Economy Studies for Highways

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Much time and effort is devoted to collecting data and preparing estimates for highway economy studies, while the actual economic analysis is accomplished quickly. And yet if comparisons are made improperly or if certain basic assumptions are inappropriate, the decisions stemming from the analysis may be in error. The aim of this paper is to adapt certain general principles of engineering economy into the somewhat specialized circumstances of the highway framework.

Results of economy studies for highways might be stated in terms of annual costs or savings, excess of benefits over costs, benefit-cost ratio, or rate of return on investment. Properly employed and interpreted, all of these methods give correct results; improperly used, they can lead to wrong decisions. The first part of this paper illustrates, by example, the proper procedures for comparing multiple alternatives by each method and indicates some of the pitfalls to be avoided in using each of them.

Much of the raw data for economy studies for highways are based on predictions of events 20, 30, or even more years in the future. An examination of past happenings over such periods of time coupled with any consideration of today's rapid rate of change, clearly demonstrates the uncertainty of such long-range forecasts. If economy studies are made at zero interest rate, the effect is to give predictions at all future dates equal weight. As the interest rate for economy studies is increased, the effect of happenings in the more distant future is discounted. In other words, studies made at low interest rates are highly sensitive to variations in estimates of future events; studies made at higher interest rates are less sensitive to such changes. The second section of this paper examines the "sensitivity" of economy studies to assumptions regarding estimated lives, salvage values, and expected growth or decline of benefits. Findings are presented by means of examples and graphs.

THE primary purpose of this paper is to throw light on two subjects; first, the interpretation of computed benefit-cost ratios and computed rates of return on investment in proposed public works projects where more than two alternatives are to be considered; and second, the sensitivity of economy studies to assumptions regarding such factors as interest rate, assumed life, salvage value, and growth factors. It may be viewed as an expansion of the discussion of certain matters presented more concisely in other writings, particularly in parts of five papers presented at meetings of the Highway Research Board and in certain chapters of three books (1, 2, 3, 4, 5, 6, 7, 8).

Economy studies to compare alternate highway locations and designs may be divided into two aspects, as follows:

A. Estimation of first costs, lives, salvage values, and maintenance costs of the various alternatives. Estimation of the consequences of the different locations and designs to highway users and other members of the general public, with a conversion of these consequences into year-by-year monetary figures insofar as practicable.

B. Analysis of the foregoing estimates in a way that will guide a recommendation for a choice among the alternatives. This analysis may be based on any one of a number of different techniques such as comparative equivalent uniform annual costs, comparative present worths, excess of annual "benefits" over annual "costs," benefit-cost ratios, or prospective rates of return on investment. To compute equivalent annual costs, present worths, annual benefits, annual costs, and benefit-cost ratios, it is necessary to choose some one interest rate that will be used in all calculations; the operational effect of selecting any particular interest rate is to base decisions among alternatives on the assumption that the rate selected is the minimum rate of return that is sufficiently attractive to justify a proposed investment, all things considered. If the rate-of-return technique is employed, some minimum attractive rate of return must be selected as a criterion for decisions among alternatives, even though this rate is not employed in the calculations.

This paper does not discuss any of the problems of estimation mentioned under (A) although it is widely recognized that many of these problems of estimation are troublesome and controversial. Rather, it deals with the interpretation of the different types of analysis mentioned in (B). Emphasis is laid on the interrelationships of the various techniques mentioned, particularly the rate-of-return and benefit-cost ratio techniques. In the view of the authors, the subjects treated in the main body of this paper are non-controversial. However, the highway literature demonstrates a widespread failure to understand these matters on the part of many persons who are responsible for recommending choices or making choices among alternatives in the field of public works. In part, this impression has been obtained from examining nearly 100 recent reports (1958 and 1959) comparing alternate highway locations in the United States (4). In part, also, the impression comes from conversations and correspondence with persons engaged in the economic analysis of public works. The objective, then, is to present a statement of certain basic principles in a compact form that makes these principles readily available to highway analysts and other persons concerned with decisions among alternatives in the public works field.

I. Interpretation of Results from Multiple Alternatives

This subject is developed by means of a single hypothetical example involving the economic analysis of a number of different proposals for the location and design of a section of highway. In some respects, the example is simpler than many actual cases; for example, it is assumed that all of the elements of the highway investment will last throughout the 30-yr study period and will have zero salvage value at the end of that period. Moreover, it is assumed that for each location and design the decrease in relevant annual costs to highway users and others which results from the improvement will be uniform throughout the 30 yr. The foregoing simplifications are intended to make it easier for the reader to concentrate his attention on principles involved in the comparison of multiple alternatives. The second section of this paper examines the sensitivity of conclusions of economy studies comparing such highway alternatives to differences in estimated lives and salvage values, to different assumed lengths of study period, and to the difference between the expectation of growing or declining benefits.

Seven percent has been selected as the minimum attractive rate of return or interest rate used in the example. In the past analysts have generally used lower interest rates than this for economic comparisons of highway alternatives. One purpose of using seven percent here rather than, say, three percent is that the higher rate is advantageous in discussing the sensitivity of the conclusions of highway economy studies to the estimates on which they are based.

Moreover, the present writers believe that the interest rates in common use in such studies (0 percent to about 3½ percent) are unjustifiably low. One of the writers has presented the case for higher rates at some length (3). The writers are not alone in their view that the commonly used interest rates are too low (7).

Although the example is a simplified one in a number of respects, it is complicated in the sense of involving a fair number of alternatives. One of the purposes of this report is to stress certain points—not always clearly understood by analysts—relating to the possible misinterpretation of benefit-cost ratios and prospective rates of return in comparisons of more than two alternatives. Certain aspects of the relationships among different methods of analysis can be brought out to better advantage by an example that contains a considerable number of alternatives.

Hypothetical Example of Alternatives in Highway Location and Design

A certain section of highway is now in location A. A number of proposed designs at new locations and proposed improvements at the present location are to be compared with a continuation of the present condition at A. For purposes of analysis, continuing the present condition is designated as A-1.

Three possible new designs in the present location are referred to as A-2, A-3, and A-4, respectively. Two new locations B and C are also considered for this section of highway. There are five designs to be analyzed at location B and four at location C. These 13 proposals, A-1 to A-4, B-1 to B-5, and C-1 to C-4, are mutually exclusive in the sense that only one proposal will be selected. Of course the various designs at each location contain a number of common elements.

