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COSTING METHODOLOGY HANDBOOK

APRIL 1971

DEPARTMENT OF THE ARMY

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Prepared by

Comptroller of the Army Directorate of Cost Analysis

Washington, D. C.

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PREFACE

This handbook, in conjunction with a revised AR 37-18 (Weapons/Support Systems Cost Categories and Elements), is published in response to a need expressed in the Weapon System Acquisition Improvement Program to provide a vehicle for developing a standard cost methodology. The handbook attempts to fulfill part of this objective by providing a better understanding of the cost estimating/analysis process, by promoting standardization in cost analyses, and by contributing to a better cost analysis capability in the Army. The revised AR 37-18 provides more detailed guidance and standardization requirements. The handbook further contributes another step toward attaining the objectives of the Army Cost Analysis Program as stated in AR 11-18.

PART I - THE PROCESS OF COST ESTIMATING

SUMMARY

This handbook is a compilation of subjects covering the spectrum of cost estimating and cost analysis. The subjects are broken down into two major parts: (1) the process of cost estimating and (2) other special considerations which affect the cost estimating process. Three appendices covering subjects of general interest are also included.

The analyst must first realize that cost analysis emphasizes the systems approach. An individual development or production estimate, for example, is part of a larger system - the Life Cycle Cost Estimate (LCCE). The LCCE of a material system then becomes part of an even larger system - the management system for development of Army systems. The analyst must understand the system within which he labors and the effects on cost estimates of the dynamic nature of that system.

At a more specific level it is acknowledged that cost estimating requires a myriad of information. This includes information relating to the physical and performance characteristics of the system under study, management information relating to the system, and historical information relating to comparable systems. Emphasis is placed on the major sources of information and the configuration of that information.

At the heart of cost analysis are those techniques by which cost estimates are made. These are: the parametric approach; the analogy approach; the engineering approach, and expert opinion. Of the four, the parametric approach is considered most useful and receives heaviest emphasis. The use of a specific approach varies with the amount and reliability of data available and each approach has limitations.

Computation of the estimate does not complete the job for the cost analyst. Invariably there are uncertainties in the estimate which must be itemized, quantified, and evaluated. Additionally, the sensitivity of the estimate to possible fluctuations of input parameters must also be quantified and evaluated if the estimate is to be of use to decision makers. Some common means of expressing these aspects of cost estimating are presented. Appendix A emphasizes the development and the use of mathematical models in the estimating process and in evaluating the estimate validity and sensitivity.

An analysis must further weigh economic considerations as they impinge on the cost estimate. The effects of the present value of money and inflation can significantly change the perspective in making trade-offs among projects which have differing expenditure and cost/benefit patterns over time.

Conducting an analysis or making an estimate is only part of the task for an analyst. The study must be presented in a form which is understandable and usable by the individual who must make decisions based on the study. The presented study must be fully documented, the assumptions clearly stated and the alternatives properly considered. Presentation guidelines and formats are offered to assist both the analyst and the decision maker.

Of further use by the analyst at particular points in the system life cycle are those means by which cost growth is defined and measured, by which cost effectiveness analyses are conducted and by which controls may be established. In the latter case a relatively new concept for evaluating cost estimates, derived from a Study of Trends and Escalation of Costs (STECPLOT), should be considered by the analyst as a potential control device.

It is these aspects of cost analysis which are presented in detail in this handbook in support of the Weapon System Acquisition Improvement Program and in pursuit of the Army Cost Analysis Program Objectives.

CHAPTER 1

THE LIFE CYCLE AND DECISION POINTS

As a system progresses from the concept phase to full deployment, increasingly complex decisions must be made which commit the Army to greater expenditures of resources. Decisions can be more competently made if, at each significant stage, the decision-maker is provided an accurate estimate of all the costs associated with that system from birth to death. Estimates of this type are called Life Cycle Cost Estimates (LCCE).

Realistic Life Cycle Cost Estimates should be provided as early as possible in the life cycle. It is recognized that in early system stages little information may be available from which to derive a complete estimate. Still decisions must be made early in the life cycle and therefore estimates should be made as early as possible and updated continuously as the system progresses and more data is made available. Parametric estimating techniques are recommended for early estimates when little information is available (see chapter on Techniques of Costing). Later in the life cycle the use of other techniques are made possible by the availability of more firm data.

To develop a LCCE, the cost analyst must consider all costs from research and development through investment and operation of the system. DA Pamphlet 11-25, Life Cycle Management Model for Army Systems,1/ describes a Life Cycle in a manner different from a simple accumulation of costs and, since many of the management documents are related to that description, it is necessary for the analyst to understand it. The model presented is a guide however, and must be used with the understanding that management of the development of Army systems is a dynamic process. Improvements are constantly being made and documents describing management systems are often quickly outdated in some aspects.

DA Pamphlet 11-25 envisions a system as progressing through the following stages:

Concept Formulation

Contract Definition

Development and Production

Operations and Disposal

1/ At this writing (March 1971), a major revision of DA Pam 11-25 is being completed. Its purpose is to reduce the number of actions required in the complete life of a system and to reduce the paperwork involved by consolidation of all reports requirements of the Life Cycle Cost Model (e.g., QMA, QMR, SDP, ADP, EDPS) into a single "materiel need" document that will follow an item through the system incorporating greater levels of detail as more information about the progress of the item becomes known.

The Pamphlet presents, within the outline of these four phases, a complete Life Cycle Flow Chart of 240 actions affecting a system along with a narrative to describe the model.

The Life Cycle Cost Estimating process is a continuous cycle. If progress in the development of a system and increased data availability do not make an update necessary, then the passage of time and economic changes will. Thus, the original cost estimate must be used only as an initial base and from this base revised estimates must be made as the life cycle progresses. The cost estimate must be seen as an evolving base which can be reasonably tracked from the original base to the current estimate. It is emphasized that estimates must be reevaluated at each significant point of development.

