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COST FUNCTIONS AND BUDGETS

(COST CONSIDERATIONS IN SYSTEMS ANALYSIS)

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Introduction

The President of the United States held a news conference on August 25, 1965. One of the most significant things he said was the following:

> This morning I have just concluded a breakfast meeting with the Cabinet and with the heads of Federal agencies and I am asking each of them to immediately begin to introduce a very new and very revolutionary system of planning and programming and budgeting throughout the vast Federal Government, so that through the tools of modern management the full promise of a finer life can be brought to every American at the lowest possible cost.[1]

The era of program budgeting had begun for the entire federal government. In effect what the President said was: "I want all department and agency heads to try to do what McNamara and Hitch have been attempting in Defense since 1961."

Even in 1961 the basic concept of program budgeting was not new. It had been proposed for the Department of Defense as early as 1953,[2] and something akin to it had been used by the War Production Board in World War II.[3] Its use in industry apparently dates back to at least 1924.[4]

But in spite of this history, the President's announcement in the

NOTE. Any views expressed in this paper are those of the author. They should not be interpreted as reflecting the views of The RAND Corporation or the official opinion or policy of any of its governmental or private research sponsors.

[1] *New York Times*, August 26, 1965.

[2] David Novick, *Efficiency and Economy in Government Through New Budgeting and Accounting Procedures*, R-254, Santa Monica, Cal., 1953.

[3] David Novick (ed.), *Program Budgeting: Program Analysis and the Federal Budget*, Cambridge, Mass., 2nd ed., 1967, pp. xvi–xix.

[4] *Ibid.*, pp. xxi–xxii.

summer of 1965 did pose something of a "revolution" for many departments and agencies in the federal government. In terms of the ultimate goal, planning, programming and budgeting would have to become an integrated process—something which (surprisingly) was not generally true at that time. The "pure requirements" approach to planning would have to be modified. Staunch advocates of new programs could no longer argue effectively in terms of: "We need new program *X* because there is a requirement for it; there is a requirement because we need it"; and so on.

In the planning process, alternatives would have to be examined systematically, subject to realistic resource constraints. And alternative programs under consideration would have to be "costed out" to reflect their complete incremental resource impact for the long-term future—not merely the "down payment" as portrayed by next fiscal year's conventional budget.

All of this sounds commonsensical enough. It is basically very similar to what economic planners have been talking about for years. In its simplest terms, program budgeting is primarily the identification and systematic examination of objectives and the alternative ways of achieving them. The main focus is on *output*-oriented programs or "packages of public product," not the input orientation of the conventional budget, which stresses personnel, equipment, facilities, transportation, travel, contractual services, and the like.

In terms of the current jargon, the very heart of program budgeting is contained in the expression "systems analysis." While systems analysis cannot be defined with precision, the following would probably be accepted as a reasonably adequate description by most of the practitioners today:

> Systems analysis may be defined as inquiry to assist decision-makers in choosing preferred future courses of action by (1) systematically examining and re-examining the relevant objectives and the alternative policies or strategies for achieving them; and (2) comparing quantitatively where possible the economic costs, effectiveness (benefits), and risks of the alternatives. It is more a research strategy than a method or technique, and in its present state of development it is more an art than a science. In sum, systems analysis may be viewed as an approach to, or way of looking at, complex problems of choice under conditions of uncertainty.[5]

[5] For a further discussion of systems analysis, see E. S. Quade and W. I. Boucher, *Systems Analysis and Policy Planning: Applications in Defense,* New York, 1968, Chapter I.

The foregoing provides the necessary frame of reference for the discussion of the main subject of this paper: "Cost Functions and Budgets." Perhaps in view of such a framework a more descriptive title would be "Cost Considerations in Systems Analysis." In any event, the latter is the perspective we shall stress.

The Key Issues

In discussing cost analysis as a part of systems analysis, it appears that we can segregate the main issues into two categories:

1. The conceptual problems.
2. The practical problems involved in establishing cost analysis capabilities in the federal government and elsewhere.

Both of these are important. But at the present time there appears to be a special interest and sense of urgency regarding the second category. We shall therefore stress practical problems in this paper. Before turning to such a discussion, however, let us outline briefly some of the characteristics of the necessary conceptual framework for a cost analysis capability to support systems analysis studies.

The Conceptual Framework

In large measure the basic concepts underlying systems (program) cost analysis draw very heavily on concepts taken from economic theory and analysis.

A representative, but far from complete, listing of these basic concepts is as follows:[6]

1. An explicit relationship between inputs and outputs, with a strong emphasis on output-oriented identifications.
2. A strong emphasis on economic (not accounting) costs. Fundamentally this means the concept of opportunity cost.

[6] The ordering in no way reflects relative importance. Also, many of the items are interrelated. Finally, in some instances it is not clear that the particular point being made is conceptual or methodological—a distinction that is very often difficult to make.

3. As a further elaboration of (2) is the requirement to deal with such concepts as:
   a. Marginal or incremental (and hence "sunk") costs.
   b. Fixed and variable costs.
   c. Recurring and nonrecurring costs.
   d. Joint costs.
4. Explicit treatment of uncertainty. Simple "expected value" models very often will not suffice.
5. An awareness of scaling considerations. As in economic theory, many problems dealt with in systems cost analyses do not scale up or down in a simple fashion.
6. Explicit treatment of problems associated with time—e.g., the problem of time preference.
7. A strong emphasis on comparative analyses of alternatives—e.g., fixed cost (budget) comparisons and/or fixed utility (effectiveness) comparisons.
8. A recognition of the importance of sensitivity analysis, contingency analysis, *a fortiori* argument, and the identification of new alternatives as ways of assisting in the all important search for dominances.[7]

These eight points represent some of the most important characteristics of the conceptual framework for cost analysis in support of systems analysis studies. From a purely conceptual point of view, there would seem to be little room for argument about the relevance of these concepts. The main issues arise when the cost analysts try to implement the basic ideas. Let us consider two examples briefly.

Most analysts agree that in principle the matter of time preference should be treated explicitly. The disagreement arises over how this should be done—for example, what discount rate seems most appropriate for equalizing cost streams over time. Numerous seminars and conferences have been held on the subject of discounting, and the issue is still unresolved.[8] Many analysts feel that it cannot be completely

[7] Perhaps this point is more methodological than it is conceptual. We include it in the list anyway, because of its central importance in systems analysis. (Also, it is strongly related to (4)—explicit treatment of uncertainty.)

[8] Recently a survey was made of 23 federal agencies to obtain information on discounting techniques used in making evaluations of future government programs. One of the results is that the rates used vary from about 3 to 12 per cent. See statement by Elmer B. Staats, Comptroller General of the United States, before the Subcommittee on Economy in the Government, *Congressional Record—Senate,* January 30, 1968, pp. S632–S634.

resolved and that in most instances the matter is less consequential than many of the other cost analysis problems.

In fact, the analyst can do a great deal to sharpen the intuition and judgment of the decision makers[9] without resolving the rate issue. For one thing, the analyst can point out to the decision makers that an "undiscounted" situation usually does not exist. A case in point occurs in the Department of Defense where cost streams are projected 10 or 15 years into the future "without equalizing them for time preference." Here, the analyst can make the time preference assumption explicit: namely, a zero per cent discount rate for 10 or 15 years and a very high rate thereafter. He can also calculate cases built on a reasonable range of time preference assumptions and show the impact on final results (the ranking of the alternatives being considered). Finally, he can compute the "break-even point"—i.e., the case containing that discount rate which would have to be used to make the present value of two alternatives equal.

As a second illustration, let us consider the concept of opportunity cost. Again, there would seem to be little argument about the concept itself. Opportunity costs are generally recognized as being relevant in the examination and evaluation of alternative future courses of action. They are certainly much more relevant than, say, accounting-type costs generated for fiduciary financial management purposes.

Problems arise, however, when the analysts attempt to apply the concept of opportunity cost in systems analysis studies. For example, the cost analysts often generate estimates of the dollar costs of various program or system alternatives being considered in long-range planning deliberations.[10] Such estimates may be expressed in terms of time-phased expenditures and/or obligational authority, or in terms of "static" indexes of total system or program cost.[11] The specific issue is: Do these dollar cost estimates adequately reflect the opportunity costs (benefits foregone) of the alternatives being examined—at least for the purposes of the types of comparisons made in systems analyses?

They probably are not in all cases. However, most of the experts seem to think that for the purposes of comparing distant future alternatives, dollar costs *do* provide a reasonably appropriate index of

[9] To sharpen the intuition and judgment of the decision makers is the primary role of systems analysis. Generally speaking, an analysis cannot *make* the decision (e.g., see A. C. Enthoven's statement contained in an article in *Business Week*, November 13, 1965, p. 189).

[10] Other measures of cost are also calculated—e.g., manpower.