Costs to Highway Agency

Table 1 gives the investments and the estimated annual maintenance costs for the various locations. It also gives estimates of the annual costs to highway users and other members of the public; the estimates for each alternative include all such costs that it is believed will be influenced by the decision among the various locations and designs.

The various alternatives at each of the three locations may be thought of as differing primarily in the frequency and elaborateness of interchange structures in a modern highway facility. Because the example is simplified by assuming that the entire investment has a 30-yr life with zero terminal salvage value, the usual breakdown of the total investment into its various components (for example, right-of-way, grading, pavement, structures) is not shown.

Consequences of Proposed Improvement

In decision making regarding proposed investments in public works, it is relevant to consider the expected consequences to the entire public, not merely consequences to the public agencies that will build and maintain the works. In the classic phrase of the U.S. Flood Control Act of 1936, an analyst should consider consequences "to whomsoever they may accrue." For many proposed works, one segment of the public will be affected favorably whereas another segment will be affected unfavorably. Both the favorable and the unfavorable consequences ought to be considered in the decision making regarding the proposed works. For consequences to be commensurable with proposed investments, they need to be expressed in terms of money amounts.

Many of the obvious consequences of highway investments consist of costs of various kinds to highway users. If the volume and type of traffic is estimated for each alternative, the highway user costs influenced by the choice among the alternatives can also be estimated. As this paper will not include a discussion of the issues involved in estimating such costs, they have merely been stated as a total figure in Col. 4, Table 1. The reader may view this total as including estimated vehicle operating costs, costs of commercial time, accident costs, and any other highway-user costs that he deems to be relevant and that can be estimated in a satisfactory way. He may also view the total as including any expected net nonuser consequences that can be expressed in terms of money.

The writers recognize that, in many cases, some consequences of decisions among highway alternatives cannot be expressed in terms of money. Furthermore, these "irreducibles," "to whomsoever they may accrue," are relevant to the decision. In these situations, the "dollar" answers from the economy study do not dictate the final choice; on the other hand they provide a money figure against which the irreducibles can be weighed and thereby narrow the area of uncertainty with which the decision-maker is faced.

TABLE 1

ESTIMATES FOR CERTAIN MUTUALLY EXCLUSIVE HIGHWAY ALTERNATIVES

Alternative	First Cost ($1,000)	Annual Maint. Cost ($1,000)	Annual Costs to Highway Users and Others ($1,000)
A-1	0	60	2,200
A-2	1,500	35	1,920
A-3	2,000	30	1,860
A-4	3,500	40	1,810
B-1	3,000	30	1,790
B-2	4,000	20	1,690
B-3	5,000	30	1,580
B-4	6,000	40	1,510
B-5	7,000	45	1,480
C-1	5,500	40	1,620
C-2	8,000	30	1,470
C-3	9,000	40	1,400
C-4	11,000	50	1,340

Determining Minimum Equivalent Uniform Annual Cost

Under the authors' assumptions, the annual highway maintenance costs and the annual costs to highway users and others (Cols. 3 and 4, Table 1) are assumed to be uniform throughout the 30-yr study period. In contrast, the estimated investments occur in a lump sum at the start of the 30-yr period. It is explained in texts on engineering economy and on the mathematics of investment that such an initial outlay may be converted into an equivalent uniform annual figure for n years if it is multiplied by a factor $\frac{i(1 + i)^n}{(1 + i)^n - 1}$ in which i is the appropriate interest rate. In the literature of engineering economy this factor is called the capital recovery factor, sometimes abbreviated to CRF. For the assumed interest rate of seven percent and the estimated life of 30 yr, the capital recovery factor is $\frac{0.07(1.07)^{30}}{(1.07)^{30} - 1} = 0.08059$.

Assuming zero salvage value, the product of an investment and the appropriate capital recovery factor is referred to as the annual cost of capital recovery, sometimes abbreviated to CR. For example, for project A-3, CR = $2,000,000(0.08059) = $161,000. In some of the literature of engineering economy, this product is referred to as "interest plus amortization" or as "investment charges."

Table 2 gives the three sets of annual costs "to whomsoever they may accrue" influenced by the choice among the proposed highway locations and designs; namely, capital recovery costs, maintenance costs, and costs to highway users and other members of the general public. The total of these costs is given for each alternative. It is evident that with the seven percent interest rate that has been used in computing investment charges, the equivalent uniform annual costs are minimized by the selection of project B-3. This project saves $247,000 a year as compared to the continuation

of the present condition (represented by A-1). It also is evident that all of the other proposals except C-4 involve a saving as compared to continuing the present condition.
The interpretation of Table 2 is discussed further after the comparison of these alternatives by a number of other methods has been presented.

TABLE 2

EQUIVALENT UNIFORM ANNUAL COSTS FOR CERTAIN HIGHWAY ALTERNATIVES

Alternative	Capital Recovery of Init. Investment at 7% ($1,000)	Maintenance ($1,000)	Costs to Highway Users and Others ($1,000)	Total ($1,000)	Annual Saving as Compared to Continuing Present Condition ($1,000)
A-1	0	60	2,200	2,260	-
A-2	121	35	1,920	2,076	184
A-3	161	30	1,860	2,051	209
A-4	282	40	1,810	2,132	128
B-1	242	30	1,790	2,062	198
B-2	322	20	1,690	2,032	228
B-3	403	30	1,580	2,013	247
B-4	484	40	1,510	2,034	226
B-5	564	45	1,480	2,089	171
C-1	443	40	1,620	2,103	157
C-2	645	30	1,470	2,145	115
C-3	725	40	1,400	2,165	95
C-4	886	50	1,340	2,276	-16

Determining Maximum Excess of Benefits Over Costs

In Table 2 all annual costs "to whomsover they may accrue" are lumped together combining the investment charges and maintenance costs on the highway with the annual costs to highway users and others. Another possible way of looking at the analysis is to define "benefits" as the prospective reduction in estimated future costs to highway users and others as compared to such estimated costs if the present condition is to be continued. Benefits so defined are then to be compared in some manner with the highway costs (for example, with the sum of highway investment charges and highway maintenance costs). There are several different methods of using benefits and costs, so defined, to reach a choice among the alternatives submitted for consideration. One simple method is to compute the excess of benefits over costs for each alternative and to select the alternative giving the maximum excess of benefits over costs. This method is given in Table 3, which shows B-3 as the project to be selected by this criterion.
Col. 6, Table 2 gives the net annual advantage of each alternative as compared to A-1, which is a continuation of the present condition. Col. 5, Table 3 also gives net annual advantage as compared to A-1. Of course the figures in two final columns are identical and the same project, B-3, is selected by the two methods. It will be obvious to the reader that there are no real differences between the decision rules for project selection implied in Tables 2 and 3; the difference between the two methods of analysis is entirely in terminology.