Of interest to the cost analyst are those actions affecting a system during its life cycle at which decisions are made or inputs provided which will result in information to improve the life cycle cost estimate or a need to change it. Also of interest are those points in the life cycle at which cost estimates are used in the decision making process. The remainder of this chapter then is concerned not with the entire life cycle but with some of the major points in the life cycle which concern the cost analyst. The format used will be to indicate the action taken and the cost analysis impact of that action. The actions will be keyed to the life cycle flow chart shown in DA Pam 11-25.

CONCEPT FORMULATION STAGE

Block 24: Technical Approach Identified

Cost Analysis (CA) Impact: When the technical approach to materiel development has been identified a Qualitative Material Approach (QMA) is produced. The QMA better defines problem solutions and provides the cost analyst with additional information for development of the Life Cycle Cost Estimate (LCCE) to include physical characteristics, approximate time to develop and procure, personnel implications and technical risk.

Block 28: Advanced Development Plan (ADP)

CA Impact: The materiel developer must provide cost estimates for the development plans. These estimates are then reviewed and analyzed by DA or DOD. If approved, the plans commit the Army to further expenditures of funds. Therefore, the cost analyst must be aware of all the known factors impacting on the system under study to provide the best estimate at this time.

Block 33: Analysis of Trade-Offs - Trade-Off Evaluations.

CA Impact: Trade-off analysis is required prior to contract definition. These tradeoffs, produced by the material developer, must include the costs associated with the alternatives to assist in decision making. Lack of sufficient data at this time may necessitate a reliance on parametric or statistical analysis techniques by the cost analyst.

Block 36: Approval of Unit Structure and Tentative Basis of Issue Plan (BOI).

CA Impact: Approved plans, furnished by HQ DA (Assistant Chief of Staff for Force Development (ACSFOR)) provide the cost analyst with more firm guidance and additional data for the LCCE concerning the plan for the units which will man the material being developed and the plan for issuing the material.

Block 39: Cost Effectiveness Analysis.

CA Impact: Here the system is evaluated against competing systems using cost and effectiveness as governing criteria. Accurate cost estimates provided by the analyst are an essential element in this step.

Blocks 41, 42: Approval of Qualitative Material Requirements (QMR).

CA Impact: The existing LCCE is used as a major input in evaluating the proposed QMR. If changes are made to the proposed QMR, cost estimates must be changed accordingly. Approval of the QMR normally includes a directive to the developing agency to begin an end item development project.

Block 48: Develop Preliminary System Development Plan (SDP).

CA Impact: The preliminary SDP provides the cost analyst with a valuable input in the form of a consolidation of the plans for project development. As far as possible at the time, it will include aspects of operational, maintenance support, product assurance test, personnel and training, facility, financial, installation and checkout, procurement and production plans. A major effort for the cost analyst is to convert information from the SDP into the Life Cycle Cost Estimate.

CONTRACT DEFINITION PHASE

Block 74: Develop Proposed Support, Procurement and Management Plan.

CA Impact: The preliminary SDP (Block 48) is updated based on engineering accomplished and other refinements in system development. The updated plans must be scrutinized by the cost analyst and the LCCE updated accordingly.

Block 82: HQ DA Evaluation of Program Status.

CA Impact: This is one of several times during the life cycle at which the system is evaluated by DA. In fact, a system evaluation must be made and a decision to proceed must be accomplished before the system can enter a new life cycle phase. Costs associated with the system constitute an important decision criteria. Any program changes made as a result of the evaluations must be taken into account by the analyst in updating the LCCE.

Block 88: Review of Source Selection Evaluation Board (SSEB) Appraisal and Recommended Development Approach and Developer.

CA Impact: The recommendation from which source the system will be procured inherently considers the costs involved. The source recommendation will allow the analyst to reduce the number of estimates to only those in contention.

DEVELOPMENT AND PRODUCTION PHASE

Block 105: Development Contract.

CA Impact: The contract for full scale development is placed into negotiation and program cost estimates are used to evaluate the contractors proposal. Early production items which require funds will also require cost estimates. The type of cost information reports required from the contractor will also be made firm. These will later be a valuable source of information for the cost analyst.

Block 112: Prepare Total Maintenance Requirements by Location.

CA Impact: This action, accomplished by the Project Manager, considers the full range of maintenance support which will be required. The cost analyst must consider the same requirements in order to develop cost trade-off studies used to provide information relating to preferred site locations. Additionally, the cost of maintenance requirements will be a significant element of the operating cost portion of the LCCE.

Block 132: Procurement of Equipment and Missiles, Army (PEMA) and Military Construction, Army (MCA) Program Elements.

CA Impact: Staffing of Program Change Requests for PEMA and MCA funds results in PEMA and MCA data which must be incorporated into the Five Year Defense Program (FYDP). Analyst estimates of PEMA and MCA are instrumental as inputs for management decisions relating to approval of these funds.

Blocks 159, 160: Prepare Draft Army Materiel Plan (AMP) and Equipment Distribution and Planning Study (EDPS).

CA Impact: Analysts estimates of procurement costs play a major role in the development of the AMP which is a consolidation of plans for procurement.

Block 186: Approval of Complete Basis of Issue Plan (BOI).

CA Impact: Approval of the complete BOI provides the analyst more firm guidance for updating the LCCE. More accurate information can now be determined with regard to the funds necessary to support the program, prepare the budget, and update the AMP.

OPERATION AND DISPOSAL PHASE

Block 212: Follow-On Production.

CA Impact: After initial production to satisfy immediate needs, further production may be required either by the initial contractor or additional producers. The analyst may be required to project future costs based on historical data through use of parametric analysis or cost-quantity relationships.

Block 227: Recommend Reduction/Elimination of Equipment Item(s) from Supply System.

CA Impact: At a certain point in time it can be expected that a system could be reduced, replaced, or eliminated at an economic advantage or to increase effectiveness. Here the analyst may have to employ the techniques of economic analysis to assist in determining the best course of action.