[11] That is, the sum of development (if any) and investment costs plus a number of years operating cost.

opportunity costs in many applications. This point of view is argued vigorously, and rather convincingly, in the context of Department of Defense planning by Hitch and McKean:

> If we examine the problem of planning future programs from the standpoint of the Defense Department, it seems fairly obvious that money costs are pertinent. The Department faces a budgetary constraint. For the most part it does not face a limitation on particular weapons or supplies but can buy more of them by paying their prices. What does the Department give up in order to implement one course of action? The answer is money—or, to go one step further, the alternative weapons or supplies that could otherwise be purchased. The Department could substitute one item for another by paying the price of the one instead of paying the price of the other. Dollar costs do reflect what must be given up in order to adopt a particular policy. They reflect real sacrifices by the Department because the prices of different items show the rates at which they can be substituted for each other.
>
> This is not to say that money costs perfectly represent resources sacrificed by the Defense Department. The prices of goods to be bought in the future are uncertain. One course of action may itself drive up the price of particular weapons or materials, and it is not possible to predict these effects with complete accuracy. The characteristics and cost of some items will change as technology advances. The quantity of some exceptional items may literally be fixed, or nearly fixed, even if we are looking several years ahead. Nonetheless, imperfect as it is, the money cost of a future program usually shows the sacrifice that would be required of the Department better than other measures of cost. While dollars do not precisely measure the real sacrifices, costs in terms of metals and manpower would be grossly misleading. Saying that airplanes cost so much aluminum and ships so much steel plate does not tell us how one may be exchanged for the other. Saying that each costs so many dollars adheres more closely to the facts, namely, that the services can, in making future plans, trade one for the other.[12]

[12] Charles J. Hitch and Roland N. McKean, *The Economics of Defense in the Nuclear Age*, Cambridge, Mass., 1960, p. 26.

The above quotation is concerned with dollars as a proximate measure of economic cost from the viewpoint of the Department of Defense. What about from the standpoint of the nation? Hitch and McKean consider this question, and argue the case by means of an illustrative example (see *ibid.*, pp. 27–28). Their general conclusion is:

> As a consequence, money costs of *future* defense activities approximate the real alternatives that are foregone—the real sacrifices that are entailed—when one activity or weapon system is selected. This will be true for those problems in which a general monetary constraint is proper, that is, for

Our concern in this paper is not so much with whether Hitch and McKean are correct. Rather the point is that the issue under consideration pertains more to the matter of *implementation* of a concept rather than to the relevance of the concept itself. It is generally recognized that economic cost is one of the relevant considerations to be taken into account in systems analysis studies. The question is how to do it in practice.

This leads to our next subject: cost analysis in support of systems analysis in practice. How is it done? What are some of the problems?

Cost Analysis in Practice

In general terms the central problem facing cost analysts is to develop methods and techniques which will permit assessment of the resource impact of proposed alternative output-oriented programs and/or alternative combinations (mixes) of future programs.

The basic characteristics of such a cost analysis capability stem directly from the conceptual framework discussed in the preceding section. A few of the more important of these characteristics are as follows:

1. While most of the basic estimating work must be done on the input side in terms of manpower, equipment, facilities, supplies, etc., the results of a cost analysis must be packaged in the form of output-oriented entities which are of prime concern to the long-range planning decision makers.
2. Cost analysis procedures (models) must be "open-ended" with respect to key performance and other variables which characterize the class of output-oriented entities under consideration. This facilitates doing parametric-type analyses which are of prime importance in extending the range of alternatives that can be examined, in making *a fortiori* arguments, in making sensitivity tests, in exploring scaling factors, and the like.
3. Related to (2) is the requirement to deal explicitly with the problem of uncertainty. Parametric cost models help by facilitating the computation of a range of cost estimates (rather than "point" estimates alone),[13] and by permitting determination of

problems pertaining to dates sufficiently in the future to permit the production and procurement of varying quantities of weapons and materiel (*ibid.*, p. 28).

[13] For example, "high," "medium" and "low" cases.

the sensitivity of total system or program cost to variations in the values of key parameters about which we are uncertain.

4. Both (2) and (3) imply the need for cost analysis models which are in part automated. If a large number of cases are to be computed within a reasonable amount of time and effort, manual calculation alone is usually out of the question.[14]
5. A strong emphasis must be placed on developing cost analysis procedures which will permit assessment of *incremental* costs—i.e., the additional costs implied by the proposed future course of action under consideration. The costs of past actions ("sunk" costs) and the costs of firmly committed ("locked-in") future actions must be excluded.
6. Finally—and perhaps most important of all—a substantial amount of time and effort must be devoted to the continuous development and maintenance of an appropriate data base: i.e., information on past, current and near future programs to serve as a basis for the derivation of estimating relationships to be used in projecting to the distant future.

We have stressed the prime importance of "output-oriented entities" or "program packages." What does this mean in areas of specific application? In the case of the Department of Defense these entities are by now rather widely recognized as being weapon and support systems and force mixes of such systems. What about the nonmilitary realm? The following are a few examples.

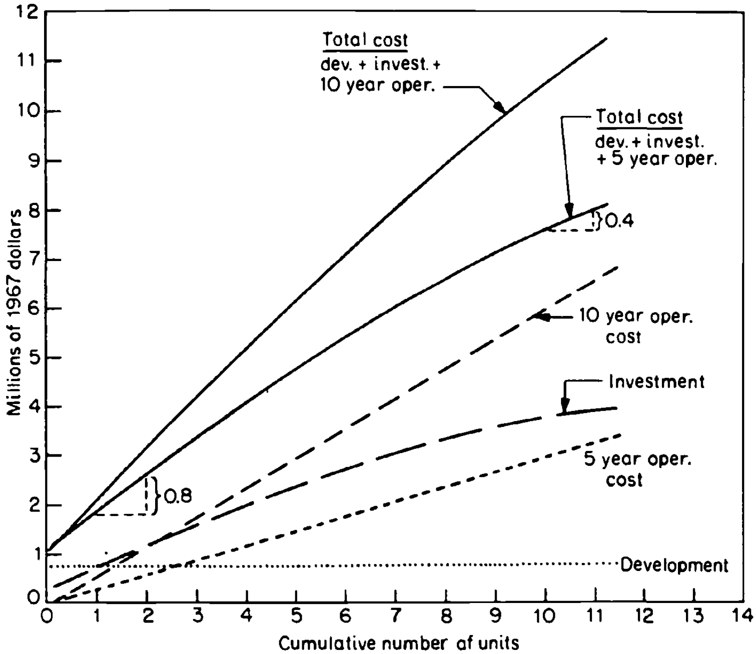
In the transportation area output-oriented entities may be various future modes of transportation—rail systems (surface and subsurface), "automated" freeway systems, airlift systems, etc., and mixes of these modes. In the mental health area the planners may be interested in such things as alternative systems for dispensing mental health services (e.g., community mental health centers), alternative programs for narcotic and drug abuse, etc. In the National Aeronautics and Space Administration the prime concern is with alternative ways of attaining certain goals in space—e.g., alternative space systems for performing future missions in the lunar, earth-orbital, and planetary areas.

In any event, the cost analyst must be able to conduct his studies in terms of the types of identifications or "planning units" that are of

[14] In some instances a tremendous number of individual calculations are required for a single case. For example, the total force structure cost model developed by The RAND Corporation to assess the resource impact of a projected total Air Force plan over a 10-year period makes about 500,000 computations for the typical single case.

FIGURE 1

SYSTEM COST VERSUS PROGRAM SIZE



primary interest to the long-range planners. This is just as true in nonnational security problem areas as it is in defense, and the basic problems are very similar.

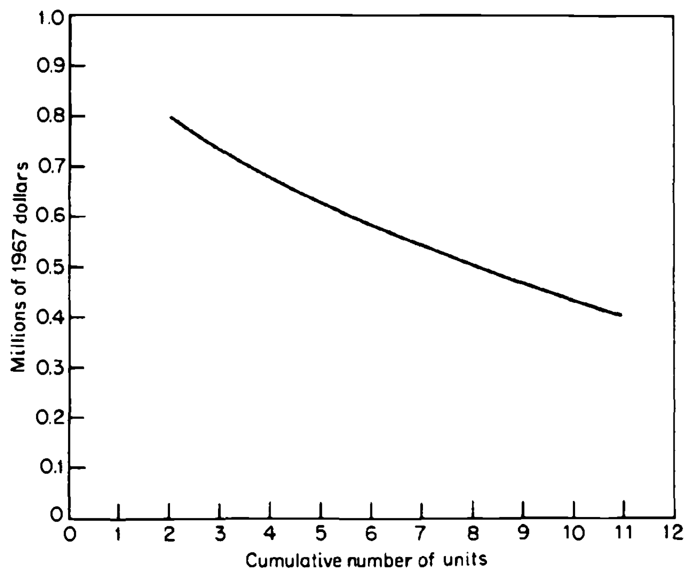
Let us now consider a few hypothetical examples to illustrate some of the types of output from the cost analysis process which are useful in systems analysis. In these illustrations the "output-oriented entities" are assumed to be alternative system or program package proposals being considered in the long-range planning process.

A very useful output of the cost analysis process (an input to systems analysis) is a cost function relating projected total system (program) cost[15] to the size (cumulative number of units) of a proposed future course of action. An example is shown in Figure 1. Here, total

[15] Here, total system (program) cost is defined as development (if any) plus initial investment plus a fixed number of future years' operating cost. Oftentimes the number of years' operation is treated parametrically to see whether the assumption about this factor affects significantly final results (the ranking of the alternatives being considered).

FIGURE 2

MARGINAL COST CURVE



NOTE: Based on total development, investment, and five-year operation curve contained in Figure 1.

system cost is increasing at a decreasing rate, and hence marginal cost (the cost of an additional unit) is a decreasing function of the cumulative number of units. This is portrayed in Figure 2.

