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SOME PROBLEMS IN COST ANALYSIS

J. G. Abert

June 1965

INSTITUTE FOR DEFENSE ANALYSES
RESEARCH AND ENGINEERING SUPPORT DIVISION

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CONTENTS

I. INTRODUCTION

The selection of a proper costing approach can cause considerable controversy during the early stages of cost-effectiveness studies. Ultimately, however, the success of the study may well depend on finding the right costing approach for the problem. In this paper various aspects of costing methodology are discussed. The introductory sections deal with some general aspects of the subject, particularly assumptions regarding time-phasing, cost-effectiveness measures, and peacetime and wartime costs. The latter sections of the paper describe the use of discounting as a means of evaluating future resource allocations.

The three basic types of cost-effectiveness studies are: (1) those that deal with systems design, (2) those that compare weapons systems, and (3) those that analyze force level questions. This paper deals, for the most part, with the second type.

As it is generally understood, cost-effectiveness analysis is a tool of the decision maker with which he attempts to compare the effectiveness, however measured, and the associated costs in terms of dollars, of two or more alternative future resource commitments in order to determine which is the most efficient means of satisfying a given requirement. In this context a system is most efficient when it gives more units of effectiveness for a given dollar, or if it means less cost per unit of effectiveness. In the first case the criterion by which efficiency is measured is maximum capability, that is, to select the system that maximizes effectiveness for a given dollar outlay. In the second case, the criterion for the most efficient system is minimum cost, that is, to select the system that produces a certain capability for the least expenditure. It should be emphasized that the purpose of cost-effectiveness analysis is to evaluate and to compare, and it is also significant that this comparison is undertaken to decide on future commitments.

In defense analyses, costs are usually called program costs. For new systems, as differentiated from old systems, program costs consist of initial investment, including research and development costs, plus some years of operating expenditures. In the case of old systems, however, initial investment costs are not counted since the equipment is already on hand. Expenditures of this type are considered to be "sunk." Sunk costs are defined as resource commitments that have been made in the past, the initial costs of which, because they do not represent alternative future resource allocations, can no longer be controlled by the decision maker. Thus in the case of old systems, only operating costs are used in computing program costs.

The effectiveness provided by the program expenditures of a system can be called "potential wartime effectiveness." Potential wartime effectiveness measures the capability provided by the system in the event of war and not merely the effectiveness exercised in peacetime during routine operations or maneuvers. The full meaning of potential wartime effectiveness is discussed later. One should note especially that both program costs and potential wartime effectiveness have time dimensions, that is, both begin at some point in time and extend for a number of years, called the program length.

II. TIME PHASING IN COST-EFFECTIVENESS ANALYSIS

The time phasing of costs and effectiveness can be characterized by regarding the time-phased costs of a system as a stream of dollars and the time-phased potential wartime effectiveness as, for example, a stream of potential sorties per day which are available if a war occurs any time during the program. Such streams generally expand or contract in time. For example, the potential wartime effectiveness provided by a system usually increases during the first few years of system implementation, then levels off, and finally primarily because of technological obsolesence begins to fall. Costs, on the other hand, usually reach a peak when a new system is initially procured after which they remain relatively constant at some level of annual operation and maintenance expenditure. The fact that both costs and potential wartime effectiveness are streams whose profiles may change over the length of the program has important implications which are sometimes overlooked. The focus of this section of the paper is on the importance of time-phasing in the design of cost-effectiveness studies.

The objective of cost-effectiveness analyses of the type described here is to compare overtime the streams of effectiveness and the streams of associated costs for two or more weapons systems. For example, if system A and system B are to be compared, system A's effectiveness over a program length of five years can be represented by EA_1, EA_2, EA_3, EA_4, and EA_5. The associated costs of system A can be written as CA_1, CA_2, CA_3, CA_4, and CA_5. Likewise system B's effectiveness stream is EB_1, EB_2, EB_3, EB_4, and EB_5, and B's costs are CB_1, CB_2, CB_3, CB_4, and CB_5. A simplified cost-effectiveness approach could show only the four cost and effectiveness profiles. However, the approach tells little about the relative efficiency of the two systems.

The first step in refining the analysis is to collapse either the cost or the effectiveness stream into single estimates which represent the evaluation and summation of the annual increments of effectiveness or costs. If, for example, the costs streams can be collapsed into single cost coefficients $\overline{CA}_0$ and $\overline{CB}_0$ then it is possible for expenditures on one system or the other to be increased or decreased until $\overline{CA}_0$ equals $\overline{CB}_0$. After the effectiveness profiles of the two systems have been adjusted for these expenditure changes, the analyst is able to present the decision maker with what can be called "equal cost" effectiveness profiles. The decision maker can then choose from among the different effectiveness streams the one he prefers for an equal program cost.

Alternatively the effectiveness profiles could be collapsed into $\overline{EA}_0$ and $\overline{EB}_0$ after which $\overline{EA}_0$ could be made equal to $\overline{EB}_0$ by varying system expenditures.* In this manner the analyst can show the cost implications of "equal effectiveness" systems.

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* Such comparisons place an extreme burden on the ability of the analyst to measure effectiveness. Such factors as rate of fire, ease of mobility, logistic requirements, and surge capability, which for the most part deal with the time dimension, are difficult to quantify, particularly when one is comparing the effectiveness of dissimilar systems.

Finally the analysis can be further refined if both costs and effectiveness are collapsed into summary estimates of the cost and effectiveness streams. In this case, the relative desirability of one system over another can be shown in terms of ratios. These ratios $\frac{\overline{EA}_0}{\overline{CA}_0}$ and $\frac{\overline{EB}_0}{\overline{CB}_0}$ or their inverse $\frac{\overline{CA}_0}{\overline{EA}_0}$ and $\frac{\overline{CB}_0}{\overline{EB}_0}$ measure system's efficiency.

The first ratio can be called the effectiveness-cost ratio and the second the cost-effectiveness ratio. The first shows the number of units of effectiveness, however measured, provided per unit of cost and the second the cost per unit of effectiveness.

Normalizing the cost or effectiveness denominators, depending on the ratio used, results in a return to one or the other of the two basic approaches to cost-effectiveness analysis - the equal cost approach and the equal effectiveness approach. This is the case even though neither the cost profiles of system A and B nor their effectiveness profiles were necessarily equal prior to the normalization.

