ESD-TR-68-426

AN INDEX FOR USE IN THE SELECTION OF COST EFFECTIVE SYSTEMS

Walter G. Hartung

October 1968

COST ANALYSIS DIVISION
COMPTROLLER
ELECTRONIC SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
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FOREWORD

Within the Electronic Systems Division (ESD) the Staff Office specifically charged with the responsibility for development of estimating techniques, methods and procedures is the Comptroller Office (ESC). The content of this technical report was prepared by the Cost Analysis Division (ESCC) as an aid to improve cost estimating.

This Technical Report has been reviewed and is approved.

RALPH E. ANGEL, Colonel, USAF
Comptroller

ABSTRACT

Life-cycle cost alone is not sufficiently inclusive to be used as a yardstick for the selection of a cost effective system. Equal life-cycle cost does not imply equal cost effectiveness. An index is developed which in addition to life-cycle cost, includes cost effective life span, expenditure chronology, system phase-in structure, and the present equivalent cost of money expended at a future date. Although the index does not determine military effectiveness, it does permit the cost comparison of various systems or programs on a logically compatible and equivalent basis.

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SECTION I

INTRODUCTION

The evaluation of a system's cost and its comparison with that of other systems involves more than a comparison of procurement or life-cycle cost. During the life-cycle period which is the development, acquisition, and operational stages of a system, a host of factors influence the total cost of the system. This paper develops an index which includes these factors and relates them to the life-cycle cost and the optimum economic life of a system.

In order to develop the index, identify the influencing factors, and illustrate the computation, let us consider a hypothetical but typical situation in which the government is to select one of two competitive systems to meet an expected threat during the 1970 time period. Both systems have equal capabilities with regard to the threat, and their total ten year life-cycle cost* is identical. System A has an initial cost of $5 million and the operation and maintenance costs are estimated at $800,000 for each of the first five years, increasing by $200,000 per year in the sixth and subsequent years. This system has a ten year life-cycle cost of $16.0 million.

System B has an initial cost of $2.0 million and has an

* All cost estimates are given in current 1968 dollars.

annual operation and maintenance cost of $1.2 million for the first six years. This annual cost increases in the seventh and subsequent years by $200,000 per year. The ten year life-cycle cost for this system is $16.0 million. A summary of these costs is given in Table 1.

The question to be considered is: Are both systems equally cost effective? Based upon life-cycle cost alone, we would have to conclude that the answer is yes. Now, a look at Table 1 shows that there is a significant difference in the cost between the two systems in the early periods of the operational lifetime of the system. In the first year, there is a $2.6 million difference between A and B. Could this money be invested elsewhere? By the end of 1975, a $1.4 million difference exists; what if the threat had significantly altered so that the weapon system (A or B) were obsolete by this time? Considering that we are in the planning stage, three years prior to initial procurement, these are questions which can and should have a serious impact on the decision to buy either System A or System B.

SUMMARY OF SYSTEM CUMULATIVE LIFE-CYCLE COSTS
(Thousands of 1968 Dollars)

YEAR	SYSTEM A	SYSTEM B	COST DIFFERENCE (A-B)
1971 (Procurement)	$ 5,000	$ 2,000	$ 3,000
1972	5,800	3,200	2,600
1973	6,600	4,400	2,200
1974	7,400	5,600	1,800
1975	8,200	6,800	1,400
1976	9,000	8,000	1,000
1977	10,000	9,200	800
1978	11,200	10,600	600
1979	12,600	12,200	400
1980	14,200	14,000	200
1981	16,000	16,000	0

TABLE 1

SECTION II

INFLUENCING FACTORS

The answer to the question as to which system is the most cost effective must consider not only the amounts of expenditures but also the points in time at which they occur. These two considerations, the life-cycle cost and the time at which the various expenditures occur, form the basis for selecting the most cost effective system. The consideration of the time at which the expenditures take place implies that there is an inherent and distinct cost advantage as to the chronology of expenditures. This cost advantage is determined from the present worth of future dollars to the government.