Cost functions expressing total system cost as a function of cumulative number of units are particularly useful in a fixed budget comparative framework of analysis. Here, the systems analyst often wants to know: "How many units of the various alternatives under consideration can I get out of certain stipulated future budget levels?"[16]

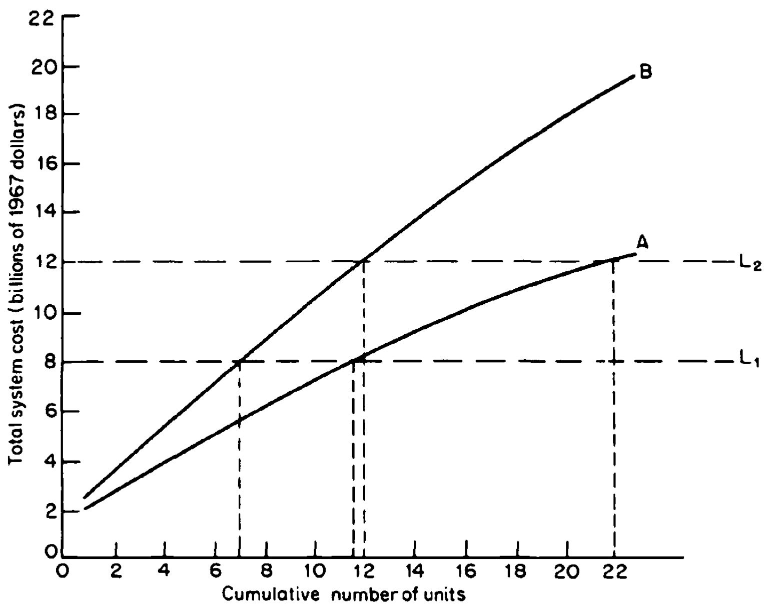
An example is presented in Figure 3 for alternatives *A* and *B*. If

[16] This is one example of why cost functions relating cost to the scale of proposed future programs are useful in systems analysis work.

Many of the cost functions emphasized in conventional economic theory relate cost to rate of output. Rate-of-output cost functions are also useful in certain types of problems in systems analysis. For example, in studying alternative configurations of proposed community mental health centers, we might want to examine how unit costs change as daily out-patient capacity rate is varied over a relevant range. In the case of military aircraft systems the analyst often examines how system cost (for a fixed force size) changes as the activity rate (e.g., flying hours per aircraft per month) is varied over a certain range.

FIGURE 3

TOTAL SYSTEM COST VERSUS PROGRAM SIZE FOR ALTERNATIVES *A* AND *B*



the specified cost level to be used in the comparative analysis is \$8 billion, 11.5 units of alternative *A* or 7 units of alternative *B* are obtainable. This is a key output of the cost analysis, which then becomes a major input to the effectiveness (utility) analysis.

Notice that in this illustration the results do not scale linearly with respect to changes in the stipulated cost level. For example, if L_1 is increased by 50 per cent to L_2 = \$12 billion, the outcome is 22 units of *A* or 12 units of *B*. The increase in the number of units is greater than the increase in L_2 over L_1:

$$L_2/L_1 = 12/8 = 150\%$$

$$A_2/A_1 = 22/11.5 = 191\%$$

$$B_2/B_1 = 12/7 = 171\%$$

In a simple way this demonstrates that in the context of a fixed budget framework of analysis, scaling considerations suggest the desirability of conducting the comparisons for more than one cost level. For example, three cases might be examined: high, medium, and low.

To illustrate a somewhat different point, let us now consider a fixed effectiveness framework of analysis for comparing alternative proposed future courses of action. Here, the analysis attempts to determine that possibility (or feasible combination of possibilities) which is likely to achieve some specified level of effectiveness at the lowest economic cost. The cost analysis in effect produces the final results after the effectiveness analysis has determined how much of each alternative is required to attain the stipulated level of effectiveness.

As one simple illustration of this approach, suppose that alternatives C and D are under consideration, and that the results of the effectiveness analysis indicate the following ranges of quantities (number of units) of C and D required to attain some specified level of effectiveness E_0:

	C	D
Low	20	4
Expected value	22	6
High	24	12

Notice that in this case the range for D is considerably greater than for C because of uncertainty.

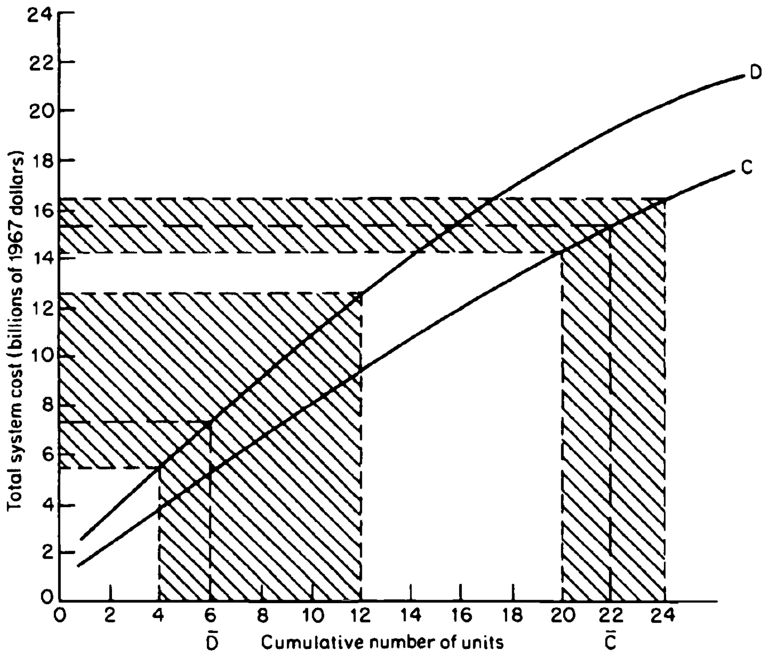
Suppose now that the estimated total system costs as a function of cumulative number of units for C and D are as shown in Figure 4. Taking the expected value outputs from the effectiveness analysis, we see from Figure 4 that D is the least cost alternative for attaining effectiveness level E_0: \$7.5 billion for D vs. \$15.3 billion for C, or a factor-of-two difference in favor of D. If the uncertainties in the effectiveness analysis are taken into account, alternative D still holds up well, even in the situation where the worst case (highest cost) for D and the best case (lowest cost) for C are paired up. Thus, at least with respect to the uncertainties taken into account in the problem, alternative D appears to be a dominant solution—something which the systems analyst is always seeking, but rarely finds.

So far, our examples have been essentially "static," i.e., projected costs have not been treated explicitly as a function of time. In many decision contexts, however, the alternatives have to be examined in terms of time-phased cost streams projected a number of years into the future.

For example, suppose there are two new proposed alternatives,

FIGURE 4

TOTAL SYSTEM COST VERSUS PROGRAM SIZE FOR ALTERNATIVES *C* AND *D*



NOTE: Fixed effectiveness = E_0.

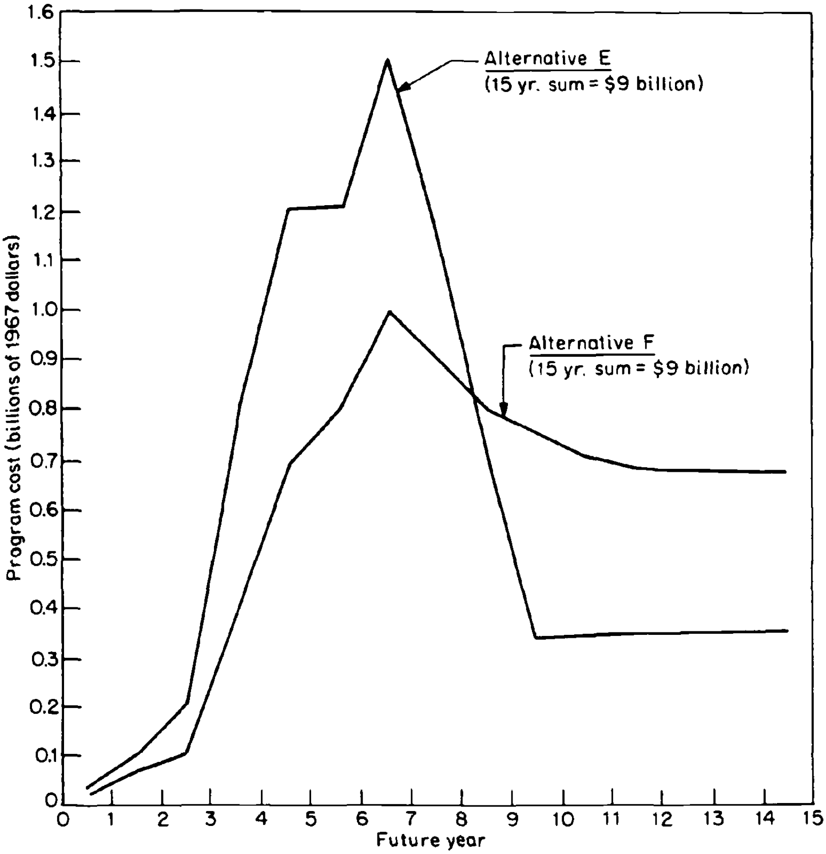
programs *E* and *F*, which are estimated to be capable of accomplishing the same objective in the future with essentially the same degree of effectiveness for the time period of interest (a "fixed-effectiveness-over-time" framework of analysis). Suppose further that the time-phased total program costs over a 15-year period in the future are as portrayed in Figure 5. Here, the time preference assumption is a *zero* discount rate for the first 15 years, and a very high rate (over 100 per cent) thereafter. Notice that in each case when the yearly costs are summed over the 15-year period, the totals are the same ($9 billion each for *E* and *F*).