The above example illustrates the fact that both costs and effectiveness vary with time and that this must be taken into account in computing the efficiency of a system. For example, in the basic type of equal effectiveness comparison, the relative potential effectiveness used to compare systems must be valid for each and every year of the program. This does not mean that the general level of effectiveness cannot increase or decrease in time, only that both systems must increase or decrease together so that the relative effectiveness, which, together with the system's costs determines whether one system is more efficient than another, remains equal.

Put simply, it is not appropriate to compare the cost and effectiveness of two systems when one system has maintained a particular level of capability over all the years of the program, while the other has only built up to equal effectiveness in the last year of the program. Unless effectiveness is adjusted, the second system has a clear-cut advantage. The program costs of the first are almost always higher than the program costs of the second, simply because the first system provides capability for a greater number of years.

The peacetime cost approach is similar to the purchasing of an insurance policy. The initial procurement and annual operating expenditures represent the cost of premiums, the coverage of the policy represents the potential wartime effectiveness of the system. There is a similarity between the comparing of insurace policies and the comparing of systems, and the similarity shows why it is important that the effectiveness ratios be valid for each year of a system comparison. Because the coverage offered by an insurance policy is usually the same for the life of the policy, similarly, each weapons system being compared should have the same relative system effectiveness during the life of the program. If the coverage offered by two insurance policies differed, or if the effectiveness of the two systems were not the same, then from a cost-effectiveness standpoint, the comparison of the two policies, and similarly the comparison of competitive weapons systems, would not be valid. Indeed, the reason the cost of one system, or the cost of one of the policies, may be less than that of another system or policy is probably that the coverage is less.

Clearly, in order to compare systems, at the second level of refinement shown above, either cost or effectiveness must be equal; otherwise, no valid comparison can be made. Fortunately, in the case of the cost stream, even though costs are measured at different times in the future, they can be weighted and summed, i.e., a measurement of time preference is available which allows the annual increments of costs to be added. The technique is known as discounting. In order to discount costs, the analyst weights future expenditures according to the time preference of the economy for command over resources in the near fut versus command over resources at some later date. This time preference is expressed by the rate of interest that must be paid on borrowed funds.* Such funds allow one to obtain command over resources now rather than at some future time.

Unfortunately, it is difficult to evaluate the time-phased effectiveness profiles of competing systems to determine whether one profile is the equivalent of another, because it is virtually impossible to determine the relative worth of effectiveness available in the near future to that of effectiveness available at a later date.** The difference in military value between potential effectiveness at one point in time and potential effectiveness at another point is only measurable in view of the preference of the decision makers, i.e., their judgment of the weights which would be assigned to effectiveness available at different times. Unfortunately, the preference for military effectiveness whether earlier or later, varies depending upon the decision maker. For this reason, there is no readily apparent way to weight and then add the potential wartime effectiveness provided in one year to the potential wartime effectiveness provided in another year to get a total for two years taken together. Thus, it is not possible to arrive at an agreed upon single number which represents, for instance, the potential wartime effectiveness of a particular system summed according to some weighting system over all the years covered by the program. Because of this the stream of effectiveness can not be evaluated in the same manner as the stream of costs.

The easiest way out of this difficulty is to construct equal effectiveness profiles for the two systems and to let the costs vary. In this way, one avoids the problem of comparing systems with dissimilar time-phased effectiveness profiles by making the profiles the same. For example, if EA is the effectiveness of system B, and the subscripts 1, 2, etc., represent the period for which the comparison is made, then EA_1 should equal EB_1 and EA_2 should equal EB_2, etc. One should note that it is not necessary that $EA_1 = EB_1 = EA_2 = EB_2$, etc., only that the relative effectiveness of the two systems be equal in each time period. If the effectiveness profiles are constructed to meet the above requirements and the cost streams discounted then both effectiveness

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* The function used to evaluate the annual increments of costs is negative exponential. The weight assigned to year one is $1/(1+r)$, to year two $1/(1+r)^2$, to year three $1/(1+r)^3$, etc., where r is the current rate of interest. In this manner the weighted costs of each year are evaluated and summed to arrive at a single cost coefficient called the program cost of the system. See Sec. X.

** For example, which would be preferred, a system which transports 50 ton/miles per day now but none next year, or one which produces no transport capability now but 60 ton/miles per day a year hence?

and costs are reduced to single numbers.* If equal-effectiveness profiles cannot be constructed, then the analyst should use the equal-cost approach. Since effectiveness is not the same in each year, the stream of effectiveness of each system is then shown along with the discounted costs; then, as mentioned before, the decision maker chooses from among the different effectiveness profiles the one he prefers for an equal program cost.

In summary, there are problems caused by the fact that the peacetime cost stream and potential wartime effectiveness stream both cover a span of time. While it is possible to compute the time-phased costs into a single point estimate called the program cost of the system, it is generally not possible to compute a single point estimate for effectiveness.

*Even though discounting reduces costs to a single cost coefficient (the program costs referred to above), there are times when it is useful and necessary to know the scheduling of budget authorizations over the years covered in the cost-effectiveness study to provide an indication of annual demands on the budget and show the peaks of authorizations and the peaks of expenditures.

III. RESOURCE ALLOCATION BY THE DEPARTMENT OF DEFENSE

Fundamentally, the objective of cost-effectiveness analysis is the aid the Department of Defense in optimizing the use of the resources available to it for national security. The cost-effectiveness approach assumes that peactime allocation of resource can be accomplished on the basis of prices paid by the Department of Defense for its share of the total resources available to the economy. Prices are used to insure efficient allocation of resources because in peacetime prices reflect the value to the economy as a whole of the resources channeled to the defense effort.

In peacetime, the Department of Defense must compete with other claimants, both public and private, for a share of the total stock of available resources. Therefore, in peacetime the prices paid by the Department of Defense for goods and services are, for the most part, competitive prices. In general, such prices represent, even if somewhat imperfectly, the cost of diverting resources from one use to another, because the resources used for defense would have been used to produce something else of value if some other sector of the economy had been willing to pay a higher price.

The main task of the Department of Defense consists of making the most efficient use, where efficiency is measured in terms of military capability, of such resources as the defense budget can provide. Efficient use of resources is realized when each and every requirement is satisifed at the least possible cost consistent with desired performance, or when for a given budget the greatest military capability is developed. These objectives are the same as those of the two criterion of cost-effectiveness analyses discussed earlier.