Computation of Benefit-Cost Ratios for Each Proposed Location and Design as Compared to a Continuation of the Present Condition

The most common technique for economic analysis of proposed public works project is by means of the benefit-cost ratio. (This ratio is also called the "benefit quotient," the "benefit ratio," and—somewhat illogically—the "cost-benefit ratio.") Table 4 gives the calculation of this ratio for each proposal to change the highway from its present condition. Because each comparison is between some new proposal (for example, A-2, B-2, C-2) and the present condition, the "costs" used as the denominator of the fraction are the highway costs in excess of the $60,000 figure (all maintenance) anticipated with alternative A-1.

Analysts do not always understand the limitations of a set of benefit-cost ratios such as those given in Col. 4, Table 4. Some persons, inspecting these ratios, might conclude that A-2 is the best alternative because it has the largest benefit-cost ratio. Other persons might select C-3 as the plan that, considering all the plans having benefit-cost ratios of at least 1.00; yields the highest total benefits. Neither group of persons would be correct.

As a matter of fact, the benefit-cost ratios in Col. 4, Table 4 do not provide a sufficient basis for a choice among the alternatives. All of these ratios merely compare a particular proposed location and design with an assumed continuation of the present condition; none of the ratios provides a basis for comparing the alternatives with one another.

Computation and Analysis of Incremental Benefit-Cost Ratios

Obviously no sound conclusion can be reached unless there is a criterion for comparing the many alternatives with each other. If the benefit-cost-ratio technique is to be employed in the economic analysis, it is necessary to compute ratios of increments of benefits to increments of costs. Table 5 gives a convenient organization of calculations for this purpose.

TABLE 3

EXCESS OF ANNUAL BENEFITS OVER ANNUAL HIGHWAY COSTS FOR CERTAIN HIGHWAY ALTERNATIVES

Alternative	Annual Benefits ($1,000)	Annual Highway Costs ($1,000)	Benefits Minus Costs ($1,000)	Improvement in Benefits Minus Costs as Compared to A-1[a], ($1,000)
A-1	0	60	- 60	-
A-2	280	156	+124	184
A-3	340	191	+149	209
A-4	390	322	+ 68	128
B-1	410	272	+138	198
B-2	510	342	+168	228
B-3	620	433	+187	247
B-4	690	524	+166	226
B-5	720	609	+111	171
C-1	580	483	+ 97	157
C-2	730	675	+ 55	115
C-3	800	765	+ 35	95
C-4	860	936	- 76	- 16

[a]Continuing the present condition.

The criterion here illustrated for the analysis of benefit-cost ratios is the same one implied in the decision favoring B-3 when annual costs were minimized in Table 2 and when the excess of benefits over costs were maximized in Table 3. This criterion is that no avoidable increment of cost is justified unless this increment of cost causes an increment of benefits at least as great as the increment of costs. It follows that for any acceptable project, the incremental benefit-cost ratio should be at least 1.00 as compared to all projects having lower costs (including the continuation of the present condition).

TABLE 4

BENEFIT-COST RATIOS COMPARING CERTAIN MUTUALLY EXCLUSIVE HIGHWAY ALTERNATIVES WITH CONTINUATION OF A PRESENT CONDITION

Alternative	Extra Annual Benefits Above A-1 ($1,000)	Extra Annual Costs Above A-1 ($1,000)	Benefit-Cost Ratio Col. 2/Col. 3
A-2	280	96	2.92
A-3	340	131	2.60
A-4	390	262	1.49
B-1	410	212	1.93
B-2	510	283	1.80
B-3	620	373	1.66
B-4	690	464	1.49
B-5	720	549	1.31
C-1	580	423	1.37
C-2	730	615	1.19
C-3	800	705	1.13
C-4	860	876	0.98

It is desirable that analysts understand clearly the interpretation of the type of analysis given in Table 5. Why does this type of analysis lead to a selection of project B-3, the same project that was selected when annual costs were minimized in Table 2 and when the excess of benefits over costs were maximized in Table 3?

Project A-2, the project having the lowest cost of the 12 proposed improvements, is clearly superior to A-1, the continuation of the present condition; an increment of annual benefits of $280,000 is caused by an increment of annual costs of only $96,000. Because of the superiority of A-2, to A-1, a comparison of the remaining 11 proposals with A-1 has no relevance in choosing among the 13 original alternatives.

A comparison of A-3 with A-2 favors A-3; $60,000 additional annual benefits are gained through only $35,000 of annual costs; the incremental benefit-cost ratio is 1.71. Project A-2 is therefore eliminated from the subsequent analysis.

Neither B-1 nor A-4 is attractive as compared to A-3 because their incremental benefit-cost ratios compared to A-3 are less than unity. It should be noted that A-4 should be compared with A-3, not with B-1, because B-1 has been eliminated by its 0.86 incremental benefit-cost ratio as compared to A-3.

A continuation of the analysis shows B-2 superior to A-3, and B-3 superior to A-2. None of the remaining 6 projects is attractive as compared to B-3 because for all of these projects, the incremental benefit-cost ratio compared to B-3 is less than unity. Therefore, Table 5 leads to the selection of B-3 as the most desirable location and design.

Stated a little differently, it is evident that in comparing B-3 with any project having lower costs, the prospective increment of benefits from B-3 is more than the prospective increment of costs. It is also evident that for all of the projects having higher costs than B-3, the prospective increment of benefits as compared to B-3 is less than the prospective increment of costs as compared to B-3.

