0)[1]
(1, 2), (1, 3) and (1, 4) vs (1, 1)
(1, 3) and (1, 4) vs (1, 2)
(1, 4) vs (1, 3)

Proposal (1, 1) compared with (1, 0) has an annual highway cost of $20,000, a savings in user costs of -$10,000 and a savings in travel time of +110,000 hr. The incremental

[1] The "do nothing" or existing situation is indicated as (1, 0).

TABLE 7

COMPUTATION OF INCREMENTAL BENEFIT-COST RATIOS

Location 1

Vs	1,1	1,2	1,3	1,4
1,0	5.0	1.71	1.80	1.57
1,1		0.40	1.31	1.24
1,2			1.88	1.50
1,3				1.13

Location 2

Vs	2,1	2,2	2,3	2,4
2,0	2.12	1.70	1.00	0.89
2,1		1.19	0.58	0.55
2,2			0.31	0.37
2,3				0.48

Location 3

Vs	3,1	3,2	3,3
3,0	2.00	1.74	1.00
3,1		1.36	0.49
3,2			0.04

Location 4

Vs	4,1	4,2	4,3
4,0	3.82	3.62	2.03
4,1		3.40	1.30
4,2			0.06

TABLE 8

ITERATIVE STEPS USING INCREMENTAL BENEFIT-COST RATIOS WITH A BUDGET CONSTRAINT OF $1,100,000 FOR V = $1.00 PER HR[a]

Iteration	Proposals Compared Against	Selection		Cumulative Highway Cost ($)
		Proposal	B-C Ratio	
1	(1, 0), (2, 0), (3, 0), (4, 0)	(1, 1)	5.0	20,000
2	(1, 1), (2, 0), (3, 0), (4, 0)	(4, 1)	3.82	130,000
3	(1, 1), (2, 0), (3, 0), (4, 1)	(4, 2)	3.40	230,000
4	(1, 1), (2, 0), (3, 0), (4, 2)	(2, 1)	2.12	490,000
5	(1, 1), (2, 1), (3, 0), (4, 2)	(3, 1)	2.00	700,000
6	(1, 1), (2, 1), (3, 1), (4, 2)	(3, 2)	1.36	840,000
7	(1, 1), (2, 1), (3, 2), (4, 2)	(1, 3)	1.31	970,000
8	(1, 3), (2, 1), (3, 2), (4, 2)	(2, 2)	1.19	1,180,000[b]
9	(1, 3), (2, 1), (3, 2), (4, 2)	(1, 4)	1.13	1,050,000

[a] No further available alternatives have benefit-cost ratios greater than 1.0; therefore, final set is composed of last project selected at each of four locations; that is, projects (1, 4), (2, 1), (3, 2), and (4, 2).

[b] Exceeds budget.

benefit-cost ratio, using a willingness to pay of $1.00 per hr, is [(1.00) (110,000) + (-10,000)] / 20,000 = 5.00. For proposal (1, 2) compared with (1, 1) the incremental benefit-cost ratio is [(1.00) (140,000 - 110,000) + (-20,000 + 10,000)] / (70,000 - 20,000) = 0.40. Table 7 gives the incremental benefit-cost ratios for all alternatives at the four locations.

The nine iterative steps required to make the selection of projects are given in Table 8. Following the iterative procedure described in the main body of the paper, in the first iteration, all 14 proposals are compared with their "do nothing" alternative [indicated in the second column as (1, 0), (2, 0), (3, 0), (4, 0)]. Following across the first line in all four tabulations in Table 7 shows that the greatest benefit-cost ratio is for proposal (1, 1) vs (1, 0). The benefit-cost ratio is 5.0 and the highway cost is $20,000, which is entered as the first iteration in Table 8.

In the second iteration, proposals (1, 2), (1, 3), and (1, 4) are compared against (1, 1), and all other proposals are compared against the "do nothing" condition. Thus, in the second column, proposals (1, 1), (2, 0), (3, 0), and (4, 0) are listed. In this iteration, proposal (4, 1) is most attractive, with a benefit-cost ratio of 3.82, as indicated in Table 8.

In the eighth iteration, proposal (2, 2) is most attractive, but adding this to the cumulative highway expenditure to that step would exceed the budget of $1,100,000.

Th iterative procedure continues until no further projects can be selected which will not exceed the budget, or until no further alternatives have benefit-cost ratios greater than 1.0.

