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COST-EFFECTIVENESS: ESTIMATING SYSTEMS COSTS

J. D. McCullough

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J. D. McCullough*
The RAND Corporation, Bethesda, Maryland

My objective is to discuss the significant features and general procedures involved in systems cost analysis. My remarks are directed particularly to the users of cost estimates -- either study directors who must direct a team of systems analysts and cost analysts, or systems analysts who must work with cost analysts.

It has been my experience that cost analysis, as an integral part of cost-effectiveness analysis, is applicable to a wide range of problems at various levels of activity, both in and out of government and military affairs. The origins of the cost-effectiveness approach, within our present context, however, are found in the problems of choice among future military systems. It is from such military planning problems, set in the longer range planning context, that our illustrations will be drawn in this discussion. To choose among alternative courses of action for future operations is of course a universal problem, and my illustrations can apply to other areas as well.

The assigned title of the paper, "Estimating Systems Costs," is a bit misleading in that I shall not attempt to tell how to make a cost estimate. In fact, there is considerable doubt among cost analysts as to whether it is possible to set out beforehand in cookbook fashion a set of procedures that, if followed, would result in a good analysis or estimate. If it were possible, then you could, upon learning the procedures, simply be sure to adhere to them and in that way have confidence in the resulting estimates.

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These remarks were prepared as part of a panel on "The Use and Estimation of Costs" at a Symposium on Cost-Effectiveness Analysis sponsored by the Washington Operations Research Council on June 14-16, 1965.

Unfortunately, the preparation of cost estimates remains for the larger part an art. Methods are, to a great extent, adapted to the problem at hand. Many subjective elements are included in the cost estimate. The availability and reliability of data are always variable. In sum, the individual skill, experience, and natural resourcefulness of the cost analyst emerge as the critical factors.

Nevertheless, a clear methodological base, set in certain principles and concepts, has been developed. A methodology for cost estimating has been developed, or more properly, has evolved, over the years. This methodology consists of various costing principles supported by a number of specialized analytical devices. Familiarity with this methodology contributes greatly to the system analyst's ability to appraise the appropriateness, accuracy, limitations, and usefulness of cost estimates. It also helps him to be able to specify with more exactness the costs needed for the particular cost-effectiveness study at hand. It is this methodology that I wish to discuss.

Making cost-effectiveness evaluations of alternative future systems has come to be known as <u>individual system analysis</u>. This type of analysis is particularly useful for decisions about undertaking development programs or procuring systems. Individual system analysis can be contrasted with <u>force structure analysis</u>, which examines the system mix or the composition of overall programs.

It should be made clear that even the costs of individual systems can be calculated more precisely through the use of total force structure analysis by first costing the total force with the system, then without it, the difference being the cost of the system. However, a large part of the extensive costing of the total force can be simulated and shortened by making reasonable assumptions about the balance of the force, and then concentrating on single systems. This method is used extensively in military planning. It is facile and highly flexible, and, on the whole, it yields satisfactory results for planning purposes.

For problems of choice among possible systems or other types of alternatives, the stress lies on <u>comparative</u> costs, or the cost of one possibility in relation to the cost of others. For such problems, therefore, system cost analysts tend to view costs as <u>indexes</u>. Considered as indexes, estimates indicate cost differences and the extent of such differences. Emphasis does not, on the other hand, fall on the absolute accuracy of costs. This concentration on cost comparisons is fortunate because, in the long-range time frame, a high degree of absolute accuracy in costs is indeed difficult to attain. Uncertainties seem to multiply as the time horizon is extended farther into the future. By contrast, cost estimating for the preparation of budgets, or for problems addressed to near-in time periods, must place emphasis on accuracy in costing.

The use of system cost estimates is well established in the Department of Defense. A Department of Defense Directive* that prescribes procedures for the development of military systems includes two provisions necessitating cost studies. Prerequisite 3 to the Project Definition Phase prescribes that a thorough "trade-off analysis" be made. Trade-off analysis, also termed "cost sensitivity analysis," is used to examine variations in system configurations for the purpose of increasing the system's effectiveness at a given cost, or, conversely, for the purpose of reducing cost without impairing the system's effectiveness. Prerequisite 6 prescribes a cost-effectiveness analysis of the system under consideration in relation to its alternative or substitute systems.

Chart 1 contains an illustration of the results of a cost sensitivity, or trade-off, analysis for a missile system. The sensitivity of cost is examined with variations in payload for three fuel types. Total system cost in this illustration is shown to be relatively insensitive to payload. It can be seen, however, that cost is sensitive to propellant types.

Chart 2 contains another illustration of the results of a trade-off analysis. The total system cost is examined in relation to variations in missile systems component reliability, as measured by the average length of time that a weapon can remain on alert status without maintenance (mean time to failure).

