The Choice of An Analytical Technique for Economic Evaluation of Highway Safety Projects

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Abstract

The purpose of evaluation of public projects is to make efficient allocations of society's resources in aiding social decision making. Such economic evaluation is based upon the premise that in order for a project to be viable, its benefits to whomsoever they may accrue, must exceed the estimated costs. Within this conceptual framework, a number of analytical tools have been used in the past to evaluate engineering projects. These include the Internal Rate of Return (IRR), Benefit Cost Ratio (B/C), Cost Effectiveness (C/E) and Payoff Period (PP) techniques. Each of these techniques has certain basic characteristics and limitations, and can be used to identify the optimal project. The selection of a particular technique for a given project may depend upon the availability of the data, the validity of the assumptions used and the intended use of the results.

While the presentation of these techniques in a typical undergraduate Engineering Economy course is simple and straightforward, the integration of these concepts explaining their exact relationship is sometimes problematic. In this paper, its authors attempt to demonstrate that under compatible assumptions the selection of the optimal project is not affected by the choice of analytic technique. Principles of engineering economy are used to offer a theoretical foundation followed by empirical demonstrations.

1. Introduction

The purpose of evaluation of public projects is to make efficient allocations of society's resources in aiding social decision making[1]. Such economic evaluation is based upon the premise that in order for a project to be viable, its benefits to whomsoever they may accrue, must exceed the estimated costs[2]. Rational decisions among alternatives, whether they are mutually exclusive or independent, depend upon their prospective consequences that should include consideration of all benefits and disbenefits, tangible or intangible. Further, much of these consequences of decisions occur after decisions are made. The estimation thus always applies to the future, adding one more degree of complexity to the decision making processes.

Within the conceptual framework of incorporating all costs and benefits during project evaluation, a number of analytic tools have been developed, each with a specific set of characteristics:

- Internal Rate of Return (IRR) Technique
- Benefit Cost (B/C) Technique
- Cost Effectiveness (C/E) Technique, and
- Pay Off Period (PP) Technique

The use of any one of the above four techniques for project evaluation/selection purposes depends upon a number of factors: validity of assumptions, availability of data, and intended use of the results. The presentation of these techniques as a decision making tool in a typical undergraduate engineering economy course should be simple and straightforward. However, the integration of the concepts within the evaluation framework can be somewhat problematic because of the subtle differences between these techniques[3,4].

The purpose of this paper is two fold. First, a discussion of the theoretical foundation of each of the four techniques is presented with the object of bringing out their similarities and differences. Second, a comprehensive case study involving a set of mutually exclusive highway safety projects is presented where all the four techniques are used as evaluation tools. Even though the case study involves safety projects, it is possible to develop similar measures of effectiveness for any type of public works project. The case study is designed to demonstrate that under compatible assumptions, the selection of the best alternative is independent of the use of the analytic tool. In other words, a comprehensive evaluation will always identify the same alternative as the best one, whichever of the four analytic techniques is used for evaluation purposes.

2. The Four Analytic Techniques

The four techniques identified are associated with four Measures of Effectiveness (MOE's) designed to reflect the degree to which a set of mutually exclusive projects are expected to meet their economic goals. The (C/E) technique essentially identifies the project with the least cost per unit benefit, while the (B/C) ratio method is directed toward designating the project with the highest benefit per unit cost, both at a specified interest rate. The IRR technique attempts to identify the project that provides the highest return to the investor within a specified project life. The PP technique on the other hand, is designed to identify the project that provides a specified return to the investor in the fastest possible time frame.

A brief theoretical foundation of the four techniques is presented below. The following symbols are used in the discussion.

I = Initial Cost ($)
K = Annual Operation and Maintenance Cost ($)

n = Project Life (years)
S = Salvage Value ($)
i = interest rate used (%, annual)
EUAC = Equivalent Uniform Annual Cost ($/year)
EUAB = Equivalent Uniform Annual Benefit ($/year)
(C/E) = Cost Effectiveness Index
(B/C) = Benefit Cost Ratio
IRR = Internal Rate of Return (%, annual)
PP = Pay Off Period (years)
(A/P) = Capital Recovery Factor
(A/F) = Sinking Fund Factor
(P/A) = Present Worth Factor (Uniform Series)
(P/F) = Present Worth Factor (Single Payment)
PWOC = Present Worth of Cost ($)
PWOB = Present Worth of Benefit ($)
NPW = Net Present Worth = PWOB – PWOC ($)
MARR = Minimum Attractive Rate (%, annual)

The case study used in the paper relates to a set of highway safety projects, where the object of the projects is to prevent the recurrence of certain types of highway accidents. While for public project, the estimation of costs is generally straightforward, the estimation of benefits is anything but so. In case of the highway safety projects, the expected number of accidents prevented is usually taken as a measure of benefit. There is a large body of literature on how these measures are derived and it is beyond the scope of this paper to discuss these issues[5,6,7].