Concentration on these life cycle points is not to imply that the cost analyst should be aware only of those actions listed. Certainly there are many other points in the life cycle at which changes to the system are made. Therefore, the analyst must be aware of the current status at any time and he must also anticipate any possible changes to the system in question so that he will be able to provide the best possible LCCE at any time.

To be effective, the cost estimates must be as refined and up to date as possible. The analyst must therefore have a good grasp of such factors as production schedules, appropriation action, and the production engineering status.

The process of Life Cycle Cost Estimating must be thoroughly documented to ensure its completeness, continuity, and consistency with earlier estimates. (See chapter on Presentation of the Estimate for methods.) An audit trail must be clearly traceable back to the sources or basis of cost inputs used. This permits an evaluation of sources as well as of estimated costs. To aid in this evaluation, all areas where judgment has been used must be identified. Significant changes in costs as the life cycle progresses must also be identified and documented and reasons for these changes must be determined. (See chapter on Cost Growth for a discussion of reasons for changes in costs.)

Documentation of estimates will further allow a reviewer to track from the first estimate to the last and from estimates to actual cost data. Proper documentation could ultimately lead to the establishment of a useful data base for follow-on studies.

CHAPTER 2

PRELIMINARY GUIDANCE

Preliminary guidance is that guidance provided to initiate a costing effort. It should be provided in conjunction with the tasking document. Its purpose is to provide the estimator with sufficient information to take the first steps toward preparation of the estimate. These first steps would normally consist of developing a plan for preparation of the estimate, conducting a data search, and selection of a model. Failure to provide adequate preliminary guidance can result in lost time and wasted effort, and frequently leads to a less than satisfactory product.

As a starting point for the estimate, the estimator must be provided with certain basic information. In general, this basic information consists of:

a. What type of estimate is required? To what level of detail? Is the system adequately defined? What is the intended use of the estimate? At what point in the life cycle is the system? Answers to these questions provide the estimator with a feel for what type of data might be available and what type of end result his analysis is to produce. For an item in concept formulation, a parametric estimate of production cost for an estimated quantity might be all that is possible; for an item in production, a much greater level of detail is available. Likewise, the intended use of the estimate will indicate what costs are to be included. An estimate to support a program estimate differs from one that portrays total economic impact.

b. How much time is allowed for preparation of the estimate? If time available impacts on the accuracy of the estimate, is the tasking organization aware of this? The organization requesting the estimate may be seeking a "quick and dirty" estimate for limited use; on the other hand, it may be seeking a well-documented figure to support a specific decision. It is most important that the person receiving the estimate understand what he is getting.

c. What year dollars are to be used? Is there a requirement for escalation and/or discounting? If so, what factors are to be used? The basic requirement is that the year dollars used be clearly stated, so that they can subsequently be updated. Escalation is a requirement for programming documents. The discounting technique may be appropriate if time-phased alternatives are being considered. For both escalation and discounting there are OSD approved indices.

d. Is any particular estimating technique to be used or avoided? There may be interest in developing a particular bank of data for a given system or type of system. For instance, it may be a purpose of the estimate to develop cost estimating relationships (CER). On the other hand, a well-defined work breakdown structure might be sought. A work breakdown structure is required of the project manager early in the life cycle, and should be used, if appropriate.

e. What quantities are to be used? This information may not be provided directly, but may be derived from other information. Quantities, for instance, might have to be obtained from a proposed force structure and tentative basis of issue (TBOI) with appropriate logistical factors. If quantities are derived in this manner, care must be taken to include service school and other non-TOE requirements. If operating costs are included, the quantities to be operated must be identified.

f. Are alternative configurations to be considered? What sensitivity analyses are required? Generally, the decision maker will be interested in seeing variations to the basic system costed out. Identifying these variations early in the estimating process may simplify the data collection effort. It would also impact on the model selected.

g. How are risk and uncertainty to be handled? Particularly, for those items early in the life cycle, a range estimate, or a "best estimate" bounded by higher and lower estimates may be appropriate.

h. What cost displays are required? The basic variables involved are cost categories, appropriation categories, fiscal years, and work breakdown structure. In addition, costs may be aggregated to meet particular cost definitions (flyaway, procurement, program, etc.).

i. Are there budgetary constraints? The five year defense plan (FYDP) and program objectives memorandum (POM) are the more common sources of budgetary constraints.

j. What additional assumptions must be made? What general factors are acceptable for use? In general, many items of preliminary guidance can be covered by reference to available source documents. The various commodity commands within USAMC have factors available for use with their particular systems. COA publishes the Army Force Planning Cost Handbook for personnel costs. Factors from any source, particularly from published documents, should be reviewed to insure that they are still current.

The items of information mentioned above should be considered a minimal set and do not by any means represent all the information the estimator will require to complete the estimate. If these items are not provided in the initial guidance from the tasking organization, they must be requested. It is often helpful if the office performing the estimate can propose answers to these questions.

CHAPTER 3

SYSTEM DESCRIPTION & INFORMATION SEARCH

Preliminary guidance, although often inadequate, should at least set the stage for the cost analyst to begin to describe the system under study. The amount and availability of data to complete the description will largely depend on the life cycle stage of the system. Early in the life cycle, little other than conceptual data may be available. Late in the life cycle, considerable detailed data can be found. A major problem for the analyst is to secure the data required to develop a complete system description.

Of specific interest, especially in the early stages, are the physical, performance, technical, and mission characteristics which the system is expected to achieve. These factors can provide the basis with which the analyst can draw comparisons with other systems for cost estimation purposes. In this regard the Combat Developments Objectives Guide (CDOG) can be valuable in initially describing the system under study. The CDOG, prepared by Combat Developments Command, contains all the DA approved operational and organizational objectives, Qualitative Material Requirements (QMR), Small Development Requirements (SDR), and Qualitative Material Development Objectives (QMDO). It further contains priorities, a compilation of studies, field experiments, and tests. If this information is not provided by the tasking organization, the analyst should definitely check the CDOG data. Even if the CDOG does not provide information directly, it can often provide a lead to further information sources.

Later in the life cycle many more documents and information sources are available and the system description becomes less a problem. Some potential sources are mentioned later in conjunction with information search for historical and managerial information.