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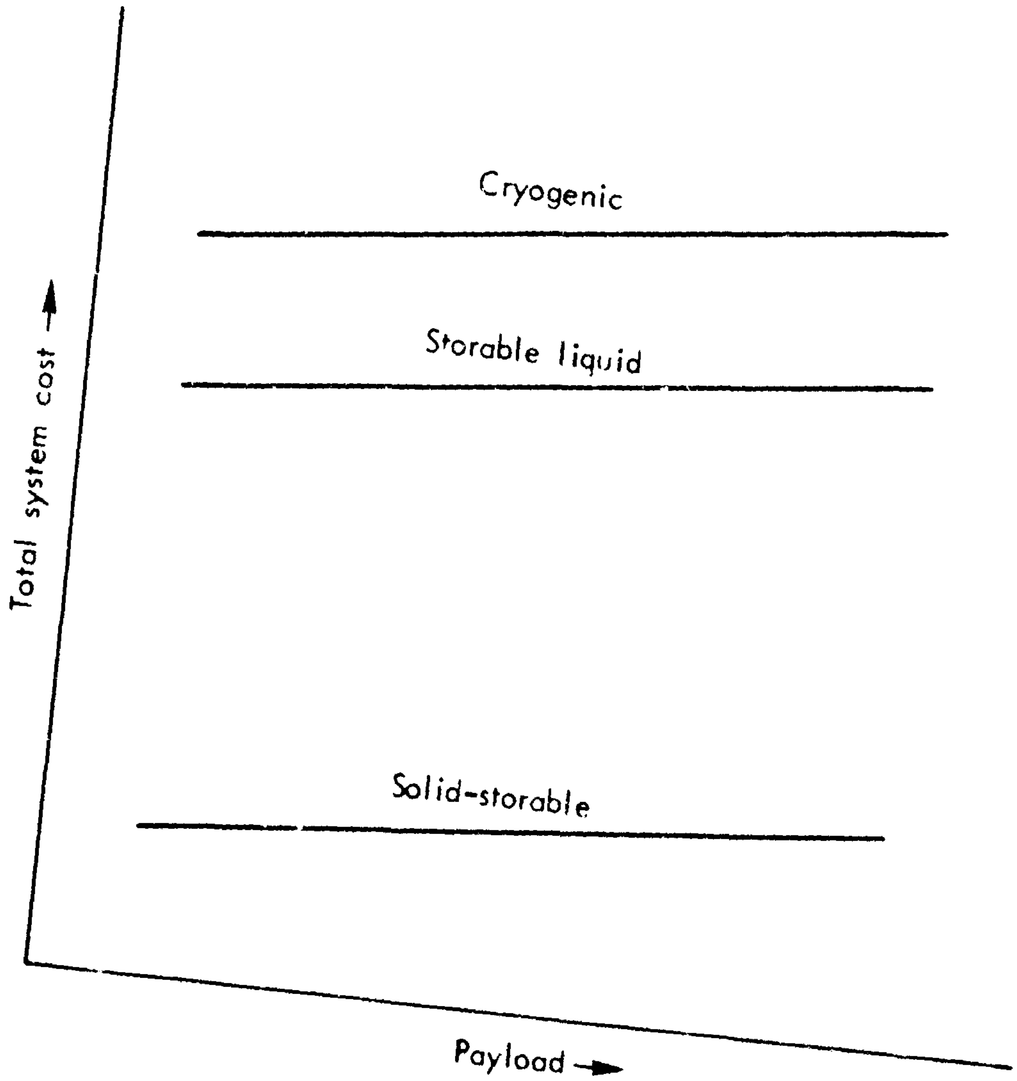

Chart 1— Trade-off analysis: Missile system cost versus payload for various types of propellants (fixed number of ready missiles)

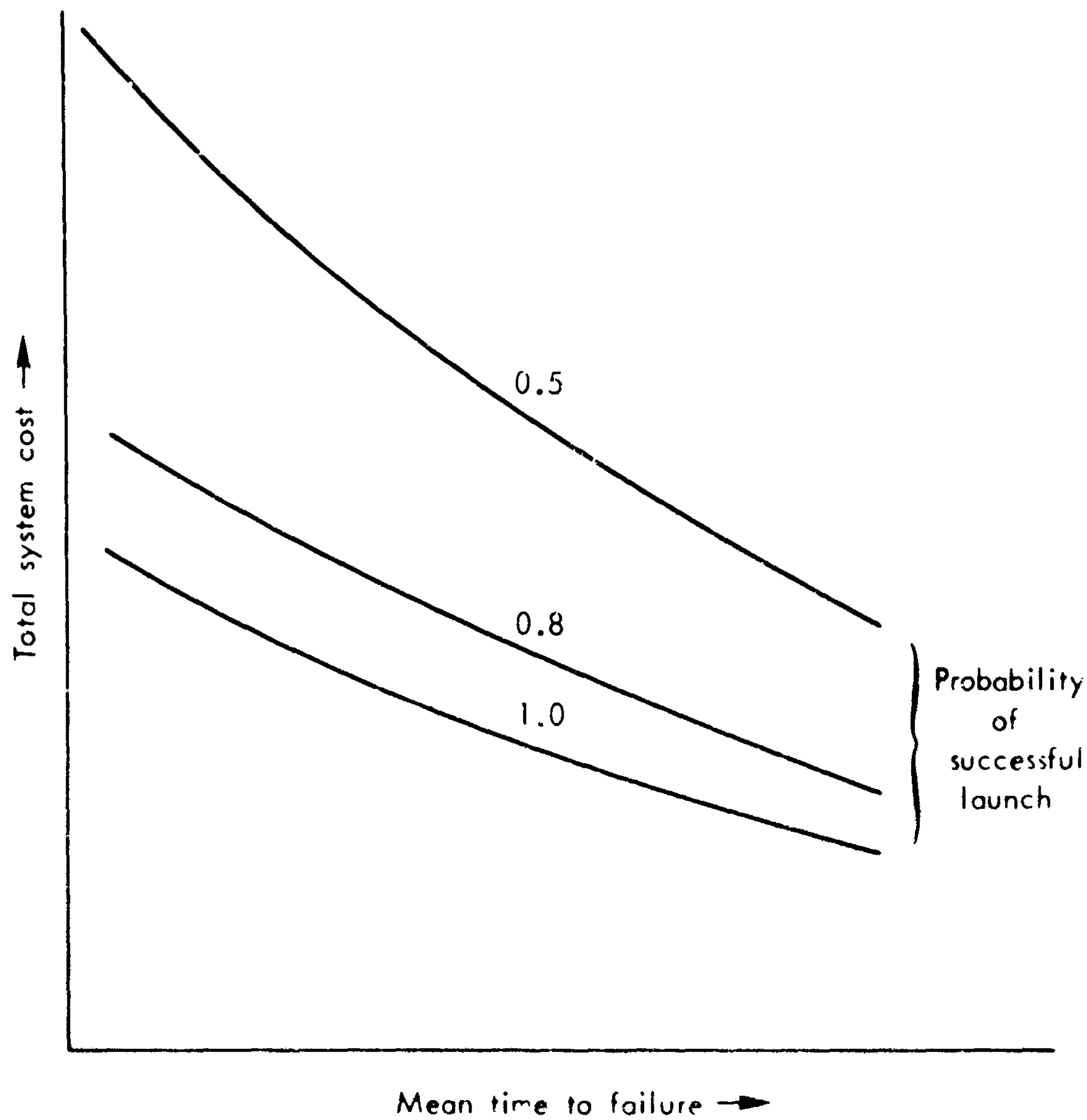

Chart 2—Trade-off analysis: Missile system cost versus mean time to failure for various probabilities of successful launch (fixed number of launched missiles)