2.1 Cost Effectiveness (C/E) Technique

The principle of Cost Effectiveness (C/E) techniques is based upon the premise that the alternative that costs the least amount of dollars to derive one unit of benefit is considered to be most cost effective. For the highway safety project case, this should be the alternative that costs the least to prevent a highway accident (of a specific type). The algorithm is as follows:

(C/E) = EUAC/N (1), when
EUAC = I(A/P) + K – S(A/F) ($/year) (2)
N = Number of Accidents Prevented Annually
(C/E) = Cost Effective Value (Dollars spent to prevent each accident)

The (C/E) technique only provides comparative MOE's of the alternatives being tested, and not an absolute measure of any alternative. Thus, it can be used to rank alternatives in increasing (or decreasing) order of their desirability. It cannot be used to determine if the benefits of any alternative "outweigh" its costs. The advantage of this technique is that, it is not necessary to attach a dollar value to the benefits, a task often considered the most difficult one in evaluating public projects. For example in highway safety projects, how does one attach a dollar value to an accident prevented, or a human life saved? There is a large body of literature on what items should be included in assessing such safety benefits, and how such assessments should be made. Suffice it to say, that there is not a consensus among experts on this question[8,9]. In such situations, the Cost Effectiveness method can be an ideal evaluation tool, provided the monetary assessment of the benefits is not an issue.

2.2 Benefit Cost (B/C) Technique

Benefit Cost (B/C) ratio is one of the more common techniques used in project evaluation, primarily because of its ease of interpretation. (B/C) ratio is simply a measure of the number of units of benefits that the project is expected to provide per unit cost. There are four classes of (B/C) analysis, *ex ante*, *ex post*, *in medias res*, and *ex ante/ex post (or in medias res)* comparison[1]. *Ex ante* analysis, (most common) is used to directly assist decision makers about a specific project, program, etc., among alternatives, prior to implementation. *Ex post* analysis is used at the termination of a project, program, etc. to determine how successful, valuable, or worthwhile it was. *In medias res* analysis is a combination of *ex ante* and *ex post*, during the duration of a project, as opposed to being a decision making tool or for post analysis. The last analysis, *ex ante/ ex post* comparison (or *in medias res*), compares the ex ante analysis for the decision making to the ex post analysis for a specific project, program, etc., to compare the efficacy of the methods. The method used in this paper is the *ex ante* analysis. The algorithm used is:

(B/C) = Benefit/Cost = EUAB/EUAC, where

EUAC can be computed as shown in equation 2. The computation of EUAB can be problematic, particularly in public projects, a detailed discussion of which is beyond the scope of this paper (5). In the specific highway safety project case, EUAB can be computed as:

EUAB = N x C (3), where
N = Number of Accidents (of a particular type) Prevented Annually
C = Unit $ Value of Each Accident Prevented, so that

(B/C) = (N x C)/EUAC (4)

In the evaluation process, all projects with (B/C) ratios less than unity are to be rejected, as the benefits are not considered enough to offset the costs. Projects with (B/C) ratios exceeding unity are considered viable. The selection of the best project might depend on the mission of the program. If the mission is to maximize overall benefits, the project with the highest (B/C) ratio should be selected. If on the other hand, an investment perspective is used, when the mission is to maximize investment to derive the highest possible return, it is necessary to explore the marginal (B/C) ratios. These decisions rules can be formulized as:

Mission A:

- To maximize benefit, select the project with the highest (B/C) ratio, provided (B/C) ≥ 1.00

Mission B:

- To maximize investment to derive the highest return, select the project with the highest investment, subject to
  $(B/C)_{absolute} \geq 1.00$, and
  $(B/C)_{marginal} \geq 1.00$

Both of the above approaches are used in practice and they may not necessarily lead to the same solution.