IV. THE RELEVANT COSTS

It goes without saying that the costs which are used to compare alternative systems must be appropriate to and consistent with the specific objectives of the study. It is surprising, however, how little attention has been paid to costing methodology and to the selection of relevant costs. It appears that the main problem has been caused by a failure to define explicitly the overall context in which costs are to be calculated: specifically, resource allocation in a major-war context, or a peacetime (or limited war) context.

A major war is defined as a military action of a magnitude which disrupts the normal economic life of the country. Implicit in most cost-effectiveness studies if they measure costs in terms of dollars is the basic assumption that the probability of such war is low. However in this case the relevant costs are only the peacetime dollar costs of the systems being compared and not the estimated wartime costs. This is a valid approach because in peacetime, prices are adequate guides to resource allocation. Such is not the case, as will be discussed later, for wartime costs. The relevant costs, therefore, are the dollar costs incurred in providing the resources necessary to achieve and to maintain a given level of potential wartime effectiveness. The dollar costs of replacing units in the event of war should not be used in the system comparison. The efficiency of a system should be computed as a function of peacetime costs and of potential wartime effectiveness, i.e., effectiveness that is available and on hand when and if it is needed. The only costs that are relevant in the context of peacetime resource allocation are the dollar expended in building up the necessary wartime effectiveness.

V. THE IRRELEVANCY OF WARTIME COSTS

Anticipated or estimated wartime dollar costs are not relevant to cost-effectiveness analysis regardless of whether the probability of war is felt to be high or low. If the assumption is accepted that the probability of war is low, then the probability of incurring wartime costs is also low, and only peacetime costs are relevant in deciding whether to procure and deploy one system or another.

Even when the probability of a major conflict is high, decisions should not be based on wartime prices, i.e., replacement costs, a very simple reason is that it is almost impossible to estimate what prices would be if a war occurred. Wartime prices depend in great part on when the war starts, and on whether the production line will still be in operation at the time the war starts. Even if a war does occur, however, the amount of replacement that will be necessary, i.e., the length and magnitude of the war, is unknown. Finally, the residual value of the system after the war is unknown. All these factors would have to be known with some certainty in order to estimate the best of replacement in wartime. One would also have to consider the possibility that expanded units might not be replaced with similar units, but that a follow-on system or even an entirely different system might be needed as a replacement.

If the probability of war is high, then the rules for estimating system's costs change. Replacement costs become a major factor. However, the resource allocation should be done in terms of physical constraints and not dollars. This is because during wartime it can be expected that the regular production and distribution processes of the economy will be disrupted to the extent that prices, no matter how well estimated, would reveal little about the value of the war effort of alternative uses of the available resources. On the one hand, during wartime, the government usually abandons the budget as a constraint on the amount of resources that can be channeled to the war effort. Dollars, then, are not necessarily a scarce resource either to the Department of Defense or to the economy as a whole. On the other hand, even if dollars were relatively scarce, resources would not likely be constrained. In wartime, constraints on resources for providing military capability --bottlenecks as they are called--would probably be caused first by shortages of physical resources such as trained manpower, raw materials, transportation, and logistic facilities before a shortage of dollars would take effect.

An additional reason why costing a wartime system in terms of dollar costs is not appropriate and why wartime prices should not be used for resource allocation is that direct controls or other restrictions are generally imposed on the use of critical items such as raw materials, machinery and machine tools, as well as on the ability of labor to move from job to job. Restrictions such as these mean that the price paid for these resources do not reflect their true opportunity costs simply because these resources are not free to respond to the price movements which reflect the demand for their use. Moreover, wartime prices are usually manipulated, either directly by means of price-fixing, or indirectly by means of rationing. Thus wartime prices do not reflect relative scarcities, and therefore the minimization of wartime dollar costs as a guide to system selection does not adequately take into account the value to the war effort of the alternative uses of the available resources. For this reason, basing wartime resource allocation on wartime dollar costs does not insure efficient military decisions.

If the probability of a major war is felt to be high, then, even in peacetime, defense systems should be chosen which tend to minimize directly the wartime call on those resources which have in the past proven to be wartime bottlenecks. This minimization should not be accomplished through the proxy of minimizing dollar costs. To adequately take into account wartime resource bottlenecks, it would be necessary to undertake studies to determine the probable availability during wartime of such resources as raw materials, skilled labor, and transportation facilities. When the objective of the decision maker is to provide a peacetime military capability, i.e., potential wartime effectiveness (the case when it is assumed that there is a low probability of war), the correct procedure is to minimize peacetime costs. The inclusion of wartine costs merely serves to dilute the effect of differences between the relevant peacetime costs of the system being evaluated, thus, introducing fallacious and misleading criteria into the decision-making function.

Peacetime costs include a certain level of system inventory. For the purpose of cost effectiveness analysis, this level should be limited to the units actually contemplated for procurement, that is, the units whose potential effectiveness is being measured. Costs should not include replacement units which it may be necessary to procure during a war. The costs of replacement units during war are irrelevant. The decision maker is not concerned with the relative cheapness of units which may or may not be procured or, if procured, may or may not reach the combat area. The objective of the decision maker is to maintain efficiently a given level of capability which would be available in the event of war. His objective is not to minimize the cost of resupply, or, as is the case in some studies, to restore a force to its prewar level. In actual fact, the need to restore a force to its prewar level represents a contingency with an even lower probability than that of having a war. Thus, wartime production costs in dollars, sometimes called replacement costs, should not be considered in cost-effectiveness studies of the type described here.

In summary, peacetime costs take into account the value in peacetime of resources in alternative uses, i.e., the relative scarcity of the resources used for defense, because these resources must be procured by the Department of Defense at prices set by a competitive peacetime market. Therefore, peacetime costs should be used in evaluating alternative resource allocations when the probability of war is considered to be low. On the other hand, when the probability of war is felt to be high, the minimization of the wartime call on critical physical resources should be used as criteria for choosing between alternative systems. In the wartime context; systems should not be chosen which minimize either peacetime dollar costs or wartime dollar costs, for neither has any necessary validity for judgments about the feasibility of sustaining and reinforcing the nation's military forces during a wartime situation.