Chart 3 is concerned with the costs of competing systems. These estimates serve to illustrate the requirement for cost-effectiveness analysis present in Prerequisite 6, described above. Cost is associated with force sizes for each of the three systems. Here can be determined for a fixed budget, (O-F) for example, the different numbers of squadrons that can be procured. The fixed-budget approach depicted in Chart 3 constitutes one of the approaches in conducting cost-effectiveness analysis. The other is the specified-effectiveness approach. These two approaches can be described as follows:

1. <u>The Fixed Budget Approach</u>. The criterion for choice in the fixed budget case is maximum effectiveness. Alternative means of attaining objectives are examined within specific budget levels. A fixed level of resources allocated in the most efficient manner would achieve the highest level of effectiveness. The specified military capability may apply to individual systems, combinations of systems, or complete programs.
2. <u>The Specified-Effectiveness Approach</u>. The criterion for choice in the fixed effectiveness case is least cost. Alternative means of achieving a prescribed capability or level of effec- are studied to determine how such effectiveness can be attained with the least resources. Here too the level of effectiveness may apply to individual systems, combinations of systems, or complete programs.

<u>FEATURES OF COST ANALYSIS</u>

Estimates of the future costs of military systems, forces, and programs are developed from systems cost analysis. The analytical approach to developing costs of military systems envisioned for time periods sometimes far into the future has a number of distinctive features. The more important of these are as follows:

1. End-product orientation.
2. Extended time horizon.
3. Incremental costing.
4. Life cycle costs.

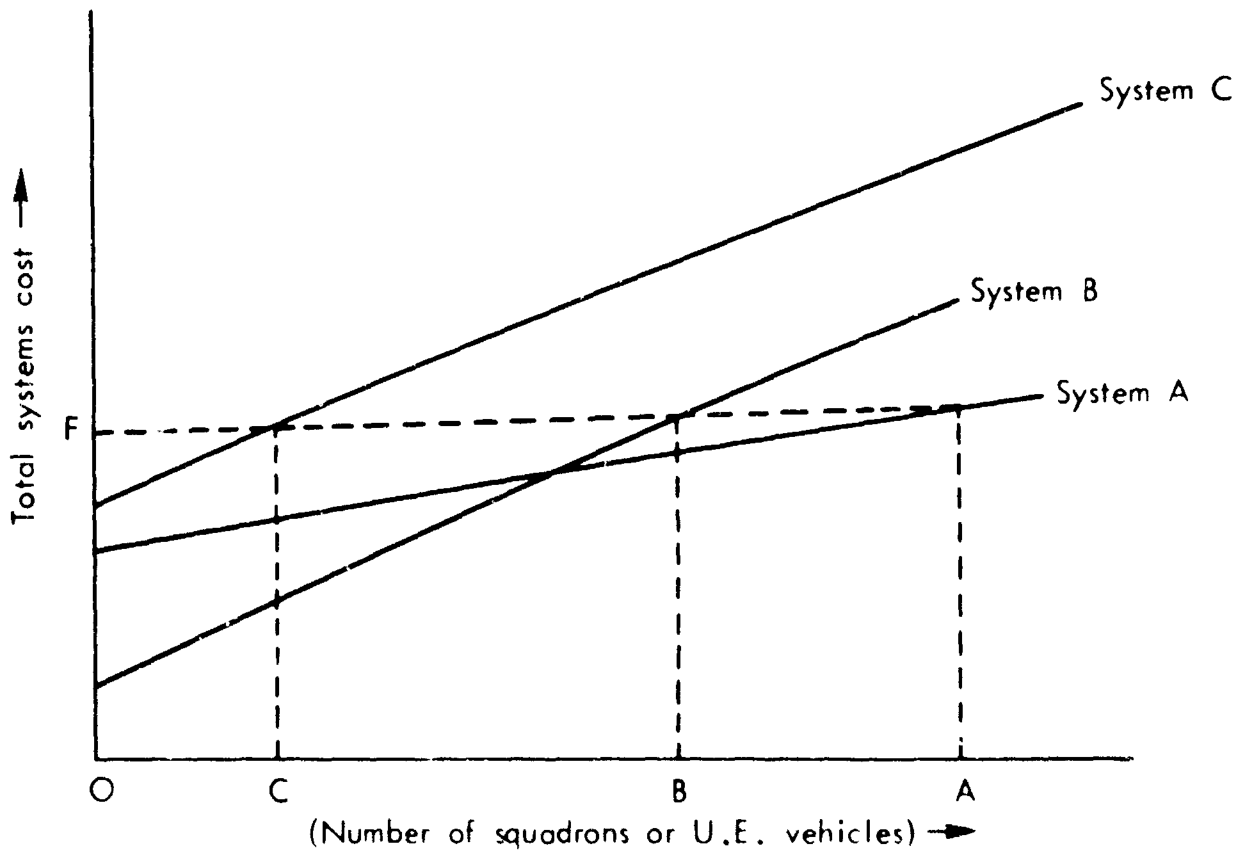

Chart 3 — Individual systems cost analysis fixed budget case

5. Constant dollars as the measure of resources.
6. Statistical techniques.

End-product Orientation

The end-product orientation of cost analysis reflects the systems approach of systems analysis. It is a basic principle of systems cost analysis that requirements for diverse resources be identified and associated with end-products, the end-product in our illustrations being the Air Force weapon or support system. The immediate problem is to identify all costs associated with the selection of a particular system. This reflects the view that decisions must not be based solely on the cost of the major equipment, or solely on personnel requirements, or on any other particular resource associated with the system, no matter how critical its role. Instead, the cost of a system should reflect the total resource impact of the decision relating to that system. Identifying and indicating the magnitude of all relevant costs of a particular system or course of action is the basic purpose of a cost estimate. The DOD Programming System, established by DOD Directives 7045.1 through 7045.5, refers to the basic end-product as "Program Elements."