<u>Computation of Prospective Rate of Return on Investment as Compared to a Continuation of a Present Condition</u>

Table 6 gives a method of computing rate of return on investment applicable to the

TABLE 5

INCREMENTAL BENEFIT-COST RATIOS COMPARING MUTUALLY EXCLUSIVE HIGHWAY ALTERNATIVES WITH ONE ANOTHER[a]

Projects Compared	Increment of Annual Benefits ($1,000)	Increment of Annual Costs ($1,000)	Incremental Benefit-Cost Ratio	Decision in Favor of
A-2 over A-1	280	96	2.92	A-2
A-3 over A-2	60	35	1.71	A-3
B-1 over A-3	70	81	0.86	A-3
A-4 over A-3	50	131	0.38	A-3
B-2 over A-3	170	152	1.12	B-2
B-3 over B-2	110	90	1.22	B-3
C-1 over B-3	- 40	50	Negative	B-3
B-4 over B-3	70	91	0.77	B-3
B-5 over B-3	100	176	0.57	B-3
C-2 over B-3	110	242	0.45	B-3
C-3 over B-3	180	332	0.54	B-3
C-4 over B-3	240	503	0.48	B-3

[a]Projects examined in order of increasing annual costs.

simple assumptions of our example. For convenience, the projects are listed in increasing order of investment. Col. 2 gives the reduced annual disbursements for each proposal as compared to A-1, the continuation of the present condition. Col. 4 is ob-

TABLE 6

PROSPECTIVE RATES OF RETURN ON TOTAL INVESTMENT IN CERTAIN HIGHWAY ALTERNATIVES AS COMPARED TO CONTINUATION OF A PRESENT CONDITION

Alternative	Reduction in Total of Annual Maintenance Costs and Annual Costs to Highway Users and Others as Compared to A-1[a] ($1,000)	Investment ($1,000)	Capital Recovery Factor for 30 Yr, Col. 2/Col. 3	Rate of Return on Investment as Compared to A-1[a] (%)
A-2	305	1,500	0.203	20.2
A-3	370	2,000	0.185	18.4
B-1	440	3,000	0.147	14.4
A-4	410	3,500	0.117	11.2
B-2	550	4,000	0.138	13.5
B-3	650	5,000	0.130	12.6
C-1	600	5,500	0.109	10.3
B-4	710	6,000	0.118	11.2
B-5	735	7,000	0.105	9.9
C-2	760	8,000	0.095	8.7
C-3	820	9,000	0.091	8.3
C-4	870	11,000	0.079	6.8

[a]Continuing the present condition.

tained by dividing the figure from col. 2 by the investment shown in col. 3. Under the special conditions of uniform annual savings and zero terminal salvage values, this quotient is the capital recovery factor corresponding to the estimated life (30 yr in the example). The interest rate or rate of return that will be earned on the investment can be determined by interpolation in a table of capital recovery factors or may be read from a graph such as Figure 1. (Because of the relatively long life and the relatively high rates of return, many of these rates of return are almost as large as the corresponding capital recovery factors.)

The possible misinterpretations of prospective rates of return as compared to a continuation of a present condition are similar to those of benefit-cost ratios as compared to continuing a present condition. One analyst might select project A-2 as the one yielding the highest prospective rate of return, 20.2 percent. Another might conclude that with a stipulated minimum attractive rate of return of seven percent, the only project ruled out by Table 6 is project C-4 that yields only 6.8 percent; therefore C-3 might be selected with its 8.3 percent rate of return as the highest investment

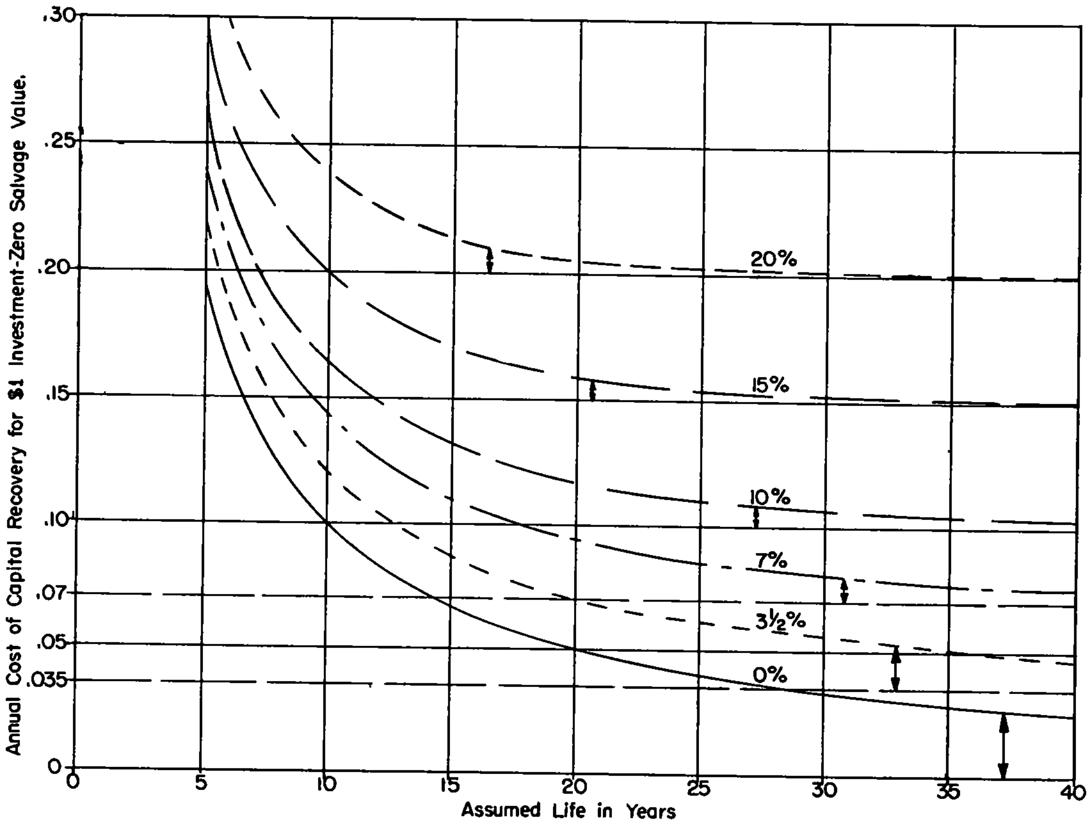


Figure 1. Capital recovery factors for various lives and selected interest rates.

that meets the stipulated standard of attractiveness. However, neither the selection of A-2 nor C-3 is consistent with the stipulated criterion for selection; namely, the minimum attractive rate of return of 7 percent.