On the basis of the data presented so far, we have an equal-effectiveness, equal-cost situation; so presumably the decision makers would be indifferent regarding the choice of *E* or *F*—at least on the basis of the quantitative information available at this point.

FIGURE 5

TIME-PHASED PROGRAM COSTS FOR ALTERNATIVES *E* AND *F*

(DISCOUNTED FOR TIME PREFERENCE AT 0.0 PER CENT FOR THE FIRST FIFTEEN YEARS, 100+ PER CENT THEREAFTER)



Notice, however, that the time impacts of the costs for *E* and *F* are considerably different. The basic reason for the difference is that alternative *E* requires higher cost outlays (relative to *F*) early in the period because of greater development and investment costs. These outlays pay off in terms of an efficient operational program having relatively low operating costs later in the period. Alternative *F*, on the other hand, has lower development and investment costs than *E*. This, however, implies a less efficient operational program than *E*, with the result that larger operating costs are required to accomplish the specified task with the same degree of effectiveness as *E*. Therefore, the costs for *F* during the latter years of the 15-year period are about two times those of *E*.

In view of these differences in the time impact of the costs of *E* and *F*, the question arises as to whether the planners would still be indifferent regarding the choice of *E* or *F* if the time preference assumptions are varied. Suppose the base case (Figure 5) is modified to reflect the following time preference specifications: a discount rate of 6 per cent for 15 years, and a very high rate (over 100 per cent) thereafter. The results are as follows:

	Present Value in Billions of Dollars	
	Base Case (0; 100+%)	First Modification (6; 100+%)[a]
Alternative *E*	$9	$5.8
Alternative *F*	9	5.3
Difference	0	0.5

[a] The time-phased cost profiles for this case are presented in Figure 6.

Thus, the first modification (6 per cent for the first 15 years) results in a rather sharp reduction in the present value of the 15-year costs for *both* *E* and *F*. However, the difference between them can hardly be regarded as significant in view of the many uncertainties involved in the total analysis. The decision makers are likely to continue to be indifferent regarding the choice of *E* or *F* on the basis of the present values of the two cost streams.

Would this still be the case for a discount rate considerably higher than 6 per cent? Let us try a 10 per cent rate for 15 years, and a very high rate (over 100 per cent) thereafter. The results are:

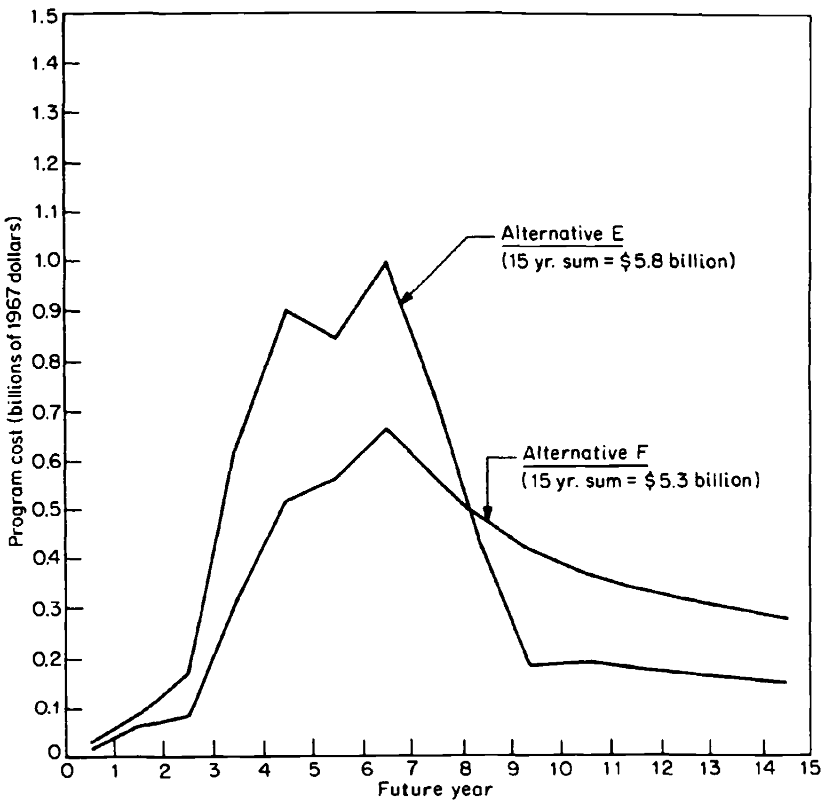
	Present Value in Billions of Dollars		
	Base Case (0; 100+%)	First Mod. (6; 100+%)	Second Mod. (10; 100+%)
Alternative *E*	$9	$5.8	$4.5
Alternative *F*	9	5.3	3.9
Difference	0	0.5	0.6

The second modification results in a further reduction in the present values of the fifteen-year costs for both *E* and *F*. Here again it is very

FIGURE 6

TIME-PHASED PROGRAM COST FOR ALTERNATIVES *E* AND *F*

(DISCOUNTED FOR TIME PREFERENCE AT 6 PER CENT FOR THE FIRST FIFTEEN YEARS, 100+ PER CENT THEREAFTER)



doubtful that the difference in present values between *E* and *F* is significant. The uncertainties in the basic problem are such that a 15 per cent difference in cost is no doubt well within the "noise level" of the analysis. Also, it should be pointed out that in most contexts a 10 per cent discount rate for time preference is fairly high,[17] which makes the second modification a rather extreme case.

[17] Recall that in this exercise we have been discounting for time preference only—not for time preference *plus* a supplemental rate for risk. When analysts apply rates like 10 to 15 per cent, they usually have in mind a combined rate to allow for time preference and risk or uncertainty.

In sum, in this particular example, the conclusion would seem to be that the decision regarding the choice of alternative *E* or *F* is likely to be independent of the assumptions made with respect to the treatment of time preference.[18]

As a final example, let us consider the examination of variations in total system (program) cost as the characteristics of the system (program) are varied, assuming a fixed number of years of operation. This is an important technique of analysis in systems analysis.

For an illustration, we shall use the context of the national security area and consider the case of a proposed future aircraft system where the mission requires that a fleet of aircraft be continuously airborne on a series of stations which cover a large geographical area. A Navy antisubmarine warfare (ASW) mission in the future is a possible example.

Continuously airborne alert aircraft systems typically involve a host of significant variables: endurance hours of the aircraft to be employed in the system, extent of the area coverage, nature of the payload requirements, aircraft maintenance policy (one, two, or three shifts), and the like. Intrasystem cost analysis must usually explore the consequences of variations in these variables.

Figure 7 shows an example for a future ASW system to patrol and destroy ballistic missile carrying enemy submarines, where aircraft endurance hours and area coverage (nautical miles out to sea from U.S. coastlines) are varied. Here total system cost is defined to be research and development + investment + five years of operation. Notice that as the area coverage is extended, the requirement for longer endurance becomes increasingly more severe.

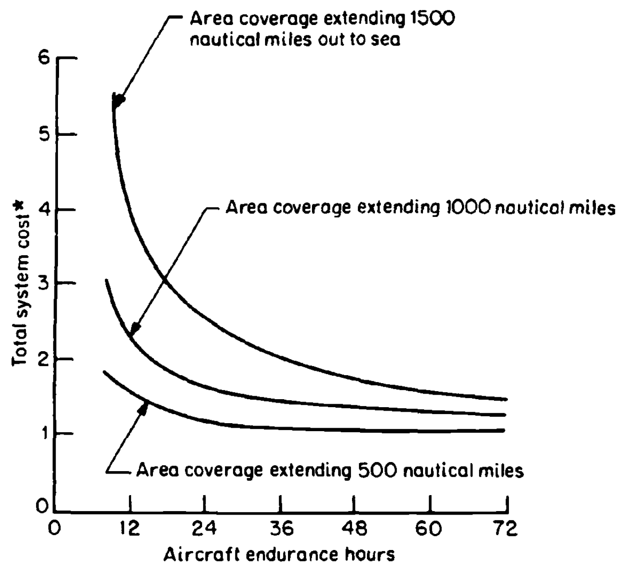
Figure 8 contains another ASW system cost example. Here total system cost (defined as in Figure 7) for each pound of payload (elec-

[18] Examples of other cases are the following:

Case	Present Value in Billions of Dollars		
	Alt. *E*	Alt. *F*	Difference
6% for 25 yrs.	$6.9	$7.4	$0.5
10% for 25 yrs.	5.0	4.9	0.1
15% for 25 yrs.	3.5	3.1	0.4
5% for first 10 yrs. 10% for next 5 yrs. 20% for next 5 yrs. 50% for next 5 yrs.	6.6	6.5	0.1
10% for first 15 yrs. 50% for yrs. 16–25	4.6	4.2	0.4

FIGURE 7

ASW SYSTEM COST VERSUS AIRCRAFT ENDURANCE FOR SEVERAL AREA COVERAGES



* Synthetic number scale.