Extended Time Horizon

Development decisions are often required from five to ten years before a military system can be brought into being. The span of time covered in a cost-effectiveness analysis must be sufficiently long to cover such lead times. The extended time horizon therefore becomes an integral part of cost analysis in its application as a technique for longer range planning.

This extended time horizon has important implications for the development of cost estimates. It brings with it a great deal of uncertainty, and the farther out in time the analysis is addressed, the greater the uncertainty. Costing equipment envisaged for ten years in the future, for example, often constitutes costing equipment never before produced. Involved are new materials, new manufacturing processes, new training concepts -- all of which make their costing difficult and the resulting estimates uncertain. Thus, stress is placed on the comparability of estimates rather than on their absolute values.

Incremental Costing

Cost analysis, like systems analysis which it serves, can be viewed as an application of the economic concept of marginal analysis. The analysis must always move from some base that represents the existing capability and the existing resource base. The problem is to determine how much additional resources are needed to acquire some specified additional capability, or, conversely, how much additional effectiveness would result from some additional expenditure. It is, therefore, the incremental cost that is relevant. Sunk costs are not included, and inherited assets are not costed.

Chart 4 contains an exampl of three systems and the various effects on total cost that resul from the exclusion of costs incurred earlier. In the one case, costs of the existing missile system include operating costs only. R&D costs and investments in the system were incurred earlier, and, consequently, omitted. The system occupying the middle position on the chart has inherited a limited number of silos from an earlier system. The system cost includes R&D and investments, except for the first 500 silos. After this inheritance has been exhausted, investment in silos is needed, resulting in an upward break in the cost curve. The other system inherits no silos. Its cost curve is higher and has no breaks.

These are the costs that are relevant to decisionmaking. To account for all costs, including sunk costs and inheritances, might be viewed as the "equitable" or "fair" approach but would not be an appropriate input for decisionmaking purposes.

The use of other costing concepts such as opportunity cost, the inclusion of residual values, and the consideration of amortization is also being explored. However, considerably more work on costing methods will be needed before such concepts can be put into wide practice.