After the system being studied has been described as well as possible, it is necessary for the analyst to plan the course of the study from data collection through report presentation. To do this the cost analyst must determine as early as possible the data he needs to develop his analysis. This may be data concerning costs incurred in the life cycle of similar systems, or it may be data from various management documents which affect the system under study. The ideal solution to these problems would be an automated cost data base which would consolidate all available information and furnish it on a real time basis and in the various forms required. Unfortunately, no such system is yet fully available, therefore, the analyst must do most of his research by manual document search.

Of considerable benefit then is a basic knowledge of some of the available data sources and the content of those sources. The remainder of this chapter is intended to provide this basic knowledge by describing some of the most used sources. Those sources are:

THE FIVE YEAR DEFENSE PROGRAM

The Five Year Defense Program or FYDP is the basic program document for all of the Department of Defense. It is not a source of data for estimating equipment costs, but a summary by mission of the resource allocation, past and planned, for DOD. Its importance to the weapons cost analyst springs from two facts:

1. It is the official record of Secretary of Defense approved programs.

2. The structure of the FYDP influences both the questions that must be answered in an analysis and the records which DOD maintains.

The FYDP divides up the activities of the DOD into some 1400 program elements, aggregated into ten major programs. Here you see the ten major programs with examples of the program elements:

	MAJOR PROGRAM	ELEMENT CODE	PROGRAM ELEMENT
1.	Strategic Forces	12518A	Safeguard Training
2.	General Purpose Forces	22113A	Infantry Divisions
3.	Intelligence and Communications	31011A	Cryptologic Activities
4.	Airlift/Sealift	43111A	Port Terminal Operations
5.	Army Reserves	58112A	Individual Training (ARNG)
6.	Research and Development	64714A	Night Vision Development
7.	Central Supply and Maintenance	71112A	Inventory Control Point Operations
8.	Training, Medical and Other General Personnel Activities	81111A	Recruit Training
9.	Administration and Associated Activities	91113A	Departmental Headquarters
10.	Support of Other Nations	01003A	Thailand

Each program element is identified by a five-digit code and a letter for the service - A for Army, N for Navy, F for Air Force, and other letters for other defense agencies. The first digit of the program element number corresponds to the ten major programs. For each program element, the FYDP shows the forces, dollars, and manpower associated with it from the program element inception until five program years past the current year.

Cost are broken down into development, investment, and operations, and also by appropriation within these categories. Personnel are broken down into active officers, active enlisted men, US direct hire civilians, and 22 other categories mainly related to the reserves.

Except for the R&D program, few of the program elements in the FYDP are directly related to weapons--the notable exception in the Army is for missile systems. As an example, some missile systems appear in the FYDP whereas tanks do not because a missile system and the organization which operates it can have an independent mission, whereas tanks appear only as part of a larger force such as an armored division. In this regard, there are several program elements directly related to the SAFEGUARD System, but even then it is not equipment but the organization fulfilling a function which is identified.

THE ARMY MATERIEL PLAN

The Army Materiel Plan (AMP) is used as a basic source document in developing and executing the PEMA portion of the Army Budget. It displays equipment requirements determined from approved unit authorizations and develops a yearly procurement schedule to fill these requirements. The plan contains data for the prior years, current year, budget year, and four succeeding fiscal years. It is prepared by the AMC Subcommands and other agencies responsible for PEMA procurement. The AMP matches up production capability equipment requirements as stated in force unit authorization documents with the existing inventory.

The cost information contained is only of a summary type however, the cost analyst can find the AMP helpful because:

1. Most equipment items are covered by the AMP.

2. The historical costs and cost projections should be current.

3. The total requirements for the item are stated based on current authorizations.

4. The current inventory is included.

5. Tentative procurement plans are included although the AMP itself does not authorize procurement.

6. Information about prior and current contracts is provided.

Information relating to specific systems is contained in six basic pages. The first page summarizes the materiel plan for the particular item. The second page breaks out the requirement by force and the inventory (pipeline, TOA, etc.) by theater. It also provides factors used in AMP requirements computations. The third page gives further detail on the inventory by model and theater as well as a very brief description of the item, the DA project number, the date of type classification, the average useful life, the age of the inventory, and depot repair capability. Page four shows procurement and production information such as:

Contract type

Delivery date

Initial and reorder lead time

Economic and Minimum production quantities with unit cost

Production base support

Mobilization requirement and schedule

Page five contains a breakout of past and projected losses by year and loss category. Page six is the program cost breakdown.

THE ARMY FORCE PLANNING COST HANDBOOK

The Army Force Planning Cost Handbook (AFPCH) can be used by the analyst as an aid in analyzing variations in resource requirements resulting from proposed changes to approved Army forces in a peacetime environment. It gives a breakout of costs for 87 representative units including a list of authorized major equipment; however, it is not equipment oriented. The information contained in the AFPCH will allow an analyst to develop a planning estimate for the near future of costs involved in changes such as:

Force Structure

Force Deployments

Activity Rates

Training Requirements

Airlift Requirements

Equipment Modernization

Logistics Guidance

Manpower

For instance, costs could be estimated for adding an engineer battalion to a corps or moving a division from CONUS to Europe.

The AFPCH is not designed for use in programming or budgeting but for the development of incremental planning costs for changes in the active force.

The cost methodology and sources used are explained in the beginning of the handbook and several factors are given which may be of use to the analyst developing operating cost estimates of new weapon systems.

SELECTED ACQUISITION REPORTS

The Selected Acquisition Reports (SAR) are summaries of the current estimate of technical, schedule, and cost performance of selected major weapon systems in comparison with current plans and the original program. The reports are provided to Congress and are the official DOD position on the development and procurement status of new weapons systems. As such they receive the personal attention of the Secretary of the Army and the Secretary of Defense (or his Deputy) and thus have become the prime tool by which top level management keeps informed on new weapons. The SAR's are updated quarterly by the project manager and reviewed thoroughly at HQ AMC, the DA Staff, the Office of the Chief of Staff, the Army Secretariat and the Office of the Secretary of Defense before being released to Congress.