Appendix B

SELECTION OF PROPOSALS USING INCREMENTAL COST OF TIME

This appendix describes the detailed procedure of the use of a cost of time concept to select an optimal set of highway improvement proposals. The data presented in the main body of the paper on hypothetical proposals at four locations are used as an example to display the numerical calculations that are involved.

The first step is to order the alternatives in terms of increasing highway cost and compute the incremental costs of time for all alternatives over all other alternatives at each location separately. At location one, the incremental costs are computed for

(1, 1), (1, 2), (1, 3) and (1, 4) vs (1, 0)[2]
(1, 2), (1, 3) and (1, 4) vs (1, 1)
(1, 3) and (1, 4) vs (1, 2)
(1, 4) vs (1, 3)

Proposal (1, 1) compared with (1, 0) has an annual highway cost of $20,000, a savings in user costs of -$10,000 and a savings in travel time of +110,000 hr. The incremental cost of time is [($20,000) - (-$10,000)] / + 110,000 = $0.27 per hr. For proposal (1, 2) compared with (1, 1) the incremental cost of time is [($70,000 - $20,000) + ($20,000 - $10,000)] / (140,000 - 110,000) = $2.00 per hr. Table 9 gives the incremental costs for all alternatives at the four locations.

The seven iterative steps are given in Table 10. The iterative procedure is described in the main body of the paper. In the first iteration, all 14 proposals are compared with their "do nothing" alternative. Project (3, 1) presents the most attractive investment with a cost of -$3.20 per hr over (3, 0). The negative cost of time indicates that both total dollar costs and travel time would be reduced. Its capital cost is $210,000, which is less than the $1,100,000 equivalent annual budget, and it is selected for completion.

In the second iteration, proposals at locations 1, 2, and 4 are compared with their

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[2] The "do nothing" or existing situation is indicated as (1, 0).

TABLE 9

COMPUTATION OF INCREMENTAL COSTS OF TIME
(Dollars per Hour)

Location 1

Vs ↙	1,1	1,2	1,3	1,4
1,0	0.27	0.64	0.40	0.32
1,1		2.00	.56	.38
1,2			-.17	-.60
1,3				2.00

Location 2

Vs ↙	2,1	2,2	2,3	2,4
2,0	.45	.57	1.00	1.13
2,1		.83	1.74	1.91
2,2			3.20	3.09
2,3				2.86

Location 3

Vs ↙	3,1	3,2	3,3
3,0	-3.20	.21	1.00
3,1		.82	1.38
3,2			1.93

Location 4

Vs ↙	4,1	4,2	4,3
4,0	-.19	.32	.68
4,1		.56	.92
4,2			1.39

TABLE 10

ITERATIVE STEPS USING INCREMENTAL COST OF TIME WITH A BUDGET CONSTRAINT OF $1,100,000[a]

Itera-tion	Proposals Compared Against	Selection: Proposal	Selection: Cost of Time	Cumulative Highway Cost ($)	
1	(1, 0), (2, 0), (3, 0), (4, 0)	(3, 1)	-3.20	210,000	
2	(1, 0), (2, 0), (3, 1), (4, 0)	(4, 1)	-0.19	320,000	
3	(1, 0), (2, 0), (3, 1), (4, 1)	(1, 1)	0.27	340,000	
4	(1, 1), (2, 0), (3, 1), (4, 1)	(1, 4)	0.38	550,000	230,000
5	(1, 4), (2, 0), (3, 1), (4, 1)	(2, 1)	0.45	810,000	260,000
6	(1, 4), (2, 1), (3, 1), (4, 1)	(4, 2)	0.56	910,000	210,000
7	(1, 4), (2, 1), (3, 1), (4, 2)	(3, 2)	0.82	1,050,000	350,000
					1050,000

[a] No further alternatives can be selected to keep cumulative highway cost less than budget; therefore, final set is composed of last project selected at each of four locations; that is, projects (1, 4), (2, 1), (3, 2), and (4, 2).

"do nothing" condition, and proposals (3, 2) and (3, 3) are compared with (3, 1). In this iteration, proposal (4, 1) is the most attractive and the highway cost of (3, 1) plus (4, 1) does not exceed the budget.

In the seventh iteration, proposal (3, 2) is chosen. No further improvements are possible without exceeding the budget.