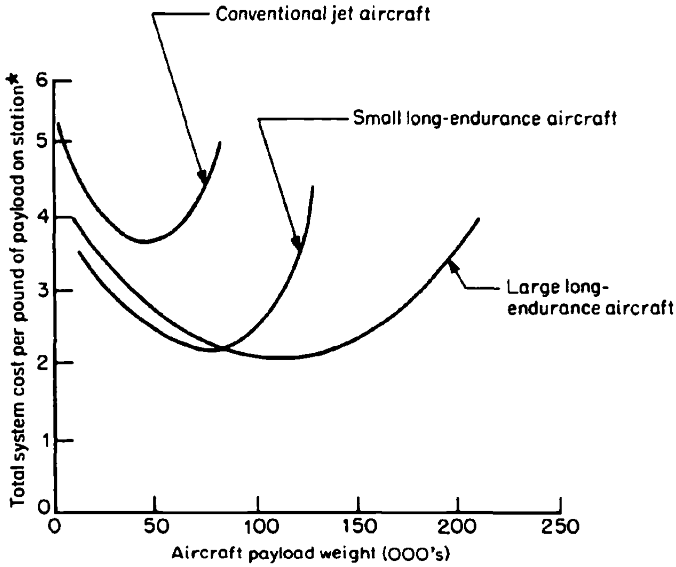
tronics, ASW missiles, etc.) on station is expressed as a function of the pounds of payload carried per aircraft.[19] Curves are shown for three types of aircraft that might be candidates for use in the proposed ASW system.

Notice that the use of conventional jets in this mission application results in a considerably higher minimum cost point than for long-endurance aircraft, and that system cost per pound of payload on station is very sensitive to individual aircraft payload weight. Note also that as we move to the large, long-endurance aircraft, the costs become much less sensitive to a particular loading or payload weight. This might suggest that if the size of the payload to perform the future mission is clouded by uncertainties, then flexibility may be achieved by going to the large, long-endurance aircraft.

[19] Area coverage is fixed at 1,000 nautical miles.

FIGURE 8

SYSTEM COST PER POUND OF PAYLOAD ON STATION VERSUS AIRCRAFT PAYLOAD WEIGHT



* Synthetic number scale.
NOTE: Area coverage = 1,000 nautical miles.

A Major Difficulty: The Data Problem

What are the main difficulties involved in doing cost analyses of the type described in the previous section? There are many—some bureaucratic, some substantive. Because of space limitations, all of these difficulties cannot be outlined and discussed here. We shall therefore take the most severe—the data problem—and treat it at some length.[20]

In most cases the ability to engage in cost analysis as an integral part of systems analysis studies requires the development and use of

[20] Much of the discussion to follow draws rather heavily on the national security area. This is because the author has had more experience in the Department of Defense than in other governmental agencies. The basic data problems, however, are very similar in all areas, and the methodological and procedural points to be made in this section are applicable to a wide variety of contexts.

cost models. A cost model is a device for generating estimates of the resource impact of future output-oriented program packages in terms of the inputs that would be required to develop, install, and operate these proposed programs over a period of years. The input structure typically involves various categories of facilities, equipment, personnel, supplies, etc., or combinations of these items (maintenance, for example).

For each category in the input structure we must have an estimating relationship (or series of relationships) expressing cost as a function of an appropriate set of cost-generating or explanatory variables.[21] These estimating relationships form the very heart of a cost analysis capability.

Estimating relationships have to be derived on the basis of something. Sometimes that something has to be "experience and judgment" (preferably of an expert). Generally speaking, however, we would prefer that they be developed from statistical analyses of past, current, and near-future data and information. At this point we run headlong into "the data problem." And it is a problem of fundamental importance, because a substantive cost analysis capability cannot exist without an appropriate information and data bank.

Why Is There a Data Problem?

The reader may well wonder why the data problem is so severe. Has not the Government been developing information systems and collecting a huge volume of data in numerous areas for many years? Have not industry and other institutions been doing the same thing? How could there be a "data problem"?

These are legitimate questions. The answers are numerous and varied. Here, we shall try to select a few of the more important ones, with a view to giving the reader a reasonable degree of understanding of why a data problem exists.[22]

[21] The cost of a certain type of equipment for the future may be estimated as a function of its performance and/or physical characteristics and estimated production quantity. The cost of equipment maintenance may be estimated as a function of equipment characteristics and projected activity rate.

[22] The points discussed below relate for the most part to technical aspects of the problem. Other factors can be important also. For example, formal information and data systems are sometimes established without sufficient understanding of the relevant organizational and institutional considerations pertaining to the agency in question.

INFORMATION IN THE WRONG FORMAT. Information systems in the Government and elsewhere have indeed generated a tremendous amount of data. In many instances, however, these data are not in an appropriate format to be very useful in a program cost analysis activity serving the long-range planning process.

The main reason for this is that these information systems were established primarily to serve the needs of managers of functional areas of operational activity (maintenance, supply, etc.), of managers responsible for fiscal integrity or fiduciary accounting requirements ("keeping hands out of the till"), of managers concerned with critical resource items across the board (e.g., personnel), of budgeteers concerned with the conventional budget, and the like. In short, the orientation of a large number of past and existing information systems is toward the input side per se, with little or no provision for making meaningful translations reflecting impacts on output-oriented program packages.[23]

THE "MATCHING UP" OR INTEGRATION PROBLEM. The analyst must not only collect historical *cost* data in the right format, particularly when the objective is to derive estimating relationships. He must also obtain information on quantities, physical and performance characteristics, activity rates, and other types of cost-generating variables. The latter must be matched specifically to the cost data points.

Sometimes this is difficult because the information on the cost-generating variables must be extracted from different sets of records than those containing the cost data. And differing sets of records can often have dissimilar bases for reporting—for example, with respect to lot size, time period covered, and the like.

DIFFERENCES IN DEFINITIONS OF CATEGORIES. A different kind of "matching up" problem frequently occurs. This concerns the lack of a one-to-one correspondence between the definition of the content of categories in the input structures set up for program cost analysis purposes, and the definition of analogous categories in the existing data and information collection systems.

[23] Oftentimes the suggestion is made that if the analyst will probe the data base at successively greater levels of detail, he will eventually find the kinds of identifications he needs. Sometimes this is true. On the other hand, one is likely to find that if an information system is structured to deal in terms of, say, "object classes," then going into more detail will simply yield greater amounts of information in the same terms (object classes).

It is not possible to set up *the* preferred input structure which will meet the requirements of cost analyses in support of long-range planning and at the same time be in complete harmony with existing data and information systems at any point in time. Differences in definition of certain categories in the input structure and their counterparts in the existing data base are therefore bound to be present. This creates a data problem for the cost analyst when he is collecting information to serve as the basis for deriving estimating relationships for various categories and subcategories in his input structure. He will often have to make adjustments to the raw data to correct for these definitional differences.

THE INFLUENCE OF TEMPORAL FACTORS. Historical data are, of course, generated over time. This means that numerous dynamic factors will have influences on the information being collected in a certain area. First of all, the information collection systems themselves have a habit of changing over time—for example, the appropriate definition of the content of various categories being used to accumulate the historical data may change as the system evolves. Also, in the case of financial data, price level changes will occur and be reflected in the information being collected over time.

In addition to these types of temporal considerations is the important fact that many government agencies deal with a rapidly changing technology, both with respect to hardware and with respect to organizational and operational concepts. Almost by definition, this means that even with a near perfect information collection system, only a relatively small sample of data can be generated for a given era or class of technology. In the major equipment area, for example, the analyst is lucky if he can have available 15 or 20 good data points for a certain class of hardware. He is more likely to have less than half that number.

By the nature of things, therefore, the analyst is all too often in the world of *very* small samples. As all good statisticians know, this poses real problems in our attempts to develop meaningful *structural* relationships which will permit us to project forward to distant future programs and capabilities.

So much for our listing of problem areas concerning the data base. We repeat that the four points outlined above do not represent a complete enumeration; they should, however, convince the reader that there is such a thing as a "data problem." The question now is: What do we do about it?

Dealing with the Data Problem

At first thought, one might be tempted to say: "If there is a data problem, let's solve it once-and-for-all by establishing *the* information collection system to meet all our needs." People have often made statements like this. Is such a thing feasible?

We think not, for several reasons. Some of the more important of these are the following:

1. Cost analysis problems in support of systems analyses typically vary considerably from one study to another. The requirements for estimating relationships—and hence data and information requirements—are not constant over time, or even for a given small interval of time. In short, the cost analyst who is working in support of the long-range planning process could not specify his data and information needs "once-and-for-all." It would be difficult, if not impossible, then, to establish *the* comprehensive information system.

2. Even if something approaching (1) could be done, we still have to worry about economics. Large information systems—especially those designed for complete enumerations—are very expensive. This poses a systems analysis problem in itself. Would the (large) incremental cost of a new complete enumeration information system be justified in terms of the benefits to be derived—particularly in the context of long-range planning, where high precision in an absolute sense is usually not a prime requirement? The answer is probably "no."[24]

3. In addition to points (1) and (2) is the problem of small samples arising from the fact that many government agencies have to deal with a rapidly changing technology. As indicated previously, this means that in many instances only a relatively small number of observations will be available for a certain era or class of technology. Here, even a near perfect information system cannot increase the sample size.