An important aspect of the SAR is that information is shown concerning the original cost estimate, the approved program, and the current estimate. Additionally, any differences are explained. Changes in costs must be specifically explained in terms of nine causes:

1. Engineering Change. An alteration in the physical or functional characteristics of a system.

2. Quantity Change. A change in quantity to be procured.

3. Support Change. A change in support item requirements.

4. Schedule Change. A change in a delivery schedule, completion date or intermediate milestone of development or production.

5. Unpredictable Change. A change caused by Acts of God, work stoppage, Federal or State law changes, or other similar unforeseeable events.

6. Economic Change. A change due to the operation of one or more factors of the economy.

7. Estimating Change. A change in program or project cost due to refinements of the base estimate.

8. Contract Performance Incentives. A net change in contractual amount due to the contractor's actual performance being different than was predicted by performance (including delivery) incentive targets; (as differentiated from cost incentive targets) established in a Fixed Price Incentive (FPI) or Cost Plus Incentive Fee Contract.

9. Contract Cost Overrun/Underrun. A net change in contractual amount over/under that contemplated by a contract target price (FPI contract), estimated cost plus fee (any type cost reimbursement contract) or fixed price redeterminable (FPR contract), due to the contractor's actual contract costs being over/under target or anticipated contract costs, but not attributable to any other cost growth previously defined.

The SAR was not developed as a source for cost estimating--data is not shown by work breakdown structure or by cost element; however, the analyst may wish to use past SAR data from similar systems when developing gross estimates of new systems.

The emphasis on comparison of estimates and tracking progress is worth noting. Very often the analyst is involved in more than a snapshot picture of a system--he may have to become familiar with the whole history of a program and the SAR can be of assistance.

CONTRACTOR REPORTS AND FINANCIAL RECORDS

Further sources of data for the cost analyst are the reports which contractors are required to submit. There are many different types of reports and those authorized are listed in the Armed Services Procurement Regulation (ASPR) and in AR 700-51 which contains the Authorized Data List. Reports required for a specific contract are listed on DD Form 1423, the Contract Data Requirements List, and in Requests For Proposals.

Three of these reports are of particular interest to the analyst. They are:

Cost Information Reports (CIR)

Cost and Performance Reports (CPR)

Production Information Reports (PIR)

Cost Information Reports. To date these apply only to aircraft, missile, and space systems. Their purpose is to assist industry and government in estimating, analyzing, and tracking the costs of system development and production. The reporting requirements are applicable to that portion of the system life cycle from final approval for engineering development through completion of production. The reports are designed to:

1. Provide actual costs to date and estimated costs at completion of contracts.

2. Provide estimates of costs by fiscal year for support of the Five Year Defense Program.

3. Provide information in support of DD Form 633, Department of Defense Contract Pricing Proposal for new weapon or support systems.

4. Provide a reporting framework in accordance with the Work Breakdown Structure (WBS).

Five specific forms may be required of the contractor:

DD Form 1558 - Contract Cost Data Summary

DD Form 1558-1 - Functional Cost-Hour Report

DD Form 1558-2 - Progress Curve Report

DD Form 1558-3 - Fiscal Year Data Summary

DD Form 1558-4 - Fiscal Year Functional Cost Hour Report

Cost and Performance Report. The CPR reflects the current picture and outlook for manhours, funds, and work completion under the contract. It is used by the contracting officer and project engineer to analyze contractor progress and efficient use of manpower and funds.

The CPR contains the following:

1. Manhours: Total manhours expended on program tasks during the month; cumulative total to date; and percentage of total manhours to date.

2. Funds: Total funds expended, by task, for the month; cumulative total spent to date; outstanding commitments; and percentage of total funds spent to date.

3. Work completion: Percentage of work completed, by tasks, during the month; and the percentage of completion of total work called for under the contract.

Procurement Information Reports. The PIR is very similar to the CIR - the main differences are that the PIR is applied to systems besides missiles and aircraft, it covers a greater number of systems and it does not necessarily cover the entire work breakdown structure as the CIR does.

There are two formats in the PIR:

1. A Progress Curve Report

2. A Functional Cost-Hour Report.

Both are very similar to the reports in the CIR, the main difference being that the PIR gives a breakdown of the item the CIR refers to as "other" under Engineering, Tooling, Quality Control, and Manufacturing.

Although not yet fully implemented the PIR should fill many of the gaps in data collection. It has the proper detailed cost element breakdown and is oriented towards WBS packages. It has the advantage of brevity over the CIR since the report can be limited to selected components of the system in which there is particular interest.

These contractor reports and others are a significant source of data to the analyst because the data is generally current and detailed. There are some drawbacks though since reporting requirements vary from contractor to contractor, accounting systems and therefore cost allocations vary from contractor to contractor, and the reports do not cover all the information an analyst would normally need.

Another possible source of data are the contractors financial records if they are made available. These could be especially helpful to fill gaps not covered by required reports. These should be used with caution however since they are the product of an individualized accounting system and the assignment of costs can be inconsistent. The records would normally not include such items as costs for government furnished equipment or work done by government personnel. Nevertheless, if adequate data cannot be obtained from required reports, the analyst may have to use the financial records and make the analysis on a more gross level than would be possible with report data.

WEAPONS SYSTEM COST DATA HANDBOOK (WESCOD)

The Weapons System Cost Data Handbook (WESCOD) provides a summary source of cost data for all major weapon/support systems. Program costs are supported by data on schedules, assumptions and quantities. Sensitivity of the baseline program cost to key variables is included where available and the source of each cost estimate is provided for the user requiring more detailed information.

The cost data in the handbook represents the best estimate at the date for each individual system. The estimates are developed using historical data, cost estimating relations, current cost studies and analyses of the budgeting cycle and production process. This handbook is updated semi-annually.