The (B/C) ratio is the most widely used technique in project evaluation, because of the ease of interpretation and computation. However, the disadvantage, particularly compared to the (C/E) technique is the need to determine the dollar worth of the benefits derived.

2.3 Internal Rate of Return (IRR) Technique

The IRR technique is used quite frequently also, in spite of difficulties in computation. Unlike the previous two cases, where an interest rate is assumed at the outset, the IRR technique requires the computation of the interest (or the yield) that the project is expected to return to the investor. The algorithm is based upon the premise that the IRR is the interest rate at which the Net Present Worth (NPW) of the project equals zero, and can be written as:

Set NPW = 0, i.e.
PWOB = PWOC, i.e.
$$N \times C \times (P/A) = I + K(P/A) - S(P/F), \qquad (5)$$

A theoretical solution of equation (5) to derive the appropriate interest can be difficult. A more practical approach is to find an empirical solution using a trial and error process, by systematically altering the interest rate until the solution is found. All projects yielding an IRR, which is less than an initially specified Minimum Attractive Rate of Return (MARR) are to be rejected. All projects that yield an IRR exceeding the MARR become viable, and as in the case of the (B/C) ratio technique, the selection of the best project depends upon the mission of the program. The decision rules can be formalized as:

Mission A:

- To maximize yield, select the project with the highest IRR, provided IRR ≥ MARR

Mission B:

- To maximize the investment to derive the highest yield, select the project with the highest investment, subject to

$IRR_{absolute} \geq$ MARR, and
$IRR_{marginal} \geq$ MARR

Both approaches are used in practice and they may not necessarily lead to the same solution.

Inspite of its computational difficulty, the IRR technique is widely used, primarily because it provides a piece of crucial information from an investment perspective, i.e. the return on the investment.

2.4 Pay Off Period (PP) Technique

This is one of the least used techniques, and is only used when " the time taken by the project to pay for itself" is the desired answer. The algorithm used is the same as the one used in the IRR technique (equation 5). However, the solution strategy is different. In this case, an interest rate must be assumed (that is usually the MARR or higher), and the value of n_1, (number of years) is sought by trial and error, until the equation (5) is satisfied. The decision rule used in project selection is as follows:

If $n_1 > n$ Reject
If $n_1 \leq n$ Accept

The premise is that if a project pays for itself earlier than the period the project is expected to last, it essentially provides "free" service to the investor for the difference between the two periods. If on the other hand, it takes a longer period to pay for itself, the additional period is a "liability" to the investor. Unlike the (B/C) and the IRR technique, the concept of marginal investment and return is not used in the PP technique. Thus when a number of projects exist, whose Pay off Periods are less than the project life, a common practice would be to select the project with the least Pay off Period. This would also be the project with the highest (B/C) ratio, or the highest IRR.

3. Case Study Demonstration

We will demonstrate the interrelationship between the four techniques through a set of three mutually exclusive highway safety projects, one of which is to be undertaken with the object of preventing highway accidents. The problem is defined as follows:

> The initial cost (I) of the three mutually exclusive projects, termed A, B and C, are \$40,000, \$50,000, and \$60,000, with annual operation costs of \$2000, \$3000, and \$6000, and salvage values of \$4000, \$5000, and \$6000 respectively. Based upon experience from similar projects, Projects A, B, and C are expected to prevent a total of 7, 8, and 12 accidents (of a particular type) annually. Each of these projects has an expected life of 15 years. Given the dollar value of each accident prevented as \$2,000, which project should be selected by each of the four methods (use i = 12%)?

3.1 Cost Effectiveness (C/E) Method

We present the results of the (C/E) method and the (B/C) method in Table 1. Table 1 shows that Project C is the most cost effective, and the cost of preventing each accident for Project C is $1,050. Project C is followed by Projects A and B, with C/E values of $1,109 and $1,276 respectively. If selection of the best project is the only objective, Project C should be selected (being the most cost effective). Whether or not the benefits of Project C outweigh the costs, can not be answered by this method. Hence, the most cost effective project selected by this method may not necessarily be a cost efficient one whose benefits will exceed costs. (The concept of marginal investment analysis is not used for the (C/E) method.)