Where does all this leave us? On the one hand, a strong argument has been advanced for the importance of an appropriate information and data base. On the other hand, trying to solve the problem once and for all does not seem feasible, at least in a *general* sense. Does this mean that the situation is at an impasse?

[24] As will be pointed out later, there are alternatives to complete enumerations on a recurring basis.

The answer is "no." The problem is susceptible to reasonable solution, at least in many instances. Numerous possible alternatives to establishing new complete enumeration information systems may be considered. We shall now outline and discuss briefly examples of a few of the approaches that may be taken to help solve the data problem.

Use of Ad Hoc Sample Surveys

One very interesting possibility which the present author feels has been relatively neglected is sampling, or something akin to sampling. This can be a low cost way of obtaining information that may be very useful in deriving estimating relationships for use in long-range planning studies.

Suppose, for example, that the cost analyst is faced with the problem of developing end-product oriented estimating relationships for some functional area like maintenance or supply in the Department of Defense. Suppose further that the existing cost accounting systems accumulate historical cost data in categories such as labor, material, overhead, etc., and that no provision is made for identifications to end-product packages of military capability (e.g., weapon systems). Conceivably one solution would be to overhaul the entire formal accounting system to accumulate historical cost data in the desired form, in addition to the existing categories needed for purposes of functional management of the maintenance and supply activities. This, however, could be very expensive, and considerable time would have to elapse to permit designing, testing, and implementing of the new accounting system.

An alternative would be to select a few representative locations and to provide for an ad hoc (temporary) "ticketing" system to accumulate costs in terms of weapon systems for a relatively short period of time—say a month or two. The ad hoc arrangement would be supplementary to—and hence would not disturb—the existing formal accounting system. This approach has been used on numerous occasions in the past; and for those cases known to the author, the results have been good—at least for the purpose of deriving estimating relationships for long-range planning.[25] In any event, sampling procedures

[25] The author has conducted simple tests in several instances where complete enumerations were available. The procedure was as follows: Take the complete enumeration as a data base and, using regression analysis, derive an estimating relationship—say $C = \hat{\alpha} + \hat{\beta}X$. Then take random samples of 15 or 20 observations from the complete enumeration and derive similar relationships on the

seem worthy of consideration as an alternative to establishing new complete enumeration systems across the board.

Techniques for Assisting in Handling the Small Sample Problem

We have pointed out that the cost analyst very often finds himself confronted with small samples. Let us consider two examples to demonstrate several things that can be done to help ease the problems arising from having to use data bases containing only a small number of observations from the historical record.

The first is an extremely simple idea, but in some instances it can help a great deal. Particularly in deriving estimating relationships for use in long-range planning studies, the cost analyst should not necessarily restrict himself to the *historical* record in assembling his data base. In many cases he should seriously consider increasing the number of observations by including appropriate data points based on estimates made by experts for the very near future, and/or by taking advantage of certain kinds of qualitative information.

Suppose, for example, we have only four data points available from the historical record (see Figure 9). Suppose further that the analyst must derive an estimating relationship which will help him project out beyond the range of the historical sample (beyond the value X_0 of the explanatory variable). On the basis of the four data points alone, it is not very clear what kind of relationship between C and X should be postulated. For example, the curves AB and CD in Figure 10 would seem about equally plausible. Here is a case where the cost analyst should probe further and attempt to get some sort of additional information (either quantitative *or qualitative*) to help him make an informed judgment.

Suppose that in our hypothetical example the cost analyst, upon further exploration, was fortunate enough to find two more data points in the form of *estimates* for the near future made by reputable experts in the field under consideration. Upon checking out the methods used to make these estimates, the cost analyst decided that it would be appropriate for him to use them as a supplement to his his-

basis of these sample data bases. Then test the resulting estimates of α and β against the values obtained from the complete enumeration to see if there is a significant difference. In the particular cases examined by the author, most of the time no significant difference existed (at the 0.05 level) between estimates of the regression coefficients obtained from the small samples and those obtained by using the complete enumeration as a data base.

FIGURE 9

SMALL SAMPLE EXAMPLE

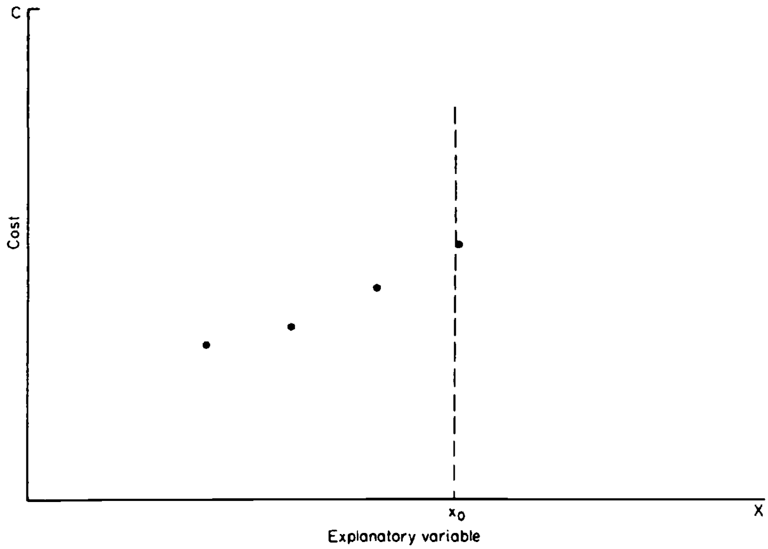
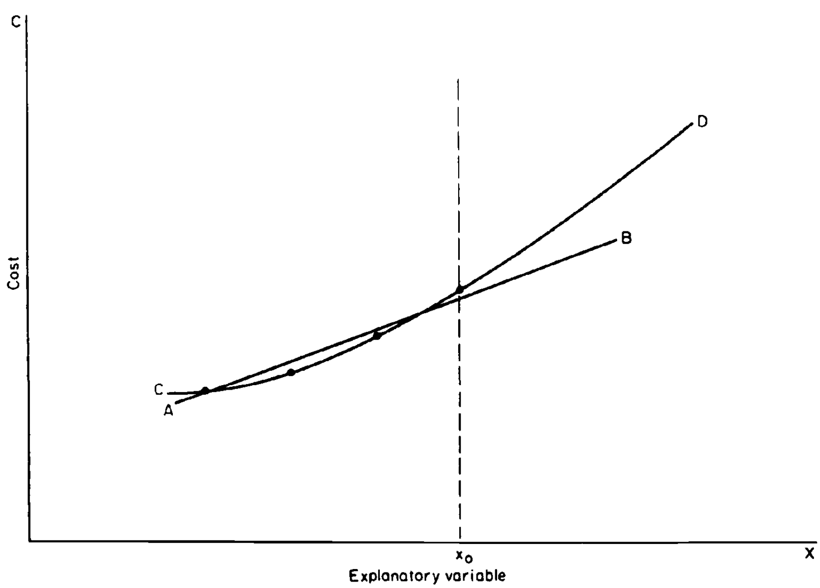


FIGURE 10

SMALL SAMPLE EXAMPLE

SOME PLAUSIBLE ESTIMATING RELATIONSHIPS



torical data base. The result is shown in Figure 11. This would tend to suggest the appropriateness of a linear hypothesis as a basis for projecting out to the vicinity of X_1 in Figure 11.

Let us assume, however, that our cost analyst wanted still further substantiation—if possible. He recalled that in his initial search for an appropriate explanatory variable, he had talked to some engineers who were experts in designing the type of equipment or activity under investigation in this particular case. He decided to consult with them again in the hope of obtaining some thread of qualitative evidence which would help in deciding whether to accept or reject the linear hypothesis. Upon listening to the engineers discuss the structural characteristics of the activity under consideration, the cost analyst became convinced that projections for large values of the explanatory variable X should be made on the basis of a linear relationship between C and X.

This hypothetical example illustrates two points about how one can deal with very small samples: (1) Under certain conditions the size of the sample can be increased by judiciously using estimates for the near future as supplements to the historical data base; (2) it may be