The total amount of money allotted for a given program will not be expended during any given year. It will be parcelled out during the development, acquisition and operational lifetime of the system. There are several factors influencing the present value of funds committed during this period. These factors can be grouped into two classes. The first includes those variables which tend to escalate the future cost of an item; the second consists of those which tend to make money increase in value. Three significant factors are identified which escalate cost: borrowing, inflation, and technological risk. Portions of the expenditures are derived from borrowing, since the government rarely collects sufficient revenue to meet its fiscal obligations. Inflation has the effect of increasing the total cost of the program. In addition, the program to be undertaken is subject to the uncertainties inherent in programs requiring significant technological advances. These factors thus increase the planned future cost of the program.

The second class of factors consists of those variables which during the development, acquisition, and operational life of a program tend to make principal grow. In this context, principal is the budgeted or estimated dollar amount of a program. Growth is primarily achieved in three ways: deflation, increase in tax revenue, and investment of principal. Deflation has the opposite effect of inflation, it makes today's dollar worth more tomorrow. The tax revenue increase, accomplished through both normal growth and rate increases, can be measured as a percent of required total expenditures, since such money, in whole or in part, represents this revenue. Thus, if tax revenue increases by ten percent, todays expenditure dollar next year will grow to 1.10 dollars. In any given fiscal year there is a set amount of funds to be parcelled out to the various programs. While portions of these funds are derived from revenue, some are obtained from borrowing. If prior to initiating one or more programs there is a choice in spending a larger or smaller amount of money, and the smaller amount is chosen, an artificial surplus is created. Hence, less borrowing is needed, depending on the amount of this surplus. This is tantamount to an investment, a monetary return derived from initiating programs having a low present equivalent cost. Even though in reality the "surplus" would probably be consumed by funding additional programs, it is none the less an actual, measurable growth factor derived from a prior decision to commit funds at the lower cost. This lower cost, as will be explained in the next section, is not an obvious dollar value. It represents the net effect of the influencing factors governing escalation and growth during the life of a program.

SECTION III

CONCEPT OF PRESENT EQUIVALENT COST

The concept of discounting or present value attempts to translate future costs into terms of today's dollars. In applying this concept, one normally specifies a rate representing the worth of money which is used to compute the discount factor. This rate is a compound interest rate which considers the cost of obtaining money and in some cases the risk of program termination. Little or no guidance exists for evaluating the factors inherent in this rate. Two deficiencies are noted in applying the concept of discounting.

One, since an arbitrary interest rate is normally used, it does not reflect any differences in system or program characteristics. In using a single rate, no distinction is made between the risk of military obsolescence and the interest cost of money. While many arguments exist for using a 5, 7, or 10 percent rate, little attention has been directed towards computing a rate which is characteristic of the system itself. Use of a common arbitrary rate implies that in an economic sense each system to be compared will behave in an identical manner. This certainly is not true and must lead to erroneous conclusions concerning the relative merits of competing systems.

Second, escalation of program cost due to inflation and technological difficulties is absent in discounting. As a consequence, discounting is biased in favor of programs where the majority of spending occurs toward the end of the life-cycle and also in programs where large technological advances are required. Thus, technologically risky programs are placed on an equal basis with programs requiring off-the-shelf equipment, i.e., little or no technological risk. Such deficiencies may explain why after many technologically advanced systems were chosen, their actual cost had no resemblance to the original estimate.

Considerations of both escalation and growth lead one to the concept of the present equivalent cost of money expended in the future. In this concept, escalation and growth are combined to compute the amount of money required today to commit a given amount of funds for expenditure tomorrow. This amount represents the present equivalent cost or present worth of the money obligated at the time of its commitment. The present equivalent cost represents the minimum funding required at the present time to meet the future financial obligations of a program.