VI. INVENTORY AND LOGISTICS PROBLEMS

Analyzing weapons systems on the basis of potential wartime effectiveness increase the importance of the assumptions made about the size and distribution of force and theater inventories. The potential wartime effectiveness of the system is directly dependent on available stocks. It should be emphasized that only those units likely to be available at the point of contact with the enemy should be considered.

From a cost standpoint, increasing the availability usually means more than merely increasing the total buy. In addition to the time phasing of the additional buy, storage and transport costs must also be considered. These other costs are not reflected in the cost-quantity relationships that are generally used to show the cost of increasing the force levels, and as a result, costs and effectiveness are often mismatched.

The error of mismatching costs and effectiveness often occurs when a study shows that one system is more effective than another because of what might be called the preferred system's surge capability, e.g., its ability to deliver large amounts of ordnance in short periods of time and thus to meet, what in the next section are called peak simultaneous requirements. The surge capability is often costed by simply moving out the cost-quantity curves which show the unit price of expendable ordnance for the system with little regard for the investment in delivery vehicles, transport, and manpower which might be necessary to effect such a surge. However, the cost of additional ordnance does not constitute the total cost of the surge capability. For example, if the decision to procure the system is based on the efficiency of the system in this surge situation, the independent capability to surge results from the logistic reality that when one system is surging, other systems are also probably extended to their maximum capacity and therefore will not be able to provide, for example, transport if such assistance is necessary to maintain the surge capability. It would not be correct, therefore, to decide on a system because of its surge capability, unless total costs are considered in the early phase of a war. For example, if the surge capability is needed in Europe, there must be a sufficient inventory and logistic support in Europe and it must be costed to determine the surge cost of the system. If the inventory is not in the European theater, then there must be sufficient airlift to fly the ordnance from CONUS to Europe, and this, too, must be costed. The important point to note is that the situations for which effectiveness and costs are calculated must be consistent.

VII. SEQUENTIAL AND SIMULTANEOUS REQUIREMENTS

Whether or not requirements are sequential or simultaneous has a direct bearing on the number of units that must be provided in peacetime in order to provide an adequate wartime capability. Clearly, it is difficult to define "adequate wartime capability" because such a definition assumes that one can estimate the peak simultaneous requirement for any one system, the expected sequential utilization of resources, and the order in which these sequential demands are expected to occur. Unfortunately, all these factors are prerequisites for determining whether the addition of another requirement will generate a need for additional units of the system.

It is particularly important to be able to determine the peak simultaneous requirement for systems that are subject to relatively low time-capability constraints. A low time-capability constraint can best be described as the opposite of a surge capability. Aircraft afford a typical example. Aircraft are generally considered to be limited to less than three sorties per day, and therefore, the difference in costs between a sequential requirement and a simultaneous requirement is high. For example, the least expensive way to accomplish an expected sequential wartime requirement for 50 sorties with a constraint of two sorties per day would be to use only one aircraft and to extend the mission to 25 days. The cost implication in terms of program costs for providing a potential wartime effectiveness for such a capability is that in peacetime only one aircraft need be procured and operated. A simultaneous requirement for 50 sorties with a constraint of two sorties per day per aircraft would mean that 25 aircraft would have to be procured and maintained.

The obvious implication, from a force-structure and cost standpoint, is that systems with high time-capabilities, i.e., surge capacities, should be substituted for systems with low time-capabilities, such as aircraft, in order to meet expected peak simultaneous wartime requirements. However, in such a case it is important that the system be able, in fact, to surge. Therefore, the actual logistic and deployment plans for the system must be consistent with its expected utilization.

A further factor in the sequential problem concerns the length of a war.* The length of the war determines how much of a particular system must be procured and operated (or stored) in peacetime in order to sustain the anticipated level of combat until additional capability can be produced and delivered. This is an important question for systems such as aircraft which require a relatively

*For the purpose of this discussion, the problem of trade-offs between the size and the length of a war is neglected. It is assumed that the war is of sufficient size to involve the commitment of all available capability.

long lead time even if the system is in production when the war starts. Long lead times can also be anticipated for missile equipment, because missile systems are generally only in production for relatively short periods and, in most cases, would take considerable time to be placed in production again before the first replacement units would be available.

To be absolutely safe, a sufficient supply of each and every system should be in stock to last (at some assumed sequential utilization rate) from D-day to the date the first replacement unit would be available. This "D-Day to Production Day" philosophy requires that tremendous amounts of resources must be committed. Generally, the Department of Defense cannot satisfy all D-day to production day requirements.

Interestingly enough, focusing on simultaneous requirements offers a method of reducing D-day to production day requirements by reducing the number of systems that would have to be stocked completely. In order to reduce the number of systems, it is necessary to have dual-purpose systems, i.e., systems that have productivity (effectiveness) in more than one mission. Such dual-purpose systems must be able to satisfy several requirements even if the system is not the most efficient means of satisfying each requirement. For example, aircraft may be the least efficient means in terms of cost-effectiveness of satisfying a ground support requirement if the ground support requirement occurs simultaneously with the requirement for air superiority. In such a circumstance, additional aircraft have to be procured and operated in peacetime in order to have aircraft potentially available for ground support during wartime. These additional aircraft must be paid for completely by the ground support requirement. However, if ground support continues to be a requirement after the initial air superiority peak, and if the air superiority requirement declines at a rate faster than the aircraft attrition rate, aircraft will become available for ground support. These aircraft are available to ground support with no cost since they were procured to meet a peak demand in the air superiority mission.

Because of the availability of free resources, the inventory problem for the system procured to meet the peak simultaneous requirement can be truncated. For example, if missiles prove to be more efficient than aircraft from a cost-effectiveness standpoint to handle a short peak simultaneous requirement for ground support and air superiority taken together when aircraft are costed at full cost, but if aircraft became available (free) after their initial surge in the air superiority mission, these aircraft could be used for the sequential ground support requirement, and the missiles used only for the simultaneous requirement. The inventory of missiles could be reduced accordingly.

Analysis may also show that the inventory of systems with low-time capabilities can be reduced in cases where expected peak requirements are short. In the case of aircraft, for example, a five-day peak simultaneous requirement means that the total program cost of each airplane is prorated over only 10 to 15 sorties. If the peak demand for aircraft were expected to last 90 days, the utilization of the aircraft would be such as to prorate the peacetime program costs over 180 to 270 sorties. Thus, the substitution of a system with a surge capability for the aircraft would be feasible in a cost-effectiveness sense.