DEVELOPMENT CONCEPT PAPER (DCP)

The Development Concept Paper (DCP) is written by Department of Defense, Research and Engineering (DDR&E) with the assistance of the Services. It contains the nature of the program, the management issues, current capabilities and deficiencies, status and analysis of concept formulation, technology gains, trade-offs and risks, development alternatives, contracting and management, and cost, schedule and performance thresholds. Cost analysts contribute to the paper and receive general program orientation from it.

AREA COORDINATION PAPER (ACP)

The Mission Area Coordinating Paper (ACP) is prepared by Department of Defense, Research and Engineering (DDR&E) to provide program guidance to Military Departments and Agencies, eliminate competing systems, phase out obsolete equipment and systems, raise and resolve major issues, delineate priorities and identify major deficiencies and technological opportunities. This paper requires data from cost analysts and provides cost analysts with general orientation for analytical cost work. The ACP contains summary costs from all Services in RDT&E, Investment and Operating Costs.

MATERIEL NEED (MN)

The Materiel Need (MN) provides development guidance throughout the life cycle of each materiel item. It is established through the joint efforts of the combat developer and the materiel developer and is revised by the same collaboration throughout the life cycle. The Materiel Need (MN) is planned to replace the QMDO (Qualitative Materiel Development Objective) and ADO (Advanced Development Objective). The Materiel Need (Engineering Development), MN(ED), replaces the QMR (Qualitative Material Requirement, the SDR (Small Development Requirement and the SDR-E (Small Development Requirement-Expedited). The Materiel Need (Production), MN(P), replaces the final QMR, SDR and SDR-E.

The MN (Materiel Need) contains items such as system description, performance, missions, threat, concepts of use, technology, costs, time to develop and deploy and other data. The cost analyst can contribute cost information to the MN and receive useful data for cost analysis from it.

PRIOR STUDIES

If there is one data source in which there is more diversity than contractor reports it is prior studies. A large number of studies have been made since the beginnin' of systems analysis. Aside from methodological papers, most of this print matter covers case studies of particular equipment and each case study is a possible source of data. Most studies will contain a synthesis of data from several sources - if the analyst can locate the right study containing the right type of data in the right form he can save himself considerable work.

However, many studies were not designed to serve as data sources for the future analyst. They have more immediate goals in mind such as providing an estimate of Research and Development costs for a specific item - so the data is aggregated and the sources are given only in enough detail to establish validity. In general the freedom to manipulate the data that the analyst who collected it enjoyed is often lost to the reader of a study. On the other hand, a study may represent a compilation of facts and figures which could not be reproduced from still existing sources.

There is no uniformity in the formats of most historical studies so it is often a time consuming process to extract what the analyst needs. More standard formats and documentation requirements should assist in making studies more useful as historical documents.

While individual studies can be an important source of data - the problem is often finding the right one. Of considerable assistance to the analyst is the Defense Documentation Center which has many studies on file and will perform a bibliography search for the user. Other experienced analysts are an excellent source of study information and may prove to be most helpful. Additionally, the Army Materiel Command and its subcommands along with various other Army activities have accumulated libraries of past studies.

CAUTIONS

In using data from different sources the analyst must fully understand the purpose for which the data was originally intended, the methodology by which it was derived and the level of uncertainty attached to it. To be useful the data must be consistent and comparable with the system under study. In many cases the raw data, as collected, is neither. Often inconsistencies will appear in the form of definitional differences, yearly price changes, production quantity differences, and in units of measurement.

In some contractor reports, for example, tooling costs for one contractor might well include some costs that another contractor would attribute to production labor overhead. In most cases yearly price changes would preclude a direct comparison of 1960 costs with 1970 costs, for example, without adjustment. Units of measurement must also be checked closely. Speed and weight, for instance, can be expressed in a number of different terms.

Of possible use to the cost analyst in structuring historical information to make it comparable with the system under study and reduce the possibility of error are the Work Breakdown Structure formats provided in Military Standard 881. The formats, which are by type system (i.e., aircraft, electronics, missile, etc.), break out and define subsystems and can be of assistance in helping insure, for instance, that the analyst does not include the cost of guidance equipment and propulsion equipment of one system with guidance equipment alone of another. This solves only a part of the problem and the analyst must be continually aware that to be usable, data must be not only comparable in a definitional sense but also comparable and consistent in units of measurement.

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CHAPTER 4

TECHNIQUES OF COSTING

INTRODUCTION

This chapter examines and describes the techniques by which cost estimates are derived. Emphasis is placed on parametric analysis as one of the techniques with a detailed discussion of simple regression analysis and cost quantity relationships using specific examples for each. Mentioned in less detail are the applications of nonlinear and multiple regression. Additional discussion is devoted to the analogy, industrial engineering and expert opinion approaches to cost estimating. The chapter stresses not only the techniques but also the limitations of those techniques.

Derivations of cost estimates for weapon/support systems have taken place for many years by both the contractor producing type system equipment and the military services sponsoring the development of the system. These estimates depend on the ability of cost analysts to establish relationships between costs and cost influencing factors. The relationships used have come from procedures categorized by many different name groups1/:

GROUP I

- Industrial engineering standards
- Rates, factors, and catalog prices
- Estimating relationships
- Specific analogies
- Expert opinion

GROUP II

- Analytical appraisal
- Comparative analysis
- Statistical analysis
- Use of standards

The level of effort and knowledge of conditions associated with these procedures range from intuition to extreme detail depending upon type system and technological innovations proposed. To simplify understanding and encourage uniformity of terminology within the Army Staff offices, agencies and major commands, four approaches to cost estimating will be defined and discussed. These approaches are Industrial Engineering, Analogy, Expert Judgment, and Parametric (statistical).

1/ "An Introduction to Equipment Cost Estimating, RAND, Dec 1969 (AD 702 424).