The worth of money can be computed based upon the factors governing cost escalation and growth of principal. Let the following be defined:

i_r - risk rate

i_i - inflation rate (a negative value for deflation)

i_b - interest rate reflecting cost of borrowing money

i_c - interest rate reflecting growth from investing money

i_g - growth rate of GNP or revenue

The equivalent compounded rate of worth of money is then computed as:

$$i = (1 - i_r)\ (1 - i_i)\ (1 - i_b)\ (1 + i_c)\ (1 + i_g) - 1 \qquad (1)$$

In equation (1), if i is greater than zero, growth exceeds the escalation of cost. In this case, for equivalent effectiveness and influencing factors, the preferred system is that where the major portion of life-cycle costs are encountered toward the end of the operational period. However, when i is negative, cost escalation is greater than growth of principal. Here, the selected system is that where the major portion of life-cycle costs are encountered early in the program, assuming equal effectiveness and influencing factors.

The rates for inflation, interest, and GNP are readily available. In order to compute a rate reflecting the cost escalation resulting from technological uncertainties, use is made of a factor F developed by Summers[1]. F is an

[1] Summers, Robert, "Cost Estimates as Predictions of Actual Weapon Costs: A Study of Major Hardware Articles", RM-3061-PR, RAND Corp., 1965.

estimate of the ratio of the actual cost to the estimated cost of a complex aircraft weapon system. It primarily measures the technological risk.

$$F = 11.929 \, EXP \left[0.097t - 0.032 \, tA - 0.311A + 0.015A^2 + 0.008L - 0.075 \, (T-1940) \right]$$

Where,

t - time within the development period at which the cost estimate is made. Expressed as a fraction of the development period.

A - measure of the technological advance to complete the system. This is a subjective index ranging from 5 to 16. As a guide,

Small Advance 5-8

Medium Advance 9-12

Large Advance 13-16

L - Length of development period in months.

T - Calendar year of the estimate.

We thus consider that the cost estimate will increase or decrease by the factor F at the end of the procurement period N. If E is the estimate, we can compute an equivalent compound interest rate (i_r) reflecting technological risk as follows:

$$E \, (1 + i_r)^N = F \times E$$

$$i_r = F^{1/N} - 1$$

This rate should be applied in conjunction with equation (2) for $r < N$. For $r > N$, i_r would be zero.

Military risk - the risk of system obsolescence before its operational life is complete - is difficult to objectively ascertain. One reasonable approach is to assume that in the initial period of development and production, it is high and diminishes during the later stages of deployment and operational life. If we assume that for high risk the economically better choice is to spend less initially, we have what amounts to discounting. Thus, if a rate i_m can be determined to reflect this risk of obsolescence, the risk can be incorporated into the index by including an additional multiplicative term $(1 + i_m)$ in equation (1).

Now, let C_R be the RDT&E cost, CI_n the initial investment expended in year n, relative to the year C_R was incurred, and R_n the operation and maintenance cost incurred during year n. If i is the rate at which the worth of money is to be computed, $v = 1/(1+i)$ is the discount factor or present equivalent cost of a dollar to be spent a year hence. When v is less than one, growth of principal exceeds the escalation of cost. If v is greater than one, cost escalation is greater than growth of principal.

Assuming expenditures can be considered to take place at the beginning of each fiscal or calendar year, the present equivalent cost of an expenditure through r years is given as:

$$P(r) = C_r + CI_1 + R_1 + (CI_2 + R_2)v + (CI_3 + R_3)v^2 + \ldots + (CI_r + R_r)\,v^{r-1} \qquad (2)$$

We can see that the present worth of expenditures during r years is dependent upon both the schedule of operational unit deliveries as indicated by CI_r and the annual operation and maintenance of those units in inventory, R_r.

In applying equation (2), the rates comprising i of equation (1) need not be identical over the period r. Thus, i could be computed on a yearly basis, making v a function of r. Hence, the effects of varying rates during the operational life time of a system can be determined and used in selecting the most cost effective system.

SECTION IV

INDEX

In order to develop an appropriate yardstick, let us suppose that the system is to be operational for N years and that the government obtained the sum P(N) by borrowing funds at some rate q and repaid the amount by fixed annual payments throughout the life of the program, N years. In this way, variable payments can be translated into fixed annual payments which can be used as a standard or index to compare the cost effectiveness of various systems.

The present worth of fixed annual payments x for N years is:

$$x + vx + v^2x + \ldots + v^{N-1}x = \frac{x\ (1-v^N)}{1-v}$$

Since the sum to be borrowed, P(N), must equal the above, we compute as the index, the equivalent fixed annual charge:

$$E(N) = \frac{1 - v_1}{1 - v_1{}^N}\ P\ (N) \qquad (3)$$

where $v_1 = 1/(1+q)$.

Since the value of P(r) is a cumulative result for r years, it explains little about the efficiency with which money is being spent in each of the r years. Hence, E(r) is used as the index since it is an indication of the efficiency by which money is utilized in that it measures the rate of expenditure per year over the period r. If E(r) were tabulated for each year the minimum value would indicate the optimal period (r_o) for spending the funds. Hence, r_o is the solution to the following inequality:

$$E(r + 1) > E(r) < E(r - 1)$$

Now, if the operational life of the system, N, is less than r_o, E(N) represents the index for selecting the cost effective system. The values of E(r) are monotonically decreasing to a minimum at N years. In this case, system replacement would not be considered.

However, if r_o is less than the operational life, replacement may be required to achieve the most efficient spending of funds. Values of P(N) would be computed for various trial replacement intervals. The value of the minimum P(N) not only signifies the best replacement period but also the most efficient utilization of funds.

The methodology for selecting the most efficient replacement scheme depends upon the constraints of the problem. In many cases, systems are not amenable to substitution by producing new items. Once production has ceased, start-up may be impossible for a variety of reasons. Also, start-up may not be possible at arbitrary points in time to comply with some optimum replacement method.

There are, however, systems in which a replacement policy is ideal. Depending upon the system, the replacement policy can be determined by use of P(N). It is a simple matter to construct a computer program to compute the feasible replacement intervals and the corresponding P(N). The minimum P(N) defines the optimum replacement strategy.

In lieu of the above, use may be made of equation (3). The year which corresponds to the minimum E(r), r_o, can be used as a base to compare competitive systems where replacement is to be considered. The index is $E(r_o)$ and compares the optimum E(r) values of various systems where replacement is desired. While it does not necessarily give the optimum replacement interval for N years of operation, it does indicate that there is a strategy such that the selected system will beat the other systems.

Where replacement is not to be considered, the index for use in selecting the most cost effective system is E(N). Again, N represents the number of years that the system is to be in operation. The system with the minimum E(N) is that where the most efficient use of funds is made. Hence, on a cost effective basis, this system should be chosen.

SECTION V

APPLICATION

The hypothetical problem of evaluating System A and System B will be utilized to illustrate the application of the index. The data in Table 1 will serve as the base. The value of i will be taken as ten percent. Hence, we are comparing the systems on the basis of a ten percent worth of money. The present equivalent costs for the first ten years of operation have been computed using equation (2) and are tabulated in Table 2. The corresponding indices E(r) were computed from equation (3) and are tabulated in Table 3 using a ten percent interest rate for q. Hence, $v_1 = .9091$ and in this example has the same value as v.

From Table 3, it can be seen that for System A, the minimum value of E(r) occurs in the ninth year, whereas for System B, the eighth year. Using these values for r_o, we can now compute the index which relates cost effective life, life-cycle cost, and present equivalent cost.

For System A,

$$P(9) = \$11,097,000 \text{ (See Table 2)}$$

$$E(9) = \frac{1 - .9091}{1 - .4241} \; 11097000 = \$1,752,000$$

For System B,

$$P(8) = \$9,352,000$$

$$E(8) = \frac{1 - .9091}{1 - .4665} \; 9352000 = \$1,594,000$$

PRESENT EQUIVALENT COSTS

SYSTEMS A AND B

Year r	PRESENT EQUIVALENT COST P(r) (Thousands of 1968 Dollars)		DIFFERENCE A-B
	A	B	
1	$5,800	$3,200	$2,600
2	6,527	4,290	2,237
3	7,188	5,278	1,910
4	7,789	6,178	1,611
5	8,335	6,998	1,337
6	8,956	7,743	1,213
7	9,633	8,532	1,101
8	10,351	9,352	999
9	11,097	10,192	905
10	11,860	11,050	810