The argument above is based on the fact that systems are either free, or are costed at 100 percent of program cost. Unless the analyst makes additional assumptions regarding the probability that certain requirements will happen simultaneously, and unless assumptions are made regarding requirement sequencing, there is no logical basis for an intermediate systems cost between zero and 100 percent of total program costs. In the above example, the sequential ground support requirement benefited from the fact that the aircraft were assumed to be procured to meet the air superiority requirement. However, if the ground support requirement were assumed to occur simultaneously with the air superiority requirement, then all aircraft should be costed fully and the fact that the aircraft are reusable, i.e., can be used to satisfy other requirements, should not influence the cost analysis.

VIII. COST-EFFECTIVENESS RATIOS IN COST-EFFECTIVENESS ANALYSIS

Cost-effectiveness ratios such as cost per sorties, cost per round, and cost per kill are often used to compare weapons systems. The first two ratios are usually inputs used to compute the third ratio. Cost per kill is the ratio which shows the relative efficiency, based on an equal effectiveness, of the weapons systems being compared.

Each of the three ratios has a cost numerator, called the program costs. The program costs consist of the sum of investment, where applicable, plus the discounted peacetime operating costs for the length of the program. Included in the investment is the cost of an inventory of ammunition which would be used in the event of war. This ammunition is an expendable cost, as differentiated from a reusable cost. Expendable costs include those of projectiles, power charges, missiles, bombs, etc. Reusable costs include those which are necessary to maintain a potential level of effectiveness but costs not generally expended except for attirtion, for example: artillery tubes and associated support equipment, missile launchers and support equipment, aircraft and ground equipment. Reusable costs also include the annual operating and maintenance costs even though some of these, such as POL and spare parts, are expended during peacetime operations.

In order to compute the cost-effectiveness ratios, reusable costs must be prorated over the expected utilization of the system. In the case of artillery, system utilization is generally determined by the number of projectiles in the inventory or the number of projectiles expected to be fired in the event of war. In the case of aircraft, system utilization is determined by the number of sorties expected from each plane in the event of war. The assumed number of expendable rounds delivered and the assumed utilization of equipment such as aircraft determine the utilization of the reusable component of program costs and thus the amount of this cost that must be prorated for each kill. In simple terms, the computation of cost-effectiveness ratios such as cost per sortie, cost per round, and cost per kill requires that a certain amount of the peacetime investment in reusable equipment and the peacetime operating costs be prorated to each sortie, round, or kill.*

*Unfortunately, in many studies the inventory of expendable units used to compute the cost per kill ratio is often far in excess of reasonable expectations of the amount of potential wartime effectiveness likely to be available. For example, a study may purport to show that the decision maker should procure a 7000-missile inventory on the basis of an analysis which shows that the proposed missile system has the lowest cost per kill ratio among the competing systems when reusable costs are prorated over the projected firing of 300,000 missiles. Clearly, if the potential wartime effectiveness of the system is going to be limited to 7000 missiles, then the cost should also be related to 7000 missiles and not to 300,000.

The proration of peacetime costs, and thus the relative desirability of one system over another is very sensitive to the assumed level of wartime utilization. For example, doubling the number of sorties assumed to be obtained during the war from each aircraft in the initial inventory halves the cost per sortie of the aircraft as a delivery vehicle. The lower cost per sortie can be achieved by halving the expected attrition rate or doubling the length of the assumed war, whichever was assumed to be the constraining factor.

As a result, investment in reusable delivery systems becomes more and more advantageous the longer the assumed war or the lower the assumed attrition rate. As the hypothetical war lengthens and more and more rounds are fired, or bombs dropped, delivery costs per target fall while ammunition (expendable) costs per target stay relatively constant[1].

Taken apart from the hypothesized system utilization, however, cost-effectiveness ratios shed little light on the relative merits of the competing systems. For decision making purposes, such cost-effectiveness ratios are valid only if a war of the intensity and duration of that hypothesized occurs, and if the expected system utilization actually takes place.

In addition, each such ratio generally pertains only to a particular type of target taken in the larger context of a target mix representing the supposed length and intensity of the war, or perhaps to a summary ratio showing the efficiency of each system against a target mix. The latter are used because there are generally many different types of targets against which the systems being compared have some level of effectiveness. Thus target mixes project some realism into the study and, in fact, are often necessary since there are usually not enough targets of any one type to utilize the total system capability.

A word of caution, however: The selection of the expected target mix can in fact determine relative system desirability when no one system is completely dominant. That is, when no one system is the most efficient means of defeating each and every target. In the latter case the selection of the target mix can drive the output of the analysis. Thus, studies which appear on the surface to present a convincing case for one system or another may simply be the result of a judiciously selected target mix. The reader must always keep in mind that comparisons based on subjective decisions as to (1) the level of system utilization on which to base the proration of reusable system costs, and (2) on the relative desirability of one system over another against a target mix, are only valid the level and the mix turn out, in fact, to be correct.

1 See IDA/EPSD Internal Note N-247, J. G. Abert, Ammunition Costs Versus Total System Costs in the Measurement of Relative Systems Efficiency.

IX. DISCOUNTING IN COST-EFFECTIVENESS ANALYSIS

A. COMPUTING DISCOUNTED PROGRAM COSTS

Discounting, as a means for computing program costs, accounts for differences in the time phasing of the cost streams of the weapons systems being evaluated. In other words, discounting is a method of evaluation which allows the analyst to weight and then to sum the stream of costs associated with any weapons system regardless of its time profile. The following sections discuss the method of calculating discounted costs, and show the practical effects of using discounting in cost-effectiveness analysis.

The main purpose of discounting is to enable the analyst to compare the cost streams of systems which have different time-phased cost profiles. If the cost profiles are the same, discounting will have no effect on the relative costs of the systems being compared. Discounting, however, will affect the cost of one system in its relation to that of another system, for example, when one of the systems being compared is new with high initial expenditures and low operating costs and the other system is older and has low initial costs but high operating expenditures. Discounting takes into account the different shapes of these cost streams by referring all future expenditures to a common point in time. Discounting evaluates the time-phased profiles of the cost streams of the systems as if they all occurred at one point in time rather than spaced over the life of the system. In this way, the systems can be compared from a cost standpoint, even though they may have different time-phased cost profiles. In effect, discounting makes it possible to evaluate and to sum, in a logical manner, costs which occur at different points in time.