FIGURE 11

SUPPLEMENTING THE HISTORICAL DATA BASE

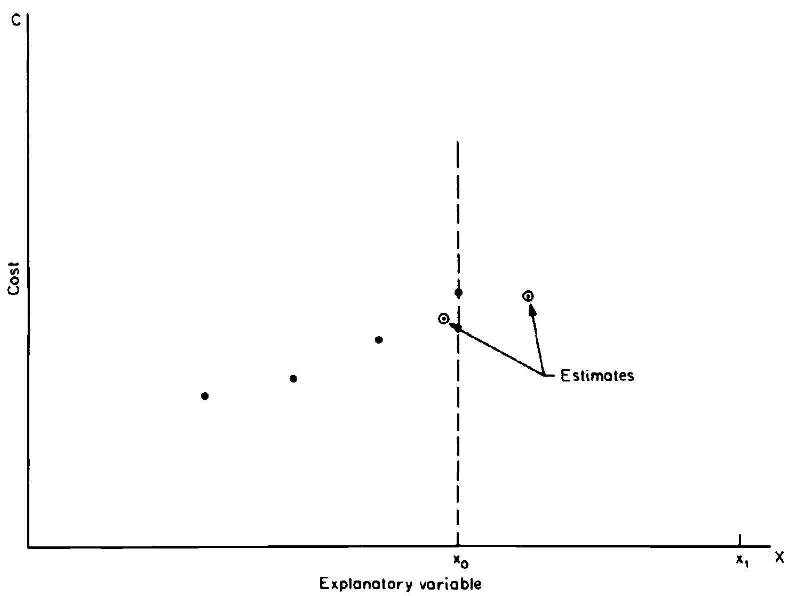
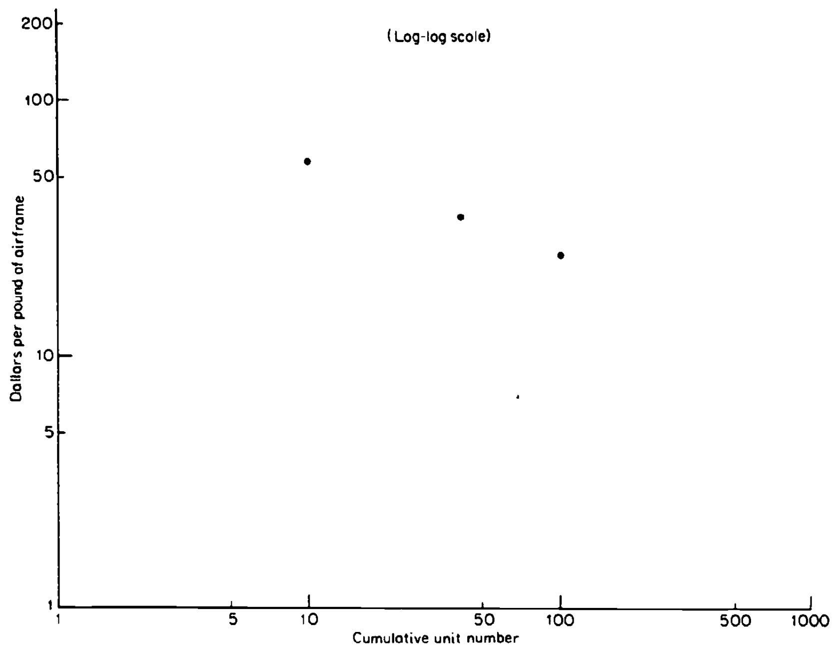


FIGURE 12

DOLLARS PER POUND OF AIRCRAFT WEIGHT VERSUS CUMULATIVE UNIT NUMBER



possible to use qualitative information to assist in deciding about what kind of estimating relationship is most appropriate.

As another example, let us consider a case where the sample is very small and we seek to gain additional information by lowering the level of aggregation one notch.

In the area of military major equipment cost analysis, cost-quantity relationships are very important. As the cumulative number of units increases, unit cost usually declines.[26] Suppose that we are interested in a certain type of aircraft airframe (call it X) and that we have only three data points. No other points are available for this particular airframe. The log-log plot of the data base is shown in Figure 12.

[26] For a thorough treatment of cost-quantity relationships, see Harold Asher, *Cost-Quantity Relationships in the Airframe Industry*, R-291, Santa Monica, Cal., 1956. Cost-quantity relationships in one form or another are also found in other areas. For example, in the automobile industry unit production costs after launching a new model are considerably higher during the earlier part of the production run than they are later in the model year. These "excess" costs are called "launching costs" in the automobile industry.

Assume now that the cost analysis is part of a systems analysis study in which large numbers of airframe *X* are being considered: 1000 or more. Should the analyst simply assume a log-linear relationship, connect his three data points, and extend the line out to cumulative outputs of 1000 or more? Most probably not. An experienced analyst knows all too well the dangers of mechanistic extrapolation, for scaling factor reasons and others as well.

Since in our hypothetical example the sample size cannot be increased, what can be done? One possibility is to see if additional information can be obtained by disaggregating. Suppose that our cost analyst goes back to the original data source and finds that additional detail is in fact available. He obtains a breakdown of the total airframe in terms of labor, material, and overhead. A plot of these data is shown in Figure 13. This slight addition to the data base immediately provides useful insights into the projection problem. If we assume log-linear relationships for the components (labor, material,

FIGURE 13

DOLLARS PER POUND OF AIRFRAME VERSUS CUMULATIVE UNIT NUMBER

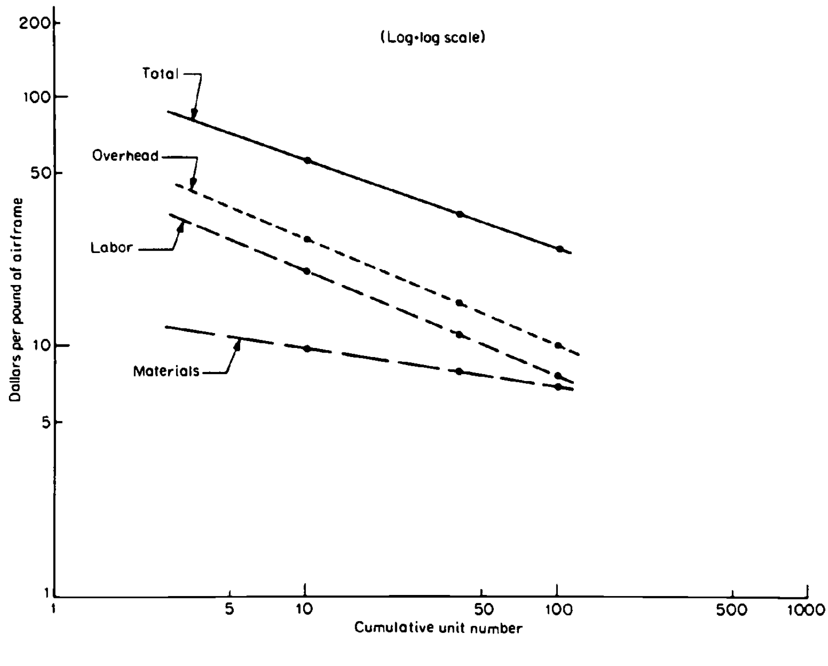
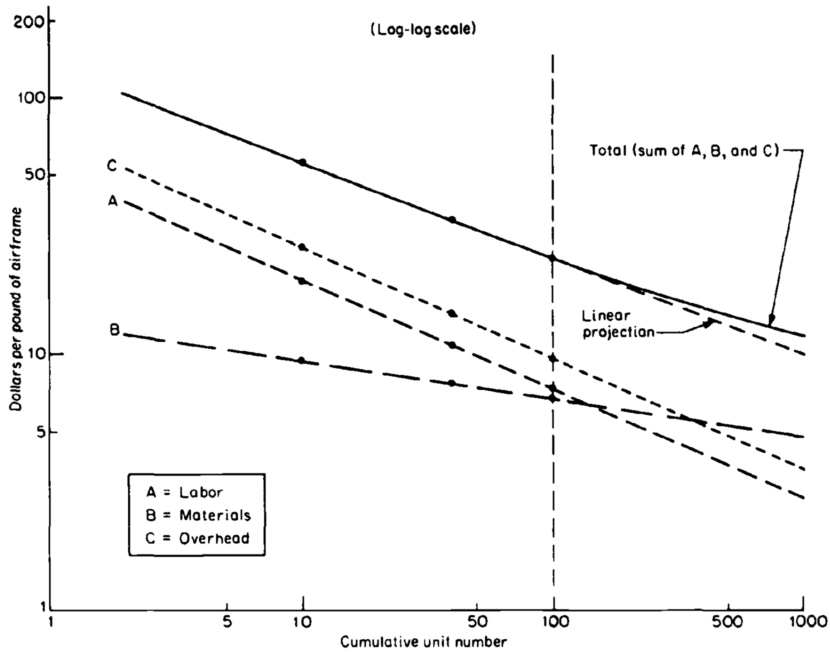


FIGURE 14

DOLLARS PER POUND OF AIRFRAME VERSUS CUMULATIVE UNIT NUMBER



and overhead),[27] it is obvious that on the basis of the available information the total curve cannot be log-linear when projected out to large cumulative unit numbers because the materials curve has a significantly different slope than the labor and overhead curves.[28]

If the curves in Figure 13 are extrapolated out to cumulative unit number 1000, the results are as portrayed in Figure 14. Here it is clear that the cost analyst has benefited from the information obtained by disaggregating one level in the data base. Merely extrapolating out to cumulative output 1000 on the basis of the three original data points no longer seems appropriate.[29] The difference between the two

[27] In general this is not necessarily a good assumption; but we shall use it here to keep the example simple. The argument is even stronger if the component curves are assumed to be convex on logarithmic grids.

[28] If the component curves are linear but nonparallel, the total curve (sum of the components) must be convex on logarithmic grids and must approach as a limit the flattest of the component curves (e.g., see Asher, *op. cit.*, pp. 70–72).

[29] The difference would be even greater if the component curves were assumed to be convex.

curves increases still further for cumulative unit numbers beyond 1000.[30]

This example illustrates how going into slightly more detail can help in cases where the cost analyst has to work with a very small sample. A word of caution is in order, however. The reader should not generalize from our example and conclude that in all (or even most) instances the assembly of a more and more detailed data base will, in itself, make for better understanding of the problem.

The Use of Experiments to Broaden the Data Base

Sometimes the cost analyst finds that in a given problem area there is simply a void in the existing formal data base. This is likely to be the case when the planners are considering new proposals for distant future programs or capabilities requiring major equipments and/or operational concepts markedly different from those of the past and the present.