Table 1
Economic Analysis of Highway Safety Projects Using the (C/E) and (B/C) Techniques

Economic Analysis Data	Project		
	A	B	C
Initial cost	$40,000	$50,000	$60,000
Annual Operating Cost	$2,000	$3,000	$4,000
Salvage	$4,000	$5,000	$6,000
Service Life (yrs.)	15	15	15
Interest Rate (%)	12	12	12
Number of Accidents Prevented Annualy (B)	7	8	12
Dollar Value of Accidents Prevented @ $2,000/accident (EUAB)	$14,000	$16,000	$24,000
Annualized Cost of Project (EUAC)	$7,765	$10,207	$12,642
MOE: (C/E) Value	$1,109	$1,276	$1,050*
MOE: (B/C) Ratio (absolute)	1.803	1.567	1.897*
MOE: (B/C) Ratio (marginal)		0.82 (B vs. A)	2.05 (C vs. A)

3.2 Benefit Cost Ratio (B/C) Method

Table 1 also shows the (B/C) ratios (absolute), computed for the three projects as 1.803, 1.567, and 1.897 for Projects A, B, and C respectively, indicating that all the three projects are viable (implying their benefits exceeding the cost). If the mission of the program is to maximize benefits, Project C, with the highest (B/C) ratio of 1.897 should be selected. Note that the ranking of the projects are exactly the same as obtained by the (C/E) technique. If the mission is to maximize investment to derive the highest return, the computation of $(B/C)_{marginal}$ for each viable comparison pair is necessary.

Table 1 also shows that the $(B/C)_{marginal}$ for B vs. A is only 0.82, indicating that the additional investment is B compared to A, only produces 82% benefits, thereby making Project B undesirable. Next, after Project B is eliminated from further consideration, the $(B/C)_{marginal}$ for C vs. A is computed to test the viability of Project C. The $(B/C)_{marginal}$, computed as 2.05, shows that the additional investment in C compared to A, produces over 200% additional benefit, clearly indicating the superiority of Project C. Note, in this example used, both Mission A and B, produced the same result. However, there is no guarantee, that both missions will always yield the same solution. The use of marginal (B/C) ratio and the marginal IRR (described below) to identify the most desirable project is often termed as the "Defender-Challenger" Approach[2].

3.3 Internal Rate of Return (IRR) Method

Results of the IRR Technique shown in Table 2 indicate that Projects A, B, and C, generate returns (IRR) of 30%, 25%, and 34% respectively, with Project C providing the highest yield, with the relative rankings of the projects exactly similar to those in the previous two techniques. Assuming a MARR of 12%, Project C should be selected, if maximizing yield is the mission of the program. If maximizing investment to derive the highest yield is the mission, computation of the $IRR_{marginal}$ for each comparison pair is necessary.

Table 2

Economic Analysis of Highway Safety Projects Using the IRR and PP Techniques

Economic Analysis Data	Project		
	A	B	C
Initial cost	$40,000	$50,000	$60,000
Annual Operating Cost	$2,000	$3,000	$4,000
Salvage	$4,000	$5,000	$6,000
Number of Accidents Prevented Annualy (B)	7	8	12
Dollar Value of Accidents Prevented @ $2,000/accident (EUAB)*	$14,000	$16,000	$24,000
IRR Absolute	30%	25%	34%
MOE: IRR Marginal		6% B vs. A	39% C vs. A
MOE: Pay off Period Using an Interest Rate of 12%	4 yrs.	5 yrs.	3 yrs.*

As Table 2 shows the $IRR_{marginal}$ for B vs. A is only 6%, which is considerably lower than the MARR of 12%, indicating that the additional investment in B compared to A does not measure up to the expectation. Eliminating B from further consideration, the $IRR_{marginal}$ for C vs. A , is computed as 39%. This indicates that the additional investment in C compared to A, produces a return much higher than the MARR of 12%. Thus Project C is the desired choice.

Note that whether we consider the $(B/C)_{marginal}$ at 12% or the $IRR_{marginal}$ against a MARR of 12%, Project C is selected by both methods, and the philosophy leading to the selection of the final alternative is exactly the same. (i.e. Does the investment produce enough benefits?) Once again, both Missions A and B lead to the same solution in this case, but it is conceivable that in other cases the two selections could be different.

3.4 Pay Off Period (PP) Technique

Table 2 also shows that at the assumed interest rate of 12%, the Pay off Period for Projects A, B, and C are 4, 5, and 3 years respectively. Since in all the three cases, the Pay off Periods are considerably lower than project life of 15 years, all of these projects are considered viable. Project C with the least Pay off Period of 3 years is considered the most desirable. One could interpret that Project C, will provide 12 years of "free" service to the investor (taxpayer in this case), after the project is paid off in 3 years. Note the rankings of the three projects are exactly the same as obtained by the other three techniques. Also, the concept of marginal investment analysis is not used for the PP technique.