Each procedure has its place in the development of cost estimates, although at various points in the development cycle of a system. The selection of the technique which best suits the requirements of the cost analyst depends upon several characteristics. Principal among these is the purpose of the cost estimate. Other important factors are the amount and detail level of information available regarding characteristics of the system being costed and the time and resources available to the organization developing the cost estimate. Occasionally, a cost estimate is required in a very short time period for a new type system on which there is no historical data. Under these conditions, the use of expert judgment and the analogical technique is the only method that can meet the established constraints. If applicable CER's were developed in advance and readily available, the use of a parametric approach might also be able to meet the highly constrained conditions of time and very limited information. Should detailed information on the system be available, the system not advancing the state-of-the-art, and one is seeking to establish a basis for maintaining control over system production, the engineering estimate is probably the most desired approach for developing a cost estimate. Finally, during the Concept Formulation phase of system development when conditions are such that only physical and performance system characteristics are established, the cost estimate can be developed over a short period of time, and limited manpower is available to develop the estimate, use of the parametric technique is the preferred approach.

In addition to these topics, the use of expert judgment is discussed within the context of using it in the estimating process. In using the data generated through expert judgment, the analyst needs to keep in mind the state of technology applicable to the system being developed, whether or not other data are actually available, and whether the advantages of expert judgment outweigh the disadvantages (e.g., extreme subjectivity, non-mathematical, etc.) for the situation at hand.

PARAMETRIC COST ESTIMATING

As already mentioned, Parametric estimating is the preferred procedure to be used in deriving a cost estimate at the concept formulation stage of materiel development. At this stage, system costs can only be based on ascribed physical and performance characteristics and their relationship to highly aggregated component costs. In other words, a functional relationship must be set up between total system cost (estimate) and the various system characteristics or parameters (c=f(ascribed characteristics)). In the present context the term parameter means a cost related explanatory attribute which may assume various values during a particular calculation.

For cost analysis purposes, a parameter is a definable characteristic of a device, item, or system. The relationships1/ under discussion may be arrived at through two processes, either empirical or statistical. Many cost/parametric relations may be observed from historical data. In using statistics to develop cost/parameter relations from cost histories of prior programs, two things must be kept in mind:2/ (1) the uncertainty inherent in any application of statistics, and (2) whether the resulting relationship is reasonable and structurally sound. The first is unavoidable, however, the influence of the second can be diminished through careful checks of the derived estimating relationships through inspection, simple test data plots, or by more complicated techniques which involve looking at each parameter over a range of possible values. For example, one would not expect, in arriving at a relationship between missile cost and the parameters of weight and range, that the cost would be inversely associated with range. Such a situation would have to be investigated and corrected before attempting to derive an actual predictive estimate. The Office of the Secretary of Defense has recognized that although the requirements of the programming system makes point estimates of cost mandatory during the concept formulation phase of system development, a range of values would give a more realistic picture of a new system's resource requirements. Thus, the point estimate given in Development Concept Papers (DCP's) for the concept formulation stage and in SAR's during later stages of system development should be developed parametrically and footnoted with an interval of values. Three possible interval forms are available: (1) the confidence interval, (2) the interval based upon the standard error of the estimate, and (3) the prediction interval.3/ The last, the prediction interval, is recommended for use during the early portion of the concept formulation phase since uncertainty of data is highest during this period. The prediction interval is a statement about the true value of system cost (C) and essentially combines the features of the confidence and standard error intervals.

COST/PARAMETER RELATIONSHIPS

The following portion of this section will be devoted to approaches for establishing cost/parameter relationships. The initial discussion

1/ Once this relationship has been developed, the process of development should be documented to provide an audit trail of the cost estimates obtained from its use. The steps on documentation contained in the RAND publication, "An Introduction to Equipment Cost Estimating" page 73 provide an excellent reference in this matter.

2/ "An Introduction to Equipment Cost Estimating, RAND, Dec 1969 (AD 702424).

3/ This topic is discussed in the document, "The Use of Classical Statistics in Deriving and Evaluating CER's" published by OSD(SA), Oct 1966 (AD 659323), in greater detail in Lindgren, B.W., Statistical Theory, Macmillan, New York, 1962, page 371 and also in the RAND Memorandum, "An Introduction to Equipment Cost Estimating, Dec 1969 (AD 702424).

is limited to a simple two variable linear regression model and will later briefly cover extensions into multiple and non-linear regression. Model derivation will be briefly discussed since an understanding of theory is certainly good background. However, the most important thing to be gained by practitioners is an appreciation of the strengths and limitations of regression analysis and the pitfalls to be avoided in its application. Thus, this discussion will try to stress those aspects. Anyone can simply plug raw data into equations and come up with an answer - good cost estimation extends far beyond that into meaningful application and analysis.

By way of background it would be well to clarify some definitions - specifically the differences between "regression" and "correlation" since the two are frequently used interchangeably. Regression, as it has become known, is concerned with determining the equation of the line, plane, or curve relating to two or more variables, and the variance associated with any predictions to be made from the model. Correlation has become associated primarily with a correlation coefficient which measures the closeness with which variables are related.

With all this in mind consider the problem at hand - cost estimating. It will be best to do that by tracking through with a hypothetical example. As cost analysts, we are asked to estimate the initial tooling costs for a new weapons system having these specific design characteristics:

Maximum Speed (Hwy)	65 MPH
Load Capacity	7.0 Ton-Miles/Gal of fuel
Weapon System Weight	10,000 Lbs

Suppose the following hypothetical tooling costs are our historical data base, along with physical and performance characteristics for 14 other weapon systems already past the initial tooling stage as shown in Figure 1.

INITIAL TOOLING COST AND VARIOUS WEAPON SYSTEM CHARACTERISTIC DATA

Weapon System Type	Initial Tooling Cost (Millions $)	Weapon System Weight (Hundreds of Lbs)	Maximum Speed (mph) (Hwy)	Load Capacity (Ton-miles/Gal)
L-1	28	27	43	1.8
L-2	35	28	48	2.0
L-3	40	29	50	1.5
M-1	60	35	65	2.0
M-2	50	32	70	5.0
M-3	55	40	100	2.6
M-4	90	45	110	4.5
H-1	70	60	43	17.0
H-2	285	135	45	29.0
H-3	130	70	100	21.0
H-4	105	90	43	9.0
H-5	80	70	23	9.0
H-6	40	40	40	7.0
H-7	185	110	45	6.8

Source: Hypothetical Data

PROBLEM: Conduct a simple linear regression analysis of initial tooling cost vs weapon system weight using the data given above. Specifically, develop the following*:

(1) The estimating or regression equation
(2) The standard error of estimate
(3) The coefficient of correlation

* Application of statistical procedures found in any statistics book will allow the reader to also determine the coefficient of variation and a confidence interval around the regression line derived from the above data.