The difficulty here is essentially the same one encountered in interpreting Table 4, which gave benefit-cost ratios as compared to continuation of a present condition. Prospective rates of return for a number of alternatives as compared to continuing a present condition do not provide an adequate basis for comparing these alternatives with one another.

Calculation and Interpretation of Prospective Rates of Return on Increments of Investment

Table 7 illustrates a convenient organization of calculation of rates of return on increments of investment under the simple assumptions of zero salvage values and uniform annual differences in disbursements for the various alternatives. The transition from computed capital recovery factors to rates of return is made in the same manner that was explained in the discussion of Table 6. Projects are considered in order of increasing investment, just as in Table 6.

Tables 6 and 7 differ from Tables 2 to 5 in that no interest rate (such as 7 percent) is assumed in making the calculations. Nevertheless, an interest rate or minimum attractive rate of return needs to be selected as a basis for making decisions among the alternatives. The decisions indicated in col. 6, Table 7 are based on a stipulated minimum attractive rate of return of 7 percent. Because 7 percent was used in the analysis minimizing annual costs (Table 2), in the analysis maximizing the excess of benefits over costs (Table 3), and in the analysis based on benefit-cost ratios (Tables 4 and 5 considered together), it might be reasonably expected that Table 7 will give the same conclusion reached by the other three methods of analysis. As a matter of fact, in Table 7 project B-3 is selected, the same project that was picked by the other three methods of analysis.

Comparison of Multiple Alternatives in Terms of Return on Total Annual Expenditures

So far, this paper has demonstrated that, properly employed, economy studies by any one of several methods will show which among various alternative solutions is the

TABLE 7

RATES OF RETURN ON INCREMENTS OF INVESTMENT CALCULATED TO COMPARE CERTAIN MUTUALLY EXCLUSIVE HIGHWAY ALTERNATIVES WITH ONE ANOTHER. PROJECTS ARE EXAMINED IN ORDER OF INCREASING INVESTMENTS. MINIMUM ATTRACTIVE RATE OF RETURN IS STIPULATED TO BE SEVEN PERCENT

Projects Compared	Increment of Reduction in Annual Disbursements ($1,000)	Increment of Investment ($1,000)	Capital Recovery Factor	Rate of Return on Increment of Investment (%)	Decision In Favor of
A-2 over A-1	305	1,500	0.203	20.2	A-2
A-3 over A-2	65	500	0.130	12.6	A-3
B-1 over A-3	70	1,000	0.070	5.7	A-3
A-4 over A-3	40	1,500	0.027	Neg.	A-3
B-2 over A-3	180	2,000	0.090	8.1	B-2
B-3 over B-2	100	1,000	0.100	9.3	B-3
B-4 over B-3	60	1,000	0.060	4.3	B-3
B-5 over B-3	85	2,000	0.0425	1.6	B-3
C-2 over B-3	110	3,000	0.0367	0.6	B-3
C-3 over B-3	170	4,000	0.0422	1.6	B-3
C-4 over B-3	220	6,000	0.0367	0.6	B-3

proper choice under a stated set of condıtions. The reasoning underlyıng these methods of analysis can be further clarıfied by reworking the same example again, this tıme ın the context of the return that the hypothetıcal hıghway agency will receive on a fıxed total of expendıtures, ıncludıng varıous levels of expendıture for the subȷect proȷect. The presumptıon underlyıng thıs approach, which is true for hıghway agencıes operatıng on fıxed annual income, ıs that ıf funds are devoted to a gıven proȷect, some other desirable use of the money must be foregone.

Additions to the data supplıed earlıer are as follows:

1. Total funds available to the highway agency for all purposes durıng the year of the study, $20, 000, 000.
2. Rate of return on all other ınvestments or expenditures that the highway agency wıll make ıs 7 percent.

Table 8 gives computatıons to determine three different bases of comparıng the alternatıve ways of investıng the entıre $20, 000, 000 annual budget. These bases are excess of benefıts over costs (col. 9) benefıt-cost ratıo (col. 10) and rate of return on investment (col. 12). In each ınstance, the selectıon of alternatıve B-3 shows as the most advantageous, ȷust as ıt dıd ın the prevıous examples. As would be expected, the excess of benefıts over costs found by the method of Table 8 agrees wıth that gıven ın Table 3, except for the last place difference resulting from roundıng of fıgures. A similar comparisons of benefıt-cost ratıos or rates of return ıs not possıble.

Because added computatıon is requıred, thıs method ıs not appropriate for routıne use. However, the wrıters have found it to be an extremely valuable ıllustrative tool and recommend it for that purpose.

In the examples developed so far ın thıs paper, the study perıod has been set at 30 yr. It has been assumed that thıs was the expected lıfe of every hıghway element and of the traffic usıng the road. More commonly the practıce ıs to assıgn dıfferent lıves to the various roadway elements and to make traffıc estımates for yet another perıod of years. The authors have deliberately avoıded these complexities. In the first place, they would encumber the example wıth added complexıty and obscure the main ıssue. Second, there may be good reason to challenge comparisons that mix long roadway life and short traffıc estimates. Thıs topic needs further exploratıon.