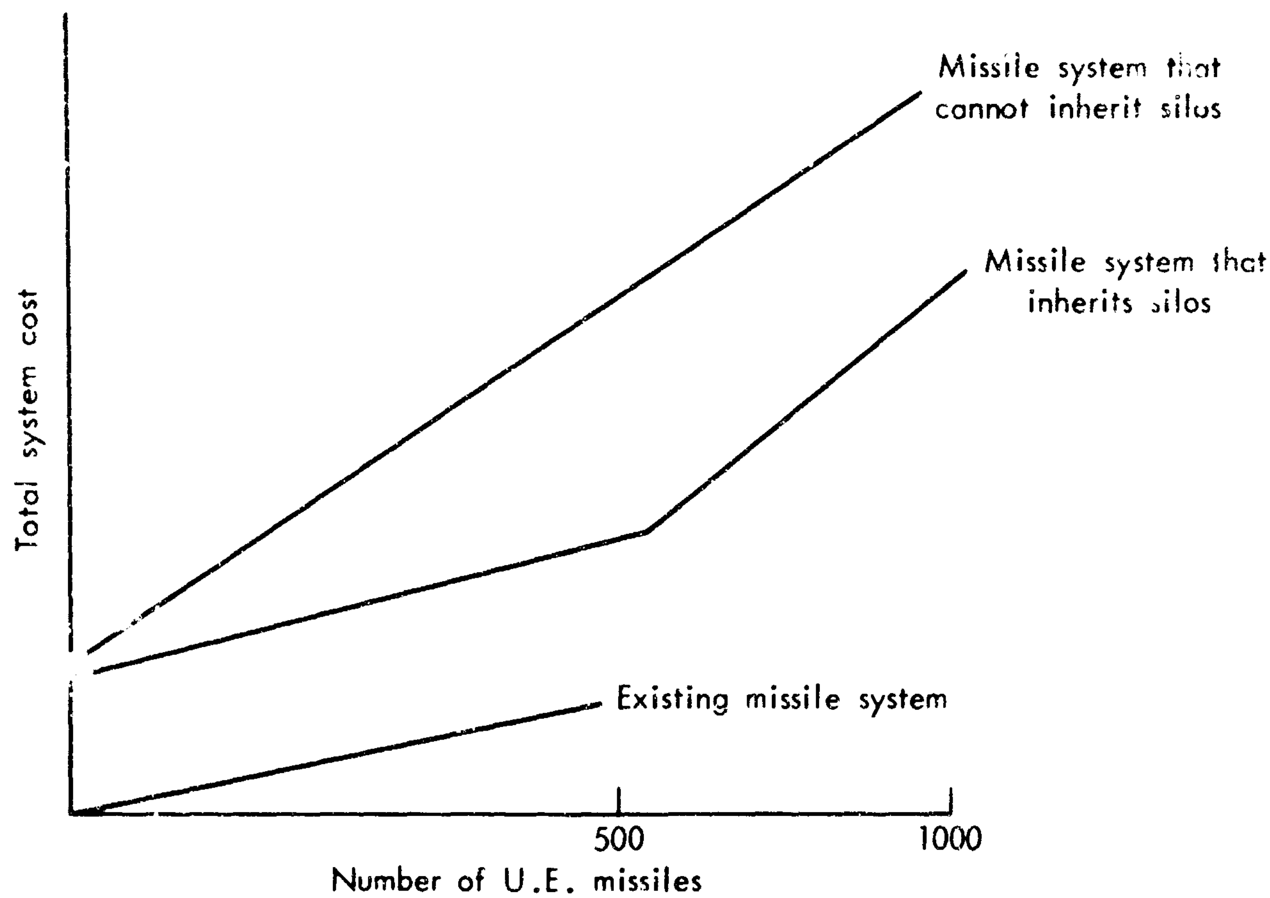

Chart 4 — Effects of "sunk" costs on total system costs

Life Cycle Costs

One distinctive feature of systems cost analysis (which has also been adopted in the DOD programming system) is the use of cost categories. System costs are identified and grouped as (1) research and development, (2) initial investment, and (3) annual operating costs. These cost categories reflect the life cycle approach of military system cost analysis. Life cycle costing results from the principle that the funds necessary to undertake a program are not the primary consideration, nor are the funds required in any particular time period; but a decision to undertake a particular course of action should take into account its total cost impact over time. The cost of developing the system must be accounted for; and the cost of procuring the system, and also the cost of operating it as a component of the force, must be taken into consideration. Definitions of the cost categories are as follows:

1. Research and Development. Costs primarily associated with the development of a new system or capability to the point where it is ready for introduction into operational use. This category includes prototype equipment and test vehicles used in a development program.
2. Investment. Costs beyond the development phase to introduce new systems or a new capability into use.
3. Operations. Recurring costs of operating, supporting, and maintaining the system or capability.

A system's research and development costs are one-time costs and are, in effect, a function of the nature of the system. Research and development costs are essentially insensitive to the number of units of the system that will be procured or the length of time that the system will be in operational use.

Investment costs are a function of the number of units planned for the system. The greater the number of units to be introduced into the program, the higher the investment cost. Such costs are essentially one-time costs per unit.

Operating costs depend on both the number of units in the program and the length of time that such units are operated, supported, and maintained.

These three distinct categories are useful in making program decisions. The R&D costs are concerned with development decisions and the choice among feasible alternatives. The investment costs concern the extensiveness of the system's employment or the relative importance that the system should occupy in the program. The operating costs concern the manner and the length of time that the system should be operated.

Chart 5 depicts cost category patterns over the life cycle of a system. The cost category levels are illustrative of typical patterns for individual systems.

Each category includes certain costs that are also in other ways significant for the planning of forces. Relationships among such categories of cost are important. For example, a system with higher development and investment costs but lower operating costs may, depending on its service life, become the least-cost system. Trade-off possibilities between one-time and recurring costs can be examined through the use of cost categories. Additional expenditures in investments may be justified through an offsetting reduction in operating costs.

The cost categories also reflect important distinctions in the allocation of resources. An expenditure for research and development represents an allocation made for the purpose of extending technology. It creates possibilities for new approaches but does not in itself provide new capability. Expenditures as investments, however, are for the purpose of adding capability. Investment allocations depend in most instances on the execution and success of prior research and development allocations. Expenditures for operations and support of systems essentially sustain capability but do not add to it. The allocations or expenditures that are possible, however, depend heavily on prior allocations for R&D and investments. Effective programming attempts to achieve an economic and technological balance over time among the three types of allocations.

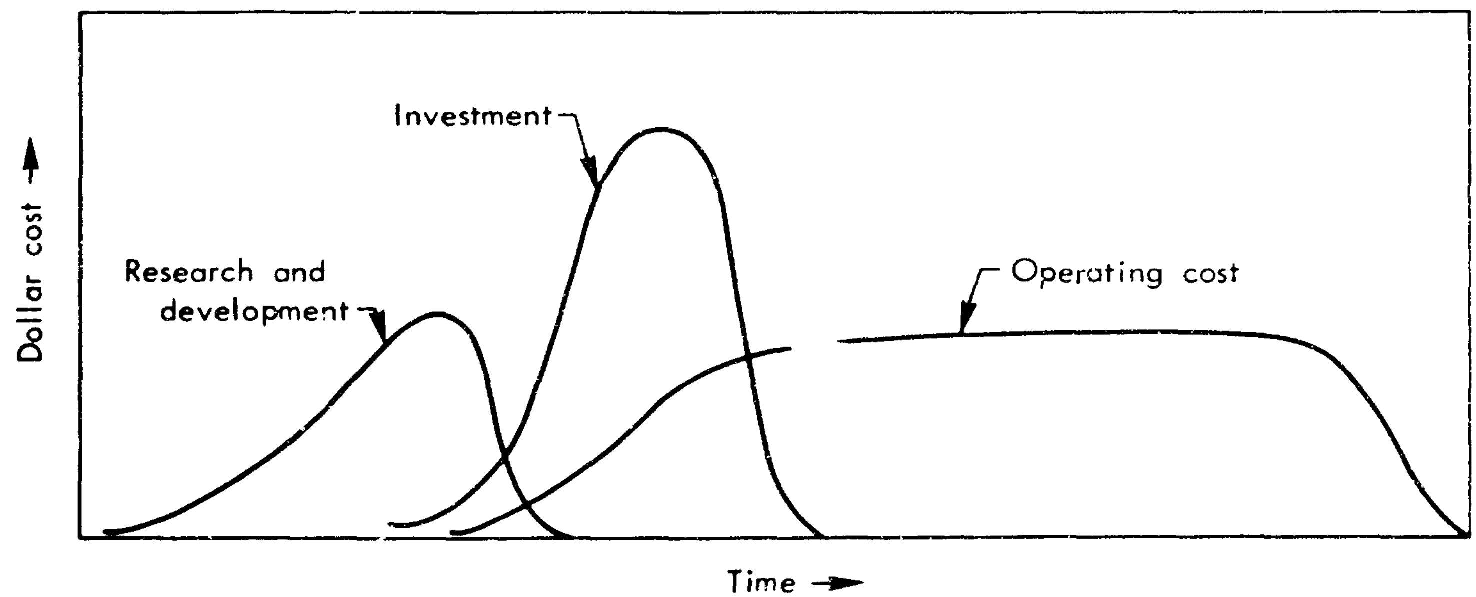

Chart 5—Life cycle costs: Illustration of system "life cycle" identification plotted against time

Dollars as a Measure of Resources

As described earlier, the purpose of cost analysis is to develop estimates of future resource requirements for military systems. Resource requirements are in terms of equipment, personnel, real facilities, supplies, etc. A total system cost cannot, however, be developed by summing over such a heterogeneity of resources that make up a military system. Nor could understandable comparisons be made between systems if their costs were expressed solely in terms of varieties of real resources. The dollar cost of such resources can serve the purpose. Hence, the standard of measure selected for cost estimating is constant dollars. Also, beyond near-in time periods, fund allocations do in fact become the critical measure. No attempt is made to predict price level changes in comparing or evaluating alternatives.