--- Figure 4-1 ---

What is wanted is to derive an equation relating tooling costs to one weapon system characteristic and use that to estimate cost of new weapon systems.

SCATTER DIAGRAMS

The first step is to simply plot historical data on a scatter diagram. Wanting to determine cost, that becomes our dependent variable, and will be represented on the Y axis. The related performance characteristic will be the independent, or known variable, and will be represented on

X axis. The purpose of the scatter diagram is to insure, before making the computations, that there is, in fact, a linear relationship between the variables. Having data on three characteristics, the objective is to pick the variable with the closest apparent linear relationship to cost.

The historical data plotted against cost is shown in Figure 2.

Apparently the best relationship is between weapon system weight and cost; so that will be used for the example analysis. The purpose now is to determine the best linear relationship between historical tooling cost and weapon system weight, in order to predict the tooling cost of the new weapon system. Before doing that though, it would be well to pause at this point and observe some cautions.

While having glossed over the source of data, one should be aware from the previous discussion on information sources that locating good, reliable, historical data is often a major problem in itself. Let it be said here that results can be no more reliable than the input data, and care should be used in selecting that data. Care must also be taken to insure that the variables used are, in fact, related. As an example, someone once compared beer consumption with church attendance and found that there was a strong positive correlation between the two. His conclusion was that lowering the price of beer would increase church attendance. The point is to insure from the onset that the variables are related to each other so that you do not end up with an interesting but useless study.

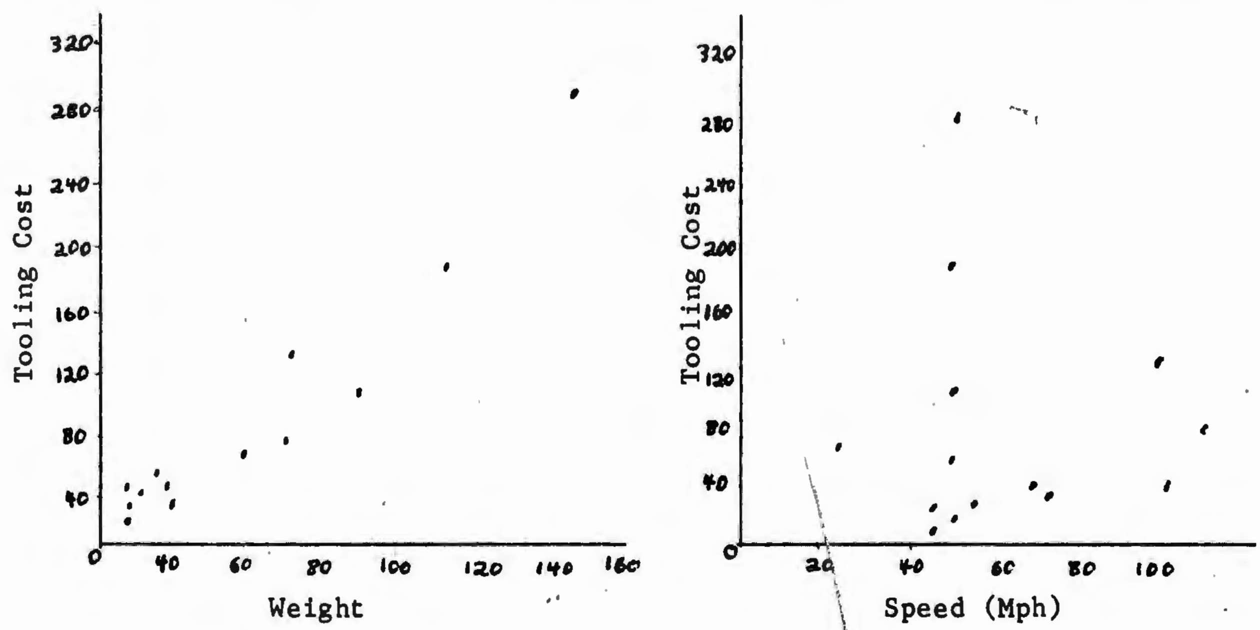
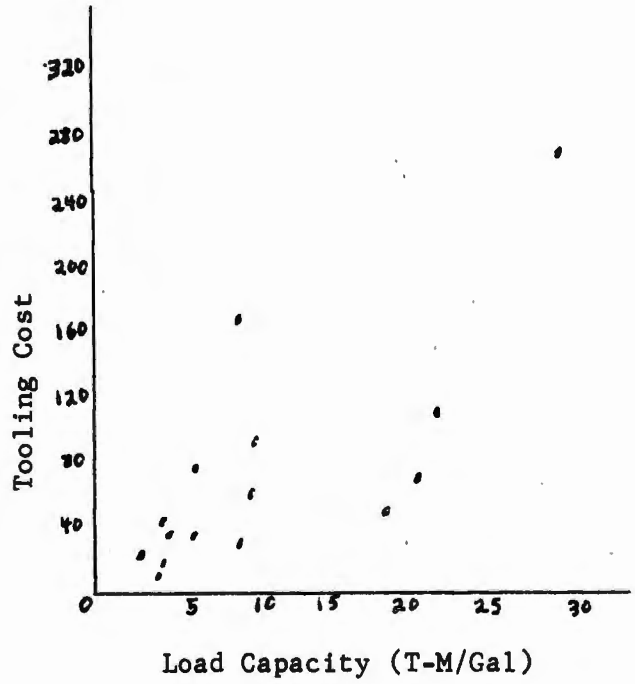