TABLE 8

COMPARISON OF ALTERNATIVE HIGHWAY INVESTMENTS IN TERMS OF TOTAL ANNUAL EXPENDITURES OF A HYPOTHETICAL HIGHWAY AGENCY

Alternative (1)	Total Annual Funds Available to Agency ($1,000) (2)	Expenditure on Subject Project ($1,000) (3)	Reduction in Total Annual Maintenance Costs and Annual Costs to Highway Users for Subject Project ($1,000) (4)	Funds Remaining for Investing in Other Projects at 7% (2) - (3) ($1,000) (5)	Annual Income from Other Projects (CRF - 7% - 30) = 0 08059 (5) x (CRF - 7% - 30) ($1,000) (6)	Total Annual Benefits (4) + (6) ($1,000) (7)	Cost of Capital Recovery on Total Annual Funds Invested (2) x (CRF - 7% - 30) ($1,000) (8)	Excess of Benefits Over Costs (7) - (8) ($1,000) (9)	Benefit-Cost Ratio (7) ÷ (8) (10)	Capital Recovery Factor i = ? n = 30 yr (7) ÷ (2) (11)	Rate of Return on Investment (%) (12)
A-1	20,000	0	0	20,000	1,612	1,612	1,612	0	1 00	0 0806	7 0
A-2	20,000	1,500	305	18,500	1,491	1,796	1,612	184	1 11	0 08980	8 1
A-3	20,000	2,000	370	18,000	1,451	1,821	1,612	209	1 12	0 09105	8 3
A-4	20,000	3,500	410	16,500	1,330	1,740	1,612	128	1 08	0 08700	7 8
B-1	20,000	3,000	440	17,000	1,370	1,810	1,612	198	1 12	0 09050	8 2
B-2	20,000	4,000	550	16,000	1,289	1,839	1,612	227	1 14	0 09195	8 4
B-3	20,000	5,000	650	15,000	1,209	1,859	1,612	247	1 15	0 09295	8 5
B-4	20,000	6,000	710	14,000	1,128	1,838	1,612	226	1 14	0 09190	8 4
B-5	20,000	7,000	735	13,000	1,048	1,783	1,612	171	1 11	0 08915	8 0
C-1	20,000	5,500	600	14,500	1,169	1,769	1,612	157	1 10	0 08845	8 0
C-2	20,000	8,000	760	12,000	967	1,727	1,612	115	1 07	0 08635	7 7
C-3	20,000	9,000	820	11,000	886	1,706	1,612	94	1 06	0 0853	7 6
C-4	20,000	11,000	870	9,000	725	1,595	1,612	- 17	0 99	0 07975	6 9

II. Sensitivity Aspects

With all economy study procedures except "rate of return on investment," an interest rate must be adopted before the analysis can be undertaken. For all procedures, including rate of return, assumptions for the useful life of each element of the highway and its salvage value at the end of that life must be made. Estimates of traffic, extended into the future in terms of growth or decline for a reasonable number of years must be converted into annual amounts of cost or saving. All such assumptions influence the final result of economy studies to a greater or lesser degree. The "sensitivity" of the results to such assumptions is the subject of the remainder of this paper.

Sensitivity of Economy-Study Results to Assumed Interest Rate

The selection of an interest rate or minimum attractive rate of return lies at the very heart of every economic analysis. The greatest exactness and care in preparing estimates and forecasts can be meaningless if the interest rate is inappropriate for the conditions under which the decision is made. The authors previously have presented their arguments for relatively high interest rates (1, 3, 6) as have others (7) and these will not be repeated here. It is deemed worthwhile, however, to demonstrate the effect of interest rates on the illustrative example presented earlier in the paper.

Table 9 represents a recomputation of the example at four different interest rates; namely, 0 percent, 3½ percent, 7 percent, and 10 percent. These computations demonstrate that for each interest rate a different alternative appears to be most favorable. Lower and lower interest rates favor heavier and heavier capital investments. For example, the use of 0 percent interest as compared to 7 percent argues for alternative C-3 at an added capital investment of $4,000,000 over B-3; and 3½ percent as compared to 7 percent justifies B-4 at an extra $1,000,000 first cost.

The principle illustrated by Table 9 can be stated another way, as follows: Suppose a highway agency must choose among numerous projects, all of which show a rate of return of 7 percent. It employs 0 percent for its economy studies. It then will invest $4,000,000 in this project that would be better employed elsewhere. Thus the improper choice of interest rate has defeated the purpose for which the economy study was made.

Sensitivity of Economy Studies to Assumed Life of the Project

In an economy study employing some form of annual cost comparison, capital or investment costs are spread uniformly over each year of the assumed life of the highway element. Where salvage value is not considered, this uniform annual charge for principal and interest is found by multiplying the first cost of the element by the capital recovery factor (CRF). Tables of capital recovery factors appear in textbooks of engineering economy and finance and in some books on highway engineering (5, 6, 7). Those for interest rates of 0 percent, 3½ percent, 7 percent, 10 percent, 15 percent and 20 percent and for lives appropriate for highway economy studies are plotted in Figure 1.

As assumed life increases, the capital recovery factor approaches the interest rate as an asymptote (Fig. 1). At high interest rates, this approach occurs rapidly, as the interest rate decreases, the speed of approach slows. It follows, then, that economy studies made at higher interest rates are relatively insensitive to changes in assumed life; at low or zero interest rates, this sensitivity is high. For example, at 7 percent, the increase in the annual cost of capital recovery when the assumed life is shortened from 30 to 20 yr is 17 percent; at zero interest rate the increase is 50 percent (Fig. 1). This is another evidence that higher interest rates discount the effect of happenings in the more distant future where uncertainties of prediction are greatest.

Sensitivity of Economy Studies to Assumed Salvage Values

The salvage value of a highway is its residual dollar worth at the end of the economy study period. One method for recognizing salvage value is to determine the present sum

TABLE 9

SENSITIVITY OF DECISIONS AMONG ALTERNATIVES TO THE CHOSEN MINIMUM ATTRACTIVE RATE OF RETURN[a]

Alternative	Estimated First Cost ($1,000)	Capital Recovery of Initial Investment at 0% (1)	3½% (2)	7% (3)	10% (4)	Maintenance ($1,000) (5)	Cost to Highway Users and Others ($1,000) (6)	0 Percent: Total (1)+(5)+(6) ($1,000) (7)	0 Percent: Annual Savings as Compared to Present ($1,000) (8)	3½ Percent: Total (2)+(5)+(6) ($1,000) (9)	3½ Percent: Annual Savings as Compared to Present ($1,000) (10)	7 Percent: Total (3)+(5)+(6) ($1,000) (11)	7 Percent: Annual Savings as Compared to Present ($1,000) (12)	10 Percent: Total (4)+(5)+(6) ($1,000) (13)	10 Percent: Annual Savings as Compared to Present ($1,000) (14)
A-1	0	0	0	0	0	60	2,200	2,260	0	2,260	0	2,260	0	2,260	0
A-2	1,500	50	82	121	159	35	1,920	2,005	255	2,037	223	2,076	184	2,114	146
A-3	2,000	67	109	161	212	30	1,860	1,957	303	1,999	261	2,051	209	2,102	158[b]
A-4	3,500	117	190	282	371	40	1,810	1,967	293	2,040	220	2,132	128	2,221	39
B-1	3,000	100	163	242	318	30	1,790	1,920	340	1,983	277	2,062	198	2,138	122
B-2	4,000	133	217	322	424	20	1,690	1,843	417	1,927	333	2,032	228	2,134	126
B-3	5,000	167	273	403	530	30	1,580	1,777	483	1,882	378	2,013	247[b]	2,140	120
B-4	6,000	200	326	484	636	40	1,510	1,750	510	1,876	384[b]	2,034	226	2,186	74
B-5	7,000	233	381	564	743	45	1,480	1,758	502	1,906	354	2,089	171	2,268	- 8
C-1	5,500	183	299	443	583	40	1,620	1,843	417	1,959	301	2,103	157	2,243	17
C-2	8,000	267	435	645	849	30	1,470	1,767	493	1,935	325	2,145	115	2,349	- 89
C-3	9,000	300	489	725	955	40	1,400	1,740	520[b]	1,929	331	2,165	95	2,395	-135
C-4	11,000	367	598	886	1,167	50	1,340	1,757	503	1,988	272	2,276	16	2,557	-297