The Analytical Approach and the Use of Statistical Techniques

Military systems under study are often technically advanced far beyond our range of experience. In the early consideration of such systems, specifications cannot be defined with exactness. As mentioned earlier, many of the components of future systems have never been constructed before, and no cost experience exists. To project costs beyond the range of experience places the emphasis on analytical processes. The use of statistical methods assists in this analysis. Data on past and existing systems are analyzed statistically to derive relationships between costs and the system characteristics known at the outset. Such characteristics could be performance characteristics such as speed, or physical characteristics such as gross weight. The purpose of such analysis is to develop cost estimating relationships (CER's) suitable for predicting costs of future systems. Scatter diagrams, regression analysis, and correlation analysis are examples of statistical techniques useful in the development of such cost estimating relationships.

The use of statistical analysis and the resulting cost estimating relationships can be contrasted with an attempt to develop detailed work statements and material lists for cost estimating. In most instances, such detailed specifications are simply not available. Further, for advanced systems, there is considerable doubt as to whether the laborious effort required to develop such detailed work breakdown lists can be justified by an improvement in the final accuracy of the cost estimate.

STEPS OF COST ANALYSIS

As mentioned earlier, there are no set rules or fixed procedures which if followed would insure the successful accomplishment of a reliable system cost estimate. However, there is a general approach to system cost estimating that can be described. This approach can be viewed as a series of steps in the development of a cost estimate. These steps are as follows:

1. Defining the problem.
2. Collecting data.
3. Deriving the estimate.
4. Presenting the estimate.
5. Documenting the analysis.

Although these steps are outlined as though they are sequential and discrete, there is in the practice of developing cost estimates a considerable amount of indefiniteness between steps and a good deal of looping back as the study progresses. For example, the derivation of cost estimates may cause the system analyst to reconsider alternatives, thereby redefining the problem for the cost analyst. The derivation of the estimate could also identify needs for additional data. Further, documentation efforts to some degree must be undertaken at the very beginning of the study. It should be kept in mind therefore that these steps should be viewed largely as a tendency in the development of a cost estimate.

1. Defining the Problem. The problem definition phase requires very close contact between the cost analyst and the systems analyst so that the system to be costed can be described adequately for costing purposes. The cost analyst needs two things before he can begin to cost a system: (1) a description of the system to be costed, and (2) cost ground rules for the particular study.

System descriptions needed by cost analysts can differ considerably from those used by systems analysts. The cost analyst needs a description of the system oriented to his own "tools," i.e., the cost element list and the cost estimating relationships.

For example, the flying hour program of aircraft is usually important for costing, while many performance data are normally of lesser importance. The reverse could be true for the systems analyst who could place a great deal of importance on performance and perhaps disregard activity rates. So the required system description is specialized for cost purposes. Usually direct communication between the cost analyst and the systems analyst is necessary in order to develop an adequate system description.

Table 1 illustrates the types of data required for system descriptions. Both equipment specifications and operational assumptions must be covered.

In addition to the system description, there is the need for a complete understanding of the study ground rules. The ground rules, in effect, represent the assumptions underlying the study. Examples of study ground rules are as follows:

(a) Kind of cost index to be used (example: ten-year system cost.

(b) Date when all prior costs will be considered sunk costs (example: FY 1967).

(c) Rules regarding amortization or discounting.

(d) Rules regarding costs of other agencies (example: for DOD, the AEC).

(e) Special rules regarding base operating support personnel, attrition rates, etc.

2. Collecting Data. Data are of prime importance, and efforts to develop a satisfactory data base must be started long before it becomes necessary to use such data for specific projects. An adequate data base must cover needs for specific systems: types of resources, cost equations, cost factors, etc. Such data should be incorporated in a data bank that would provide the following:

Table 1

SYSTEM SPECIFICATIONS AND ASSUMPTIONS (EXAMPLES)

I. Primary equipment specifications (if possible, by major components, e.g., airframe or structure, propulsion, guidance).

A. Performance specifications.

1. Examples for airframes:
   a. Speed
   b. Combat radius
   c. Climb
   d. Ceiling
   e. Range
   f. Load

2. Examples for electronics:
   a. Frequency
   b. Continuous vs. spasmodic operation
   c. Functions to be performed and speed of computation
   d. Accuracy (e.g., in terms of deviation over time and/or drift rate, discrimination capability, etc.)
   e. Jamability

3. Examples for engines:
   a. Rating
   b. Specific fuel consumption
   c. Operating temperature

B. Weight data.

C. Other physical data.

1. Examples for airframes:
   a. Size data (e.g., fuselage length, wing area, wing span, etc.)
   b. Construction characteristics
      (1) Sheet and stringer
      (2) Sandwich, waffle, etc.
      (3) Foamed metal
      (4) Welded vs. riveted
      (5) Castings, forgings, extrusions, weldments, etc.
   c. Basic metal types (with respect to items in b., above)
   d. Tolerances (with respect to items in b., above)

2. Examples for electronics:
   a. Volume
   b. Type of construction technique (tube, transistor, modular)
   c. Number of tubes or transistors
   d. Number of stages
   e. Power requirement
   f. Antenna diameter (for radars)

Table 1 (Cont.)