3.5 Additional Observations

In an effort to demonstrate the sensitivity of the evaluation measures to the interest rate, a set of (B/C) ratios at interest rates of 30%, 25%, and 34% were computed for the three projects (Table 3). Recall that Projects A, B, and C had IRR's of 30%, 25%, and 34% respectively. Table 3 shows, that the (B/C) ratios, computed at the specific interest rates for the projects that correspond to their respective IRR's, are exactly unity, and that at higher interest rates, the corresponding (B/C) ratios are less than unity, and vice versa. As an example, for Project C, (the one selected as the best alternative), the B/C ratio at 34% (yield of the Project at n = 15), is exactly unity, and at 30% and 25%, the ratios are 1.075 and 1.23 respectively.

Table 3

Sensitivity of the Evaluation Process to the Assumed Interest Rates

MOE	Project A	Project B	Project C
IRR @ n =15	30%	25%	34%
(B/C) @ i = 12%, n =15	1.80	1.66	1.90
(B/C) @ i =25%, n = 15	1.13	1.00	1.23
(B/C) @ i =30%, n = 15	1.00	0.88	1.075
(B/C) @ i =34%, n =15	0.89	0.79	1.00
Pay Off Period @ i = 12%	4 yrs	5 yrs	3 yrs
Pay Off Period @ i = 25%	8 yrs	15 yrs	6 yrs
Pay Off Period @ i = 30%	15 yrs	∞	9 yrs
Pay Off Period @ i = 34%	∞	∞	15 yrs

In Table 3, we also show how the Pay off Period changes with interest rates. Recall that at the specified interest of 12%, the Pay off Periods for Projects A, B, and C were computed as 4, 5, and 3 years respectively, indicting that Project C pays for itself the quickest. Also recall, that Project C generated the highest IRR of 34% at n = 15 years. Table 3 also shows that at an assumed interest rate of 34%, Project C has a Pay off Period of exactly 15 years, and as interest rates are reduced to 30% and 25%, the Pay Off Periods for Project C are reduced to 9 and 6 years respectively. As the interest expectation of the project yield is reduced, it takes a shorter time period for the project to pay for itself. Project A, with a 30% IRR at n = 15 years, has a Pay off Period of 15 years at i = 30%. If the interest expectation is increased to 34%, it will take forever for Project A to pay for itself. On the other hand, the as interest rate is reduced to 25%, Pay off Period is reduced to 8 years. Similar interpretation can be made for Project B from Table 3.

4. Conclusions

In this paper, the authors demonstrate through a discussion of the theoretical foundation and a case study application, that the identification of the best alternative from a set of mutually exclusive projects, is independent of the evaluation tool used. Even though the case study focused on highway safety projects, this premise still holds true for the selection of any transportation or public works project. Four commonly used tools: Cost Effectiveness, Benefit Cost Ratio, Internal Rate of Return, and Pay off Period techniques are used by the authors. The case studies presented can be used in a typical undergraduate Engineering Economy course to explain the interrelationship between the four techniques, and the rational behind the finding that the selection of the best alternative under compatible assumptions, is independent of the technique used. A set of sensitivity analyses on changes in the interest rate, and their impact on the evaluation measures is designed to further explain their interrelationship.

A logical question often posed by the student is "If the selection of the alternative is independent of the technique, why is it necessary to learn the use of all four techniques?" The answer lies in the intended use of the results of the analysis, the validity of the assumptions, and the availability of the data. If selection of the optimal project is the only object of the analysis, the (C/E) technique may suffice. However, the use of the (C/E) technique does not guarantee that the project identified as the most cost-effective, will be also cost efficient relative to yielding enough benefits to cover the costs. If, on the other hand, an assessment of the exact return on investment is the desired result, the IRR technique may be the ideal tool. Similarly, if assessment of comparative benefits relative to the costs is the desired answer, the (B/C) ratio should be used. Lastly, the PP technique can be used to estimate the number of years of "free service," the project is expected to provide after all the expenditures are paid off. In all cases, the availability of data is a primary factor in the choice of the specific technique.

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