[a]Life = 30 yr; terminal salvage value = 0
[b]Most desirable project at given rate of return

that, invested at compound interest, will produce an amount equal to the salvage value at the salvage date. By subtracting this present sum from the original investment, salvage value is fully recognized in the economy study.

Conversion of salvage value to its present worth is accomplished by multiplying it by the single payment present worth factor given in compound interest tables. An identical answer results when the salvage value is divided by the single payment compound amount factor. Figure 2 offers, for interest rates of 0, $3\frac{1}{2}$, 7, and 10 percent and periods of 20 and 30 yr, a convenient graphical method for converting percent salvage value to percent present worth. To illustrate, assume a salvage value of 50 percent of first cost, interest at 7 percent, and a study period of 20 yr. Then the present worth of the 50 percent salvage value is 13 percent (see dotted lines—Fig. 2). Full credit for the 50 percent salvage value will be taken if the first cost of the item is reduced to 87 percent of its actual value.

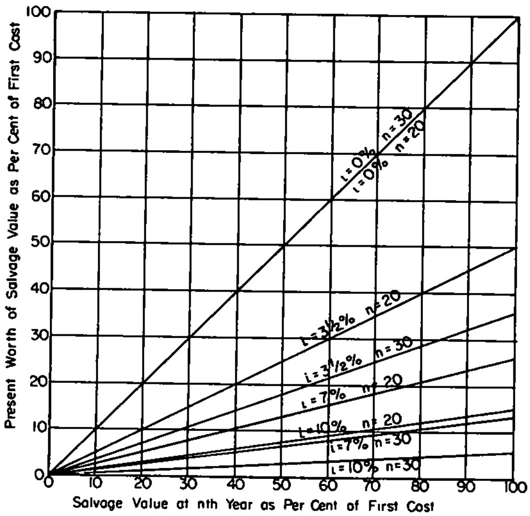


Figure 2. Relationship between salvage value at end of study period and present worth of salvage value.

Figure 2 provides a convenient means for appraising the "sensitivity" of economy studies to assumptions regarding salvage value. It can be seen that for any stated life, as interest rate increases, the percentage present worth of salvage value decreases. Thus, studies made at zero or very low interest rates are sensitive to assumptions regarding salvage value; as the interest rate increases, this sensitivity decreases. Likewise, at interest rates other than zero, the importance of salvage value decreases as the assumed life increases.

It has been suggested by Winfrey (7), among others, that "salvage values should be kept low, especially for pavements and other elements difficult to use in future reconstruction." Furthermore, at realistic interest rates and relatively long lives, the present worth of salvage value is small. Coupling these notions offers a strong argument in favor of neglecting salvage value in highway economy studies. As a specific example, Figure 2 shows that for the combination of a 10 percent salvage value, 20-yr life, and i of 7 percent, the difference between including and excluding salvage value is only $2\frac{1}{2}$ percent, which is considerably less than the expected error in other estimates.

Sensitivity to Assumed Rate of Growth of Annual Costs or Savings

Savings to highway users constitute one of the major justifications of highway improvement. To determine these user savings, estimates must be made of the savings accruing to an individual vehicle of each classification, such as passenger cars and various types of commercial vehicles. There is also a traffic projection to indicate, for each year of the study period, the number of vehicles on which the estimated individual savings will occur. For an economy study, the savings each year are determined by summing the products of unit savings times annual traffic for each vehicle class. If annual savings differ from year to year, they must be converted to a uniform equivalent annual sum by means of compound interest tables or charts.

At present, projections of future traffic commonly assume substantial increases over the study period; in many instances traffic 20 or 30 yr hence is set at double or treble existing levels. Under such circumstances, it is important that the analyst be aware of the effect of these assumptions on the results of his economy study. Furthermore, he needs to understand the interplay between these assumptions and the interest rate at which the analysis is made.

Figure 3 presents, for certain assumptions appropriate for highway economy studies, the relationship among length of study period, interest rate, traffic growth, and the resulting equivalent annual cost or savings. Data for Figure 3 are based on the following formula:

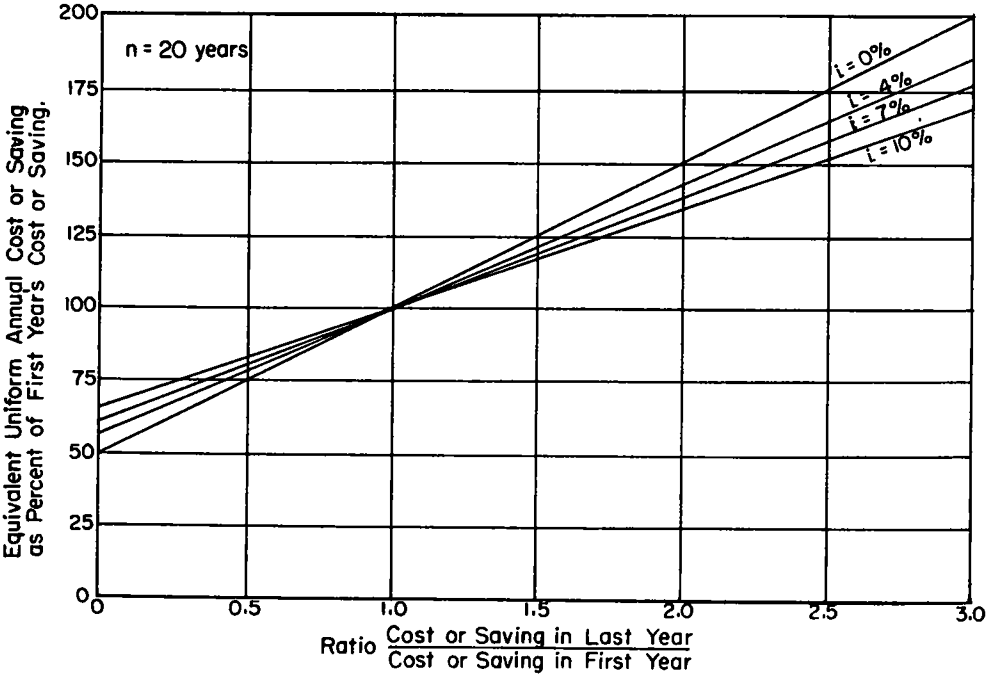
$$\text{Equivalent uniform annual cost or saving} = a + \frac{g}{i} - \frac{ng}{i}(\text{CRF} - i)$$