SYSTEM SPECIFICATIONS AND ASSUMPTIONS (EXAMPLES)

D. Who the manufacturer is or is likely to be.

II. Ground support equipment specifications analogous to those listed under I.

III. Operational concept specifications or assumptions and related matters. Examples are:

A. Force size.
B. Geographical deployment (especially overseas vs. ZI).
C. Dispersal scheme.
D. Activity rates.
E. Fixed or mobile system and description thereof.
F. "Hard" or "soft" system, and psi specification if hard.
G. Organizational concept: wing, group, etc., and number of squadrons per wing or group.
H. Alert capability and related manning concept.
I. Degree of system automation, stated by function if possible, in relation to manning and GSE requirements.
J. Number of years the system is to be in the operational inventory.
K. Training concepts; and in the case of missile systems: (a) number of missiles to be used in initial training, (b) number of live firings for "proficiency" training purposes per year.
L. Logistics support concepts, especially regarding depot maintenance (AMC depot, or contractor?). Is there to be a "central support' area?
M. Permanent or temporary facilities?
N. Tenant or nontenant operation?
O. Main aspects of the development program, especially number of vehicles in the test inventory.

(a) A means for indexing and classifying cost and related data.

(b) A physical facility for the storage of data.

(c) A means for ready access to the data by the analyst.

It is difficult to describe beforehand in a precise way the means of handling data needs for specific projects. This is primarily because data needs and availability vary considerably from system to system. Such variations stem for the most part from the status of the system, i.e., according to whether the system is in the conceptual phase, in the development phase, in the process of procurement, or currently in operation. As a system progresses through the various phases from the conceptual to the operational phase, more and more data become available. In the early phases, system descriptive data are meager indeed. In the later phases, contractor data and various other sources become available.

In sum, data occupy a critical place in the cost estimate. Preparations to meet data requirements must be started early, and data must be maintained continuously to be available for the diverse needs of cost estimating. DOD Directive 7041.1, "Cost and Economic Information System," establishes a DOD-wide system for collecting development and production cost information on major military hardware. The procedure will soon be implemented.

3. Deriving the Estimate. This step in the process is concerned with the actual calculation of the dollar estimate. Cost estimates are developed within the framework of cost element lists. Cost elements are subdivisions of the cost categories: R&D, investment, annual operating. The total cost principle of cost analysis provides that all costs associated with a system be identified and included. The development of a cost element list serves this purpose. Flexibility in the makeup of the cost element list is necessary because no single list can satisfy the needs of all systems. Cost element lists must be adapted to the type of system, the nature of the problem, and the type of analysis. However, its basic function is to identify and account for all elements of cost associated with the system. The ideal list is one that

highlights the key features of the system, while, at the same time, permitting maximum use of data collected from past systems. The list must also be translatable into budgeting and programming terms. Table 2 contains an illustration of a cost element list for a missile system. The successful development of a cost element list therefore establishes the detailed framework for cost estimating. The calculation of the cost is accomplished through the use of estimating equations or cost estimating relationships. Cost estimating relationships, either singly or in combination, are applied to specific cost elements.

A CER can be defined as a mathematical expression that describes, for estimating purposes, the cost of an item or activity as a function of one or more independent variables. Estimating relationships are basically of two types:

(a) Those used to estimate physical quantities -- e.g., numbers of aircraft, numbers of personnel, or activity rates. An example would be a relationship expressing supporting personnel as a function of the number of direct operating personnel.

(b) Those used to estimate the dollar cost impact -- e.g., cost of turbojet airframes as a function of aircraft gross weight and speed.

Two examples of CER's are shown in Table 3. The first example (I) represents a CER used to estimate physical quantities; the second (II) represents a CER used to estimate dollar cost directly.

Deriving the estimate constitutes the culmination of the analysis. The cost elements, the estimating methods, and the resource data are all brought together to derive the dollar estimate. A well-conceived and well-developed cost estimating capability is comprised of cost element identification, CER's, and resource data -- which are directly related to one another. Development of CER's must be directed toward specific cost elements. Data gathering must likewise be focused on specific cost elements and specific cost estimating relationships.

Chart 6 depicts the learning curve process that is used extensively in estimating costs. Costs are expressed as a function of production

Table 2

TYPICAL MISSILE SYSTEM COST ELEMENT LIST

Missile System B
Ten-year System Cost
(millions of dollars)

	No. of Squadrons			
	5	10	15	Basis of Estimates
R&D				
Propulsion				
Guidance				
R/V				
Other				
Total R&D	3.0	3.0	3.0	
INVESTMENT				
Flyaway--Missile				
Peculiar AGE				
Site Activation				
Specialized Tng. Eq. & Devices				
Spares Support--Initial				
Modifications				
Aircraft Procurement				
Military Construction				
Other Procurement				
Total Investment	5.0	9.0	13.0	
OPERATING				
Depot Maintenance--Missile				
Repl. Spares--Missile				
New Other Support				
Civilians--Pay				
Officers--Pay & Allowances				
Airmen--Pay & Allowances				
Other Procurement				
Aircraft Procurement--Repl. Spares				
Total Operating--1 Year	0.2	0.4	0.6	
Total Operating--10 Years	2.0	4.0	6.0	
TOTAL TEN-YEAR SYSTEM COST	10.0	16.0	22.0	

Table 3

COST ESTIMATING RELATIONSHIPS

I. Attrition Aircraft as a Function of Flying Hours

CER for fighter aircraft attrition:

6.5 aircraft per 100,000 flying hours

II. Aluminum Aircraft Airframe Manufacturing Labor Cost as a Function of Weight and Speed

CER for manufacturing labor cost:

(1) Log manufacturing hours = 0.16314 + 0.73672 log gross weight + 0.43113 log knots + 0.12136. Solution yields manufacturing hours at quantity 100.