In some instances the existing set of estimating relationships can be used to conduct simulations which will furnish a first approximation to the cost of these proposed new capabilities. In other instances, however, the cost analyst cannot assume that the structural parameters in the existing set of estimating relationships are appropriate for the new activities being considered. He must therefore develop new relationships, or devise techniques for adjusting the present ones. But how does he do this if the necessary data base does not yet exist? One possibility is to see if any experiments are being conducted pertaining to the subject at hand; and if not, to try to initiate such an experiment. Let us consider one example briefly.

A number of years ago, cost analysts were confronted with the task of estimating the cost of the first generation of proposed stainless steel airframes for the mid-1960s. These proposals usually required rather extensive use of stainless steel honeycomb paneling, the production of which would involve a significant advance in the manufacturing state of the art. The historical data base at that time was, of course, confined almost entirely to the experience accumulated in producing aluminum airframes, and little was in the formal records about the fabrication costs of stainless steel honeycomb panels—particularly large panels.

[30] The difference is only about $1.50 per pound at cumulative unit number 1000. At cumulative output 5000, the difference between the linear projection and the nonlinear total curve is about $3.00 per pound.

In the process of talking to the aerospace industry contractors regarding the problems involved in fabricating stainless steel structures, the cost analysts found that one of the companies was conducting a rather elaborate experiment. A special shop had been set up and numerous types of manufacturing operations were being performed on aluminum, stainless steel, and titanium structures. Taking aluminum as the base case, the objective of the experiment was to determine the probable incremental labor costs involved in working the other two materials for a representative sample of various types of manufacturing operations. Armed with these types of data from the experiment, the cost analysts were then in a position to devise techniques for adjusting the historical data base (aluminum experience) so that it would be more appropriate for dealing with the stainless steel airframe problem.

In visits to still other contractors' plants, the cost analysts found that several were experimenting with the construction of stainless steel honeycomb paneling. In sessions with the people conducting these operations the cost analysts obtained a wealth of information (both quantitative and qualitative) about how honeycomb cost might vary with core cell size and shape, shape and size of the panel, number of panel inserts, and the like. As a result, they were able to treat panels as a special cost analysis problem and hence to improve considerably their ability to estimate the cost of stainless steel airframes. The expenditure of the time and travel budget on field work paid off well.

Summary Comment

Rather typically, cost analysts supporting a systems analysis activity spend at least half their time struggling with the data and information problem. In this section we have tried to convey some flavor of the total problem and some notion of the types of techniques that may be employed to solve it. Basically what is required is ingenuity, persistence, and just plain hard work.

Summary

Systems analysis forms the central core of a program budgeting activity. A vitally important part of systems analysis is a cost analysis capability to generate estimates of the resource impact of alternative courses of action being considered for the distant future.

COMMENT

by EDWIN S. MILLS, *Johns Hopkins University*

Fisher's paper is a contribution to the large and growing literature on cost analysis in the area of national security. There are two ways of writing imaginatively on this subject. One may apply known techniques to practical problems in an imaginative way, or one may introduce an imaginative new technique. Unfortunately, I see neither in Fisher's paper. The latter alternative might, for example, consist of the study of a new production function and of related cost functions, or it might consist of the derivation of a new programing algorithm. No such innovations appear in Fisher's paper and he clearly views his mission as falling within my former alternative. But a contribution of this sort requires extensive empirical analysis so that one can use one's intuition to invent new ways of measuring outputs, trade-offs among inputs, etc. Almost all of Fisher's data are fictitious, and even the nature of the problem is frequently unspecified, presumably for national security reasons. The result is an impression of artificiality similar to the one left by examples in many elementary price theory textbooks.

In the course of his paper, Fisher hints at a number of interesting problems. My main criticism is that he stops the discussion at about textbook level. In addition, although some of the problems have been analyzed and partially solved in the literature, there is an annoying lack of reference to the standard price theory literature in Fisher's paper.

The rest of my comments refer to most of the significant problems raised in Fisher's paper.

The first problem discussed in the section on cost analysis in practice is that of deciding whether cost should be calculated as a function of the rate of output or of cumulative output. Although the former is typically used by economists, the latter has been used in many studies in operations research. Which is appropriate depends on the nature of the situation, and it would have been interesting to have some analysis of the conditions under which each is appropriate.

The second problem, discussed in connection with Figure 4, is that of choosing between two productive processes C and D, when it is uncertain how many units of either will be needed to achieve a certain output. Although the problem is a genuine one, Fisher contributes

Some of the principal characteristics of a systems cost analysis capability are:

1. An explicit relationship between inputs and outputs, with a strong emphasis on assessing the economic cost of alternative future output-oriented program packages.
2. Explicit treatment of uncertainty.
3. Provision for dealing with scaling considerations.
4. Explicit treatment of problems associated with time.
5. A recognition of the importance of sensitivity analysis, contingency analysis, and *a fortiori* argument.
6. Allocation of a substantial amount of time and effort to the continuous development and maintenance of an appropriate data base.

Establishing and maintaining a cost analysis capability to support systems analysis studies involves numerous difficulties. One of the most troublesome is the data base problem.

Solution to parts of the data problem may be through major overhaul of present formal information systems and through the establishment of new complete enumeration systems. This, however, does not appear feasible as a general solution—at least in the foreseeable future.

Short of such major efforts are numerous alternative possibilities. Some examples are:

1. Use of sampling techniques on an ad hoc basis.
2. Supplementing the existing historical data base by including estimated data points for the near future.
3. Statistical manipulation of the existing data base.
4. Obtaining additional information by conducting experiments.

SYSTEMATIC ERRORS IN COST ESTIMATES FOR PUBLIC INVESTMENT PROJECTS

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Introduction

This paper deals with one aspect of uncertainty in public investment on which very little research has been done—the extent, nature, and causes of error in estimating costs of public investment projects. Although there is general agreement among public investment specialists that cost estimates for project proposals typically fall short of actual costs of projects when completed, this view is based upon fragmentary information, often obtained from superficial comparison of project or program documents and reports.[1]

There is no over-all reporting of cost experience for federal public works; some reports of individual agency experience do exist, but much of the information lies unassembled and unanalyzed in federal, state, and local agency files. More significant for our purpose, even the

NOTE. Special thanks are due to the following for providing information and valuable comments and suggestions on the subject of this paper: G. P. Palo, Manager of Engineering Design and Construction, and members of his staff, Tennessee Valley Authority; Wendell E. Johnson, Chief, Engineering Division, Civil Works, Corps of Engineers, Department of the Army; Harry Shooshan, Deputy Undersecretary for Programs, U.S. Department of the Interior, and Blair Bower, Resources for the Future, Inc.

[1] Cost as used throughout this paper is defined as the money cost of construction and installation of capital facilities of a public works project; it excludes operation, maintenance and replacement costs. The definition does not include opportunity cost considerations. This definition excludes interest during construction (except where otherwise noted) and, with this exception, corresponds to the capital cost information collected by federal water-resource agencies and used as inputs to benefit-cost analyses.

readily available information has not been analyzed in terms of the extent, nature, and probable causes of difference between original estimates and final realized costs.

This paper makes only a small sortie into this largely unexplored field. Time and resources restricted the search to only one sector of U.S. federal investment—water-resource investment, by the Army Corps of Engineers, Tennessee Valley Authority and Bureau of Reclamation. The restricted scope of this study limits our ability to make generalizations. It also points to the need for much additional research on this aspect of public investment.

Extent of Previous Research

Our admittedly sketchy search of sources revealed very little published work on the cost question. This is true even in the field of water-resource investment, which has an extensive literature on benefit-cost analysis. For example, of six major books on water-resource economics,[2] only Eckstein's (1958) gives more than cursory attention to this question, and his discussion is limited to Corps of Engineers cost experience prior to 1951.[3] Altouney made a limited analysis (1963) of Bureau of Reclamation experience based on data collected by the Bureau in 1955.[4] Two of the most useful studies were concerned with cost experience overseas. Healey analyzed 13 water control projects built in India during the period 1946–60,[5] while a Select Committee on Nationalized Industries in Great Britain studied the cost experience of the North of Scotland Hydro-Electric Board in constructing twenty-four hydroelectric power plants.[6] A statistical study by two French

[2] Otto Eckstein, *Water-Resource Development: The Economics of Project Evaluation,* Cambridge, 1958; Roland McKean, *Efficiency in Government Through Systems Analysis, with Emphasis on Water Resources Development,* New York, 1958; John Krutilla and Otto Eckstein, *Multiple Purpose River Development, Studies in Applied Economic Analysis,* Baltimore, 1958; Jack Hirshleifer, James C. De Haven, and Jerome W. Milliman, *Water Supply: Economics, Technology and Policy,* Chicago, 1960; Arthur Maass *et al., Design of Water Resource Systems,* Cambridge, Mass., 1962; Robert H. Haveman, *Water Resource Investment and the Public Interest,* Nashville, 1965.

[3] Eckstein, pp. 149–151.

[4] Edward G. Altouney, *The Role of Uncertainties in the Economic Evaluation of Water Resources Projects,* Institute in Engineering-Economic Systems, Stanford University, 1963.

[5] J. M. Healey, "Errors in Project Cost Estimates," *Indian Economic Journal,* Vol. 12, July–September 1964.

[6] Select Committee on Nationalized Industries, *Report to the House of Commons,* Session Documents, Vol. 7, No. 304, 1956–57, London, H.M.S.O., 1957;