in which

a = annual cost or savings for the first year of the study period;
g = the constant dollar increase or decrease each year (for example, the increase in the second year over the first, the third over the second, etc.); and
n = the number of years (or interest periods) in the study.

In using this formula or graphs based on it, it must be recognized that "a" represents the first year's cost or saving and not that for the present or "zero" year. This distinction is important in studies where the basic assumption is, for example, that "present costs or savings double or triple in (say) 20 years." In such instances, correct use of formula or graph requires (a) increasing or decreasing the present annual cost or savings by g to determine a and (b) correcting the ratio from "last year" over "present year" into "last year" over "first year." Derivation of this gradient formula and a table of solutions are given elsewhere (6). Another formula and somewhat different results obtain if growth is computed in terms of a uniform percentage (geometric) annual increase. Only the arithmetic increase procedure is considered in this paper.

The use of Figure 3 can be illustrated by several examples. First, consider the case where annual costs or savings remain constant through the study period. Then the ratio of last year to first year is 1.00 and no conversion is needed. Figure 3 shows that, at a ratio of 1.00, equivalent uniform annual cost or savings equals 100 percent of the first year's cost or saving. Next, consider the case where the ratio of last to first year's cost or savings is 3.0. At zero percent interest and either 20- or 30-yr life, equivalent uniform annual cost or savings equal 200 percent of the first year's cost or savings. This is, of course, the average of the two. Phrased differently, the estimated annual cost or saving 20 or 30 yr hence carries equal weight to estimates for the first year. A third instance is for a ratio of 3.0, a study period of 30 yr, but with interest at 7 percent. In this instance, the equivalent uniform annual cost or savings is 1.67 times the first year's cost or savings. In this case, the effect of including interest at 7 percent has been to discount the effect of the higher savings or costs of the later years by reducing the percentage form 200 to 167. Stated differently, this and other comparisons that can be made by means of the graph indicate that studies made at higher interest rates are less sensitive to assumptions of future happenings than those made at lower or zero interest.



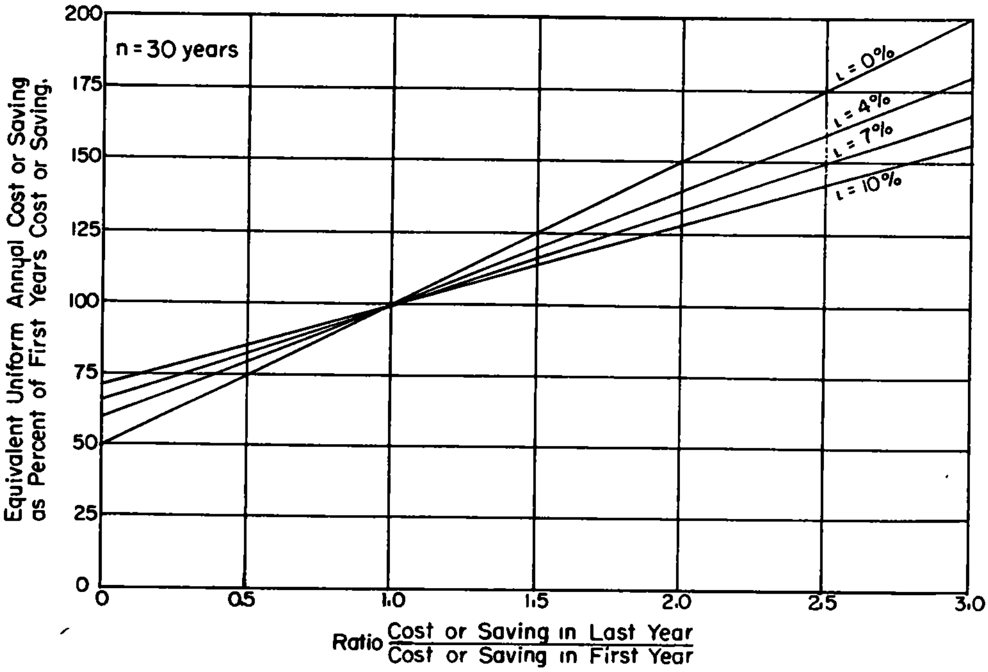


Figure 3. Relationship between growth factors and equivalent uniform annual cost or saving.

It is important that the analyst realizes how greatly his selection of growth rates influences the results of the economy study. Figure 3 provides a quick means for doing so. For example, for 20-yr life and 7 percent interest, and last year over first year ratios of 2.00 and 3.00, the percentages for equivalent annual cost or savings are 138 and 177 as contrasted with 150 and 200 at 0 percent interest. These represent significant differences that should be considered carefully. One possibility is to make two analyses, one based on a pessimistic estimate of growth and the other on an optimistic one. With this approach, the range of variation in consequences of the improvement can be gaged.

Summary of Sensitivity Aspects of Economy Studies

The foregoing discussion has indicated that economy study results show varying degrees of sensitivity to assumptions regarding service life, salvage values, and assumed rate of growth. In all instances, higher interest rates reduce the sensitivity of the conclusions of a study to these assumptions. This paper offers graphs and suggests methods by which the economic analyst can appraise the effects of changes in his assumptions on the final result.

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