(2) Manufacturing cost at quantity 100 = hours x $/hour

(3) Manufacturing cost at quantity X = kaX^b,

where

k = factor to convert hours at unit 100 to hours at unit one

a = cost at 100th unit

X = quantity desired

b = slope (for ___% reduction curve)

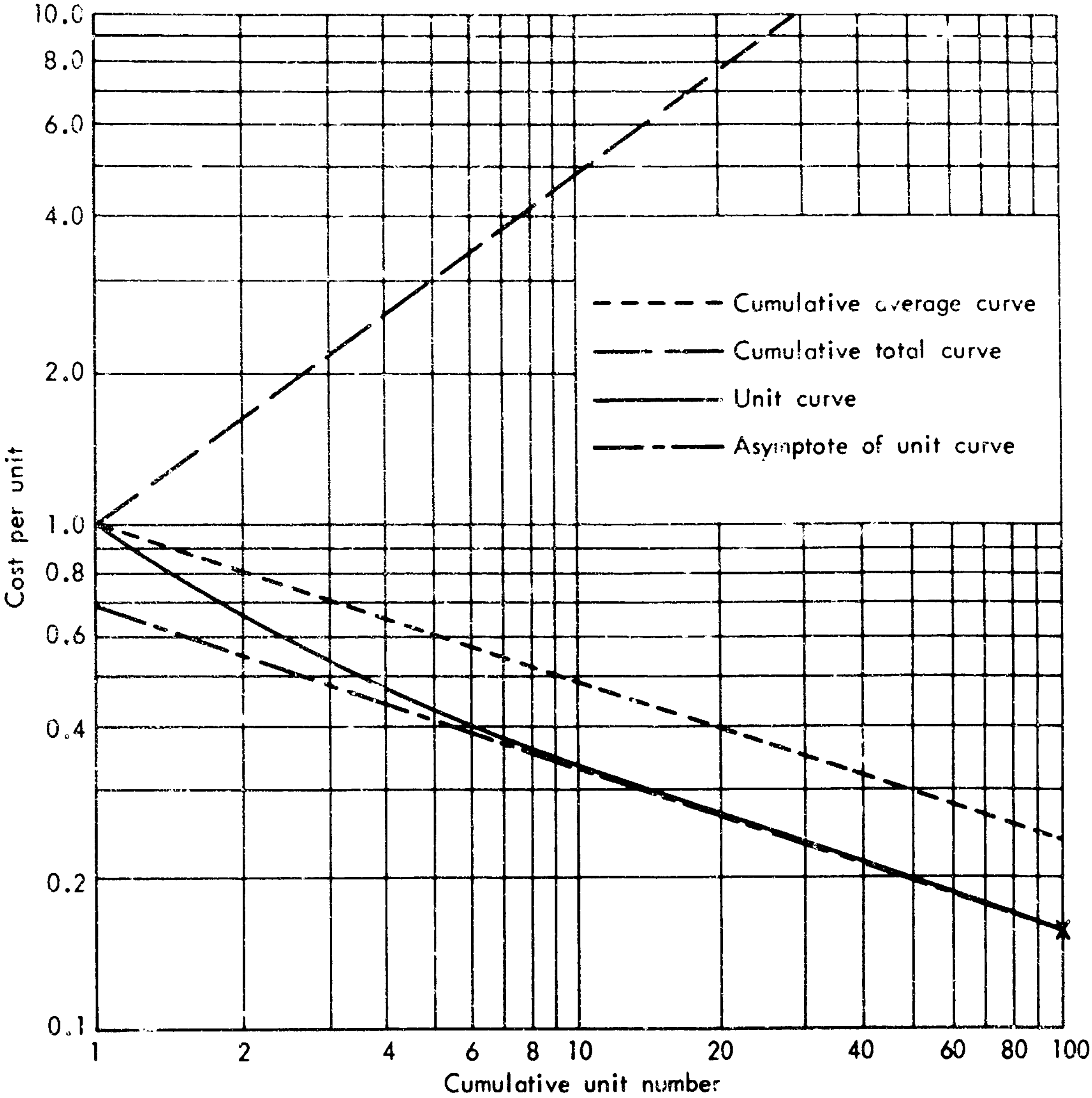

Chart 6— Progress curves resulting from the assumption of a linear cumulative average curve on logarithmic grids

quantities. The chart includes cumulative averages, cumulative totals, and unit costs. The progress curve is a special case of cost estimating relationships, and because of the extensive discussion of the learning or progress curve in the general literature, it will not be elaborated on here.

4. Presenting the Estimate. This important step is concerned with the cost analysts' communication with the users of their analyses. It is directly related to the first step, the problem definition. The analyst must present his estimates in terms appropriate for the decisions to be made. These terms will vary with each study. It is suggested that users of costs receive "pro forma" output formats from their cost analysts during the early phases of a study for joint consideration and review.

5. Documenting the Analysis. A proper documentation of the study is important to both the cost analyst and the users of estimates. It provides the analyst with a record of the study and also serves as a source for material to be used in later studies. Studies themselves serve as valuable sources of data for inclusion in the data bank.

Documentation is particularly important to the user of the cost estimate in his evaluation of the study. Documentation should openly and clearly describe the procedures, data, and sources used. It should also permit the estimates to be reproduced by following the process and facilitate the review and evaluation of data, sources, inputs, and methods.

CONCLUDING REMARKS

This discussion of concepts, principles, and the general approach toward the development of system cost estimates is intended primarily for users of estimates, rather than for cost analysts. An understanding of cost analysis can assist considerably in the use of cost estimates. Both the value and limitations of such estimates should be better understood for their proper application in cost-effectiveness analysis.

Users face a critical task in judging cost estimates and evaluating them as to suitability and credibility. The most obvious measure of the goodness of an estimate, of course, is whether or not it finally proves to be accurate. In the realm of long-range planning, however, that would take about 10 years, and the estimate is meant to serve decisionmakers now.

Emphasis therefore must be shifted toward an evaluation of the validity of the study itself and the analysis underlying it. Data, methods, and conclusions must be subjected to intelligent and critical review, and in such a review, the user of cost estimates must pose a number of questions, such as the following:

. Have the quantitative factors been properly identified and measured?
. Have the uncertainties been singled out, described, and, where possible, measured?
. Has the study been properly documented? Have the problem definition, the data and their sources, and the methodology been made explicit?

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