The general effect of discounting future costs is to lower the impact of expenditures that occur in the future on total program costs.* For example, in the case of the old and new systems mentioned above, if the undiscounted sum of investment plus five-year operating costs for the new and the old systems is the same, and if the life of each system were equal to the program length, the effect of discounting would be to lower the program cost of the old system in relation to the new. Discounting has little effect in the case of the new system since most of the costs are attributed to the initial investment. However, in the case of the old system, a large proportion of the costs are operating costs which occur in the future and are, therefore, discounted.

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* The mathematical formulation of the discounting procedure is given on pages 25-28.

The most important assumption in the discounting process is the rate at which future expenditures are discounted, i.e., the weights that are assigned to future costs. This rate is a function of the interest rate.* The interest rate represents the so-called "time preference" of the community as a whole for present expenditures as opposed to future expenditures. In other words, the interest rate measures the preference of the economy for a dollar, today instead of a dollar tomorrow. Such a preference may be caused by a need to purchase, for example, a new automobile, or by a desire to invest in a potentially rewarding business opportunity. However, if one does not have the money, it is necessary to pay a premium in order to borrow. This premium is called the interest rate. The interest rate reflects the willingness of some people to pay a premium in order to spend money today rather than to wait until tomorrow. It also reflects the willingness of other people to postpone expenditures in order to lend the funds at their disposal and thereby earn additional funds for possible future spending. The rate of interest at which funds are lent is a measure of the "time preference" of the economy for current spending instead of future spending. In slightly different terms, the interest rate also measures the cost of obtaining command over resources--the things money can buy--now rather than in the future.

Although defense spending is done by the government for the nation as a whole, evaluating expenditures for military systems should take into account the preference of the economy for current expenditures, i.e., defense expenditures should be evaluated in the same way that expenditures are evaluated in the private sector.

As mentioned earlier, it would be possible to apply discounting to streams of effectiveness if one could obtain agreement regarding the preference for a unit of effectiveness: for example, effectiveness in the near future, or effectiveness in the more distant future. However, unlike the interest rate, which expresses a preference for a dollar today instead of a dollar tomorrow, there is no universally agreed upon time preference for effectiveness. For example, one is not generally able to measure the preference for a ton/mile today versus a ton/mile tomorrow because of differences in opinion of when a potential ton/mile is, or would be, most valuable. Thus, unlike costs, it is impossible to determine the premium one would be willing to pay for present effectiveness versus future effectiveness. Unlike the weights applied to the cost stream, the analyst does not know the weighting factor nor the shape of the function to be used to discount future effectiveness. The net effect is that it is impossible to add logically the annual increments of the potential wartime effectiveness of a system over each year of the system's life and to collapse the effectiveness stream into a single point estimate as may be done with the cost stream.

*The discount rate is defined as $\frac{1}{(1+r)}$, where r is the interest rate.

Unfortunately, there seems to be some confusion about discounting. Some seem to think that high discount rates applied to the cost stream also take into account the time preference for effectiveness discussed above and the effects of uncertainty about the future effectiveness of military systems. Discounting does not take either into account. Discounting costs does not determine the present value of future effectiveness, secondly, the effects of risk and uncertainty in the system being evaluated - called technological obsolescence - cannot be accounted for by applying a high discount rate to the cost streams of the system.

Technological uncertainty about the future effectiveness of a system because of, for example, improvements in the capability of the enemy to defeat the system, should be taken into account directly in computing the potential wartime effectiveness expected to be provided in each of the program years. In terms of the cost-effectiveness comparison, discounting the cost stream at a high rate of interest to allow for this technological uncertainty has exactly the wrong effect. Whereas the total program costs of an uncertain system should be increasing in relation to the more certain system, because additional units will have to be procurred to maintain any given level of effectiveness, the use of a high discount rate to discount for uncertainty decreases the cost of the less certain system. This is because higher discount rates tend to decrease program costs. Therefore, to show uncertainty about future effectiveness of a system by increasing the discount rate that is applied to the cost stream of a system, biases the cost-effectiveness analysis in favor of that system. The cost-effectiveness analysis therefore, actually favors the system with the greatest likelihood of becoming technologically obsclete.

Some seem to think that one uses a high discount rate to indicate that future costs have less likelihood of being incurred than costs which occur sooner. Such a belief can lead to incorrect decisions regarding weapons system procurement. While high discount rates do in fact tend to lower the program costs of the system with the highest proportion of future expenditures, this should not be interpreted as signifying that these expenditures may not be made. Experience shows that when procurement of a system has begun, the tendency is to remain with the system with whatever modification in expenditures is necessary to maintain its effectiveness against the enemy.

The important point is that discounting of the cost stream is an economic evaluation of future expenditures as opposed to current ones; it is not an estimate of uncertainty regarding performance of the system, nor is it an estimate of the likelihood that the expendutures will be made.

B. DISCOUNTING AS A MEANS OF EVALUATING ALTERNATIVE RESOURCE ALLOCATIONS

The discounting of costs relates directly to the economic evaluation of alternative systems with different time-phased cost profiles. Indirectly, however, discounting reflects the alternative non-defense use of the resources which would be used to manufacture and operate the competing weapon system. Although these resources are measured in dollars, the dollars themselves are not the resources in question. Dollars simply represent the means by which the value of the materials and labor used in the manufacture of defense or other final products is measured. The value of these resources is set by the economy as a whole, or in less general terms, by the sector likely to use the resources channeled into defense. Therefore, the rate used to discount costs should reflect the time preference, including risk and uncertainty, for resources today as opposed to resources in the future, of the most likely potential alternative users of the resources consumed by defense.

A case can be made that the most likely alternative users of resources consumed by defense are in the corporate sector of the economy. In that case, interest rates of 10 percent, corresponding to the pre-tax internal rate of return on corporate investment, have been used in many studies. A rate of ten percent approximates the time preference for current resources as opposed to future resources in the corporate section of the economy. This rate takes into account the risk and uncertainty associated with corporate investment.