TABLE 2

INDEX - 10% DISCOUNT RATE
(Thousands of Dollars)

Year	A	B
1	$5800	$3200
2	3418	2246
3	2627	1729
4	2234	1772
5	1999	1678
6	1870	1616
7	1799	1594
8	1764	1594
9	1752	1609
10	1754	1635

TABLE 3

Thus, the equivalent fixed annual charge of borrowing funds, i.e., the index E(9), for purchasing and operating System A for nine years at an interest rate q is $1,752,000. The straight average annual cost for System A for nine years is $1,578,000. The average ten year life-cycle cost is $1,600,000. Since the equivalent fixed annual charge includes the cost of borrowing, it is always higher than the straight average annual cost for an identical period of time.

The equivalent fixed annual charge for System B is $1,594,000 for eight years of operation. The straight average annual cost for eight years is $1,525,000 and the average annual ten year life-cycle cost is $1,600,000.

If we are interested in comparing both systems for an identical length of operational time, ten years, we have, for System A:

$$E(10) = \frac{1 - .9091}{1 - .3855} \; 11,860,000 = \$1,753,000$$

and for System B:

$$E(10) = \frac{1 - .9091}{1 - .3855} \; 11,050,000 = \$1,634,000$$

In either case, we see that under the ten percent worth of money assumption, System B offers a cost advantage over System A, even though the predicted ten year average annual costs are equal.

The above illustration shows how the index E(r) is utilized under the discount assumption. It considered growth rather than growth and escalation. To consider both, let the following values be defined for use in equation (1):

$i_i = 0.05$

$i_b = 0.06$

$i_c = 0.05$

$i_g = 0.08$

A twenty percent risk rate will be assumed for both systems. Hence, substituting the above values in equation (1), i becomes -0.18987 and v is 1.234. It is thus clear that inflation and risk are more dominant than growth of principal. From Table 4, for a ten year period, using a ten percent rate for q, the index, E(10), for System A is $6,678,000 and for System B, $7,374,000. Hence, for equal risk, System A becomes the more attractive choice.

If instead of a ten year operation, a four year program is selected, a study of Table 4 will reveal that System B offers the least cost. Thus, it is almost axiomatic that the least cost system is not an absolute, but rather a function of the underlying assumptions. Under the assumption of straight discounting and for under four years of operation, System B is the choice. For longer periods of operation, considering systems of equal risk, System A which has the

INDEX FOR SYSTEMS A AND B
(Thousands of Dollars)

Year	System A ($i_r = 0.2$)	System B ($i_r = 0.2$)	System B ($i_r = 0.05$)
1	$5800	$3200	$3200
2	3555	2452	2329
3	2926	2379	2100
4	2727	2513	2034
5	2725	2769	2037
6	2962	3127	2077
7	3447	3720	2188
8	4185	4583	2354
9	5235	5773	2568
10	6673	7374	2826

TABLE 4

lowest yearly operation and maintenance cost is the most cost effective system.

Referring back to Table 1, it is rather obvious from the cost of procurement that System A is more involved that System B. Let us suppose that this difference is due to the fact that A requires more research and development since it is a more sophisticated piece of equipment. System B, although it performs an equivalent function, is a modified off-the-shelf type of equipment. Hence, A incurs more of a technological risk than B. Now, assume the risk to A to be twenty percent, and the risk to B to be five percent. The column on the far right in Table 4 shows the index for B for the five percent risk. In the previous example, equal weight was given to the risk involved in both systems, creating bias in favor of the more technologically advanced system. Assuming a more realistic risk factor, System B shows a marked superiority, as far as cost is concerned, over A for each of the ten years considered. Under these conditions, the risk involved in successfully developing the more advanced system does not justify the cost.

The index E(r) also indicates the efficiency of spending. In Table 4 it can be observed that as the years r increase, E(r) decreases until it reaches a minimum. From this point, it begins to increase. For System A, it is noted that the period of most efficient usage is five years, i.e., r_o is five, whereas, for System B, r_o is three years for a twenty percent risk and four for a five percent risk. Comparing these figures with those obtained from Table 3, it is quite evident that under the assumption of straight discounting, i.e., growth only, the funds are more efficiently used towards the end of the program. However, when escalation exceeds growth, the optimum periods are incurred earlier in the program. When growth and escalation are equal, the index is monotonically decreasing, indicating that the longer the operational life, the more efficient is the spending.

Now, if the year r_o should coincide with the years of operation, N, an optimum condition exists. Here, we have the most efficient utilization of funds for the number of years that the system is to be in operation. However, in reality, this rarely occurs. Hence, the system with the lowest E(N) is chosen, since this represents the most efficient application of funds as compared with the other systems, although within a given system, it may not necessarily be the most efficient.

If replacement is to be considered, the values of $E(r_o)$ may be compared. The system with the least $E(r_o)$ has a replacement scheme whereby the most efficient utilization of funds is made. Whenever the value of v is less than one, the optimum replacement interval is r_o.

Otherwise, the optimum replacement scheme is determined from computing P(N) for various intervals. That set of intervals, not necessarily equal, which yields the least value for P(N) is the optimum method of replacement.

SECTION IV

LIMITATIONS IN APPLICATION

While the index is designed for general application, there are limitations which restrict its use. In using the index, an assumption is made that the influencing factors are both relatively constant and equally applicable with respect to the total inventory of programs. This in effect assumes peacetime conditions where economic resources devoted to military defense is limited. Furthermore, in this connection it is assumed that priorities are not going to change to such an extent that cost is of no concern.

Second, the cost estimate upon which the computed index is based must be reasonably accurate. Although it is unrealistic and arbitrary to set a bound on the accuracy, it is, however, pointed out that if the inaccuracies in the life-cycle cost estimates can cause the indicies for two or more systems to change in their relative order, little or no confidence exists in the comparison made. Thus, indicies should be computed for the bounds on the annual cost estimate as well as for the point estimate. If the relative cost effectiveness of the system as indicated by the index is preserved, confidence in the selection of the most effective system is increased.

A third limitation is inherent in the rates which comprise the rate i at which the present equivalent cost is computed. These factors, brought together in equation (1), may not always be applicable or inclusive. Depending upon the nature of the system and the analyst's viewpoint, the various rates may be either deleted or substituted by rates governed by other concepts. For example, if one were strictly interested in discounting, the value of i of equation (1) would be the interest rate. Furthermore, the growth rate of revenue may be significantly different than that of the GNP at the time of the study. In this case i_g would assume a value more reflective of the growth in the revenue.

Lastly, a limitation exists in the conversion of P(r) to fixed annual payments. When the present equivalent cost is converted to a fixed annual payment by equation (3) the index used to measure cost effectiveness is defined. This process is based upon a rate q. In comparing several systems, each system is measured in relation to this arbitrary unit. Consequently, an identical value of q must be used for each system being appraised.

SECTION VII

CONCLUSION

The fixed annual charge E(N) for the present equivalent cost may be used as a basis for computing the cost effectiveness of various competing systems. This index is a yardstick which offers the advantage of combining life-cycle cost, cost effective lifespan, expenditure chronology, system phase-in structure, and the present equivalent cost of money to be expended. Reflected in the index are assumptions concerning cost of borrowing money, inflation, gross national product, technological risk, and others as may be inherent in the system-those factors which contribute to cost escalation and growth of principal.

The index provides a vehicle for exploring the consequences of reasonable assumptions about the systems in question. Use of this index permits one to combine these assumptions in terms of a rate which is peculiar to the system and the time period during which the system is to operate. Because of this, the index reduces the subjectiveness inherent in utilizing an arbitrary discount value which neither properly considers the net effect of the various influencing factors nor reflects the characteristics of a given system.

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13. ABSTRACT

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