In terms of resource allocation, other things being equal, it is usually better to postpone the diverting of resources from their alternative uses in the rest of the economy to their use for defense. This does not mean that one should spend nothing on defense, nor does it indicate how much should be spent. It simply states that if one has a choice between two military systems that promise equal effectiveness over some range of future years, one should prefer the system that postpones for the longest time the diversion of resources. The extent of this preference depends on the rate of return that the resources earmarked for equipping and operating the military systems are assumed to be able to earn if they were allowed to seek alternative employment elsewhere in the economy. The higher the assumed rate of return, the more advantageous it is to postpone diverting resources to defense in order that they may be employed elsewhere. Postponing the utilization of resources for defense means that the resources can be used to increase the total future stock of resources available to the economy.

In essence, the diversion of resources to the defense effort is assumed to represent a sacrifice of future resource growth. The practical result is that if resources are assumed to be able to earn a high rate of return elsewhere it is difficult to justify the procurement of new systems. This difficulty results because of the large initial impact on total program costs of the investment costs associated with new procurement. Higher discount rates tend to favor the retention of old systems, because maintenance and operating costs, although they may be higher than in the case of new systems, are not concentrated at the beginning of the period but are spread out over the entire period.* Because discounting favors postponed expenditures, the maintenance and operating

*While it is true that initial investment, particularly R&D expenditures, are also spread out over a number of years, these costs are generally incurred prior to the start of the program, i.e., prior to the date that the system begins to provide potential effectiveness. The value of these expenditures as of the start of the program can easily be computed using the discounting procedure in reverse.

costs have a smaller impact on total program costs than do expenditures for the initial procurement of a new system.* If, for example, two systems, one old and one new, each having equal effectiveness and equal undiscounted program costs,** the discounted total program cost for the old system will generally be less than the discounted total program cost of the new system. The result is not a mathematical trick; the lower cost for the system with the postponed expenditures simply reflects the fact that some amount of resources were left free for other employment. The total cost of such a system is reduced because the resources which were not required for the initial use of the system are assumed to increase the total stock of resources available to meet future resource commitments. This point can be emphasized by noting the similarity between the case of defense resources and the case of money deposited in the bank to meet future financial obligations. The impact of a given expenditure on a consumer's budget is less if he postpones his expenditure in order to allow his savings to earn interest. This course puts him in a better position to spend in the future.

In summary, from the standpoint of resource impact on the economy, the total cost of a system with postponed expenditures is less than that of a system with large initial expenditures. Some costing approaches simply add the initial investment in a system to its operating costs over a number of years. This approach does not take into account time phasing. Discounting, however, by estimating the difference between an expenditure today and an expenditure tomorrow, reflects the time phased economic impact of a system.

C. CALCULATING RESOURCE IMPACT BY MEANS OF DISCOUNTING

The cost-effectiveness approach calls for the evaluation of the streams of costs and the streams of effectiveness of two or more weapons systems in order to compare the relative efficiency of the systems in fulfilling a given set of military requirements. Unfortunately, as shown earlier, effectiveness is usually non-additive, i.e., the analyst cannot weigh the relative value of a unit of effectiveness-today and a unit of effectiveness-tomorrow. Time preference for effectiveness-today as opposed to effectiveness-tomorrow varies, and unlike the preference for a dollar-today instead of a dollar-tomorrow, there is no market from which to obtain a time-preference schedule for effectiveness. Costs however, can be discounted.

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* When costs are computed over a relatively short segment of a system with a relatively long assumed useful life and when allowance is made for the remaining useful life at the end of the program, this statement may be reversed. See IDA/EPSD Internal Note N-246, Martha Strayhorn, Sensitivity of Total Systems Cost To Alternative Assumptions.

** The undiscounted program is the simple sum of investment and some years of operating and maintenance expenditures.

Discounting is a tool of the analyst; like any other took, discounting requires certain input assumptions which must be supplied by the decision maker:

(1) An assumed rate of interest;

(2) The length of the program over which the systems are to be compared;

(3) The initial investment cost and the expected value (estimated remaining useful life of a system) at the end of the program.

(4) The annual operating costs.

In most practical applications of discounting, future expenditures are evaluated in terms of their present values. This means that each future expenditure is evaluated as if the expenditure occurred today rather than at some future date. By this means, the stream of costs associated with, for example, a weapons system is collapsed into a single point estimate. This single point estimate is called the present value of the stream of costs associated with the weapons system. Present value represents the amount Y_o which would have to be set aside at an assumed rate of return r to be worth Y_t at the time the future expenditure comes due. This is expressed by the standard compound interest formula,

$$Y_o(1+r)^t = Y_t$$

or

$$Y_o = \frac{Y_t}{(1+r)^t} \qquad (1)$$

Equation 1 is used in the sections which follow.

D. CALCULATING THE RESOURCE IMPACT OF INVESTMENT EXPENDITURES

The earlier sections of this paper have discussed how the diversion of dollars to defense represents a loss of potential resource growth. Thus, one can say that an investment of I dollars in defense in time period zero represents a loss of potential resource growth of Ir for each year of the life of the system. (The resource invested I times the annual rate of return r.) However, since some of these losses do not occur until future time periods and because one wants to evaluate all expenditures as if they occurred at a common point in time, one must recompute these future costs. To do this one must find the present value of each future resource sacrifice. The present value is the cost to the economy of having the resources represented by I tied up in defense. The total resource loss is the sum of the present values of $I_1r + I_2r + \ldots + I_tr$. The subscripts refer to time. Equation 1 shows that the present value of any I_ir is $\frac{I_ir}{(1+r)^i}$. Therefore, the sum (designated by the symbol Σ) of the present values of the sacrificed resource growth is,

$$Ir \sum_{i=1}^{t} \frac{1}{(1+r)^i} \qquad (2)$$

where i takes values 1 thru t.

Equation 2 represents only one component of the economic costs of investment in defense systems and takes into account only the fact that the diversion of I dollars to defense entails a sacrifice of resource growth. In addition to the growth sacrifice, there may also be a determination of the resources tied up in the system due to use obsolescence.* Suppose obsolescence takes place at a rate k per year. Thus, each year kI dollars of resources are lost, and at the end of t years, the investment has lost ktI dollars in value. Again, since this loss occurs in the future one must find the present value of the resource depreciation. Equation 1 shows that the present value of the resource loss is

$$\frac{tkI}{(1 + r)^t} \quad . \tag{3}$$

Adding the cost of sacrificed resource growth, Eq. 2, to the cost of the lost resources, Eq. 3, the present value of the total economic costs $\bar{I}_o$ associated with I dollars worth of resources invested in a military system is

$$\bar{I}_o = \left[Ir \sum_{i=1}^{t} \frac{1}{(1 + r)^i} \right] + \left[\frac{tkI}{(1 + r)^t} \right] \tag{4}$$

E. CALCULATING THE RESOURCE IMPACT OF OPERATING COSTS

Operating costs are given as A dollars per year. For simplicity, A can be assumed to be a constant. However, if A is in fact a constant, the effect of discounting is considerably reduced. Generally, discounting will have a major effect on the relative costs of the system being compared (1) if the relative operating costs rise or fall over time, and (2) if the investment-to-operating cost ratios of the system are different.**

A basic assumption concerning operating costs is that the resources necessary for the operation of a system are withdrawn from the economy at the beginning of each time period i. The total amount withdrawn is further assumed to be consumed by the end of each time period. Thus, the present value of the sacrifice in resource growth due to operating costs can be represented by the following series:

* This represents the market's evaluation of the remaining useful life of the system at time t.

** See IDA/EPSD Internal Note N-246, Martha Strayhorn, Sensitivity of Total Systems Costs to Alternative Assumptions.

$$\frac{Ar}{(1+r)} + \frac{Ar}{(1+r)^2} \cdots + \frac{Ar}{(1+r)^t}, \text{ or } Ar\sum_{i=1}^{t} \frac{1}{(1+r)^i}, \tag{5}$$

The present value of the cost of the resources consumed is given as

$$\frac{A}{(1+r)^1} + \frac{A}{(1+r)^2} + \cdots + \frac{A}{(1+r)^t}, \text{ or } A\sum_{i=1}^{t} \frac{1}{(1+r)^i} \tag{6}$$

Thus, the present value of the annual expenditures for system operation $\bar{A}_0$ is given as Eq. 5 and Eq. 6.

$$\bar{A}_o = Ar\sum_{i=1}^{t} \frac{1}{(1+r)^i} + A\sum_{i=1}^{t} \frac{1}{(1+r)^i}$$

or

$$\bar{A}_o = A\sum_{i=1}^{t} \frac{1}{(1+r)^{i-1}} \tag{7}$$

The present value of the total costs of a system with I dollars of initial investment cost and A dollars of annual operating costs is the sum of Eq. 4 and Eq. 7. Thus, the present value of the stream of costs $\bar{I}_0 + \bar{A}_0$ is

$$Ir\sum_{i=1}^{t} \frac{1}{(1+r)^i} + \frac{tkI}{(1+r)^i} + A\sum_{i=1}^{t} \frac{1}{(1+r)^{i-1}} \tag{8}$$

For purposes of computation the expressions for $\bar{I}_o$ and $\bar{A}_o$ can be reduced to,

$$\bar{I}_o = I - \frac{(1-tk)\,I}{(1+r)^t}$$

and

$$\bar{A}_o = A\left[\frac{\frac{1-1}{(1+r)}^{\,t-1}}{r}\right] + A, \text{ or } \bar{A}_o = A\left[\frac{1-\frac{1}{(1+r)}^{\,t}}{1-\frac{1}{(1+r)}}\right]$$

X. SUMMARY AND REVIEW

The purpose of cost-effectiveness studies is to make comparisons of various alternative future resource commitments. The implementation of each system being considered would result in a future stream of effectiveness (however it is measured) and a future stream of costs. Often the stream of cost and the stream of effectiveness associated with one system have time-phased profiles different from those of another system.

It is virtually impossible to make a direct comparison of such systems. There is generally no way to evaluate the worth of future effectiveness as opposed to the worth of present effectiveness. Discounting, however, can be used to make a logical if indirect comparison of the cost streams. Thus, discounting is a tool for determining the present value of cost streams. Discounting should not be used to attempt to account for future uncertainties with regard to weapon system performance. If the future effectiveness of one system is in doubt because of uncertainty about the future effectiveness of the system, it should be done directly as part of the effectiveness calculation and not by using a high discount rate.

Costs incurred at one point in time can be evaluated (and added) to costs incurred at a later time, because discounting is based on an established relationship between the value of a resource now and the value of a resource at some future date. From an economic standpoint, the cost of the system with the larger proportion of deferred costs, would be less than that of other systems.*

Having pointed out the advantages of discounting as a tool in cost-effectiveness analysis, it may be valuable to list several things that discounting costs does not do.

(1) Discounting does not take cost inflation into account. In fact, discounting has the opposite effect. If inflation is a point of issue, i.e., if the prices of defense goods in relation to the total Department of Defense budget were expected to increase, it might be preferable to procure systems now rather than later. This case, however, is a matter of relative prices and total budgets and would require serious study before a determination could be made.

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*Another method, the I + 5A rule, used in many studies, would not reveal this distinction. The I + 5A rule is a proxy for discounting only when the systems being compared have the same relative time-phased cost profiles; but this rule reveals nothing about how to evaluate systems with different cost profiles. Although I + 5A can stand for many things, it is generally considered to be in fact a proxy variable with five-year time dimensions, for amortizing investment over 10 years, plus 10 years of system costs discounted at 15 percent. When it is used in this manner, I + 5A assumes that a judgment has been made that (1) system life is 10 years, (2) the program life should be 10 years, and (3) the correct discount rate is 15 percent.

(2) Discounting does not offer any information on the total expected life of a system.

(3) Discounting reveals nothing about how rapidly a system deteriorates with regard to use depreciation.

(4) Discounting is not a method for evaluating the worth (in a subjective sense) of being able to change ones mind as a result of having procured a short-lived system instead of a long-lived one.

(5) Discounting does not show how many years a study should encompass, i.e., how long into the future a study should look. The cut-off data of a study should be determined by an estimate of how long a system will have military effectiveness, a factor reflected in the effectiveness calculations, not in the discounted costs.

It should be kept in mind that cost-effectiveness analysis of the type discussed here is not a means of evaluating the worth of a military requirement. Cost-effectiveness analysis is used to determine which among competing alternative systems is relatively the more efficient means of satisfying a given, perhaps parameterized, predetermined requirement. While it is hoped that cost-effectiveness analysis will give information about the cost of satisfying certain requirements, the analysis cannot directly determine the value (or worth) of a particular requirement. As always, the value of the requirements remains a matter of the judgment of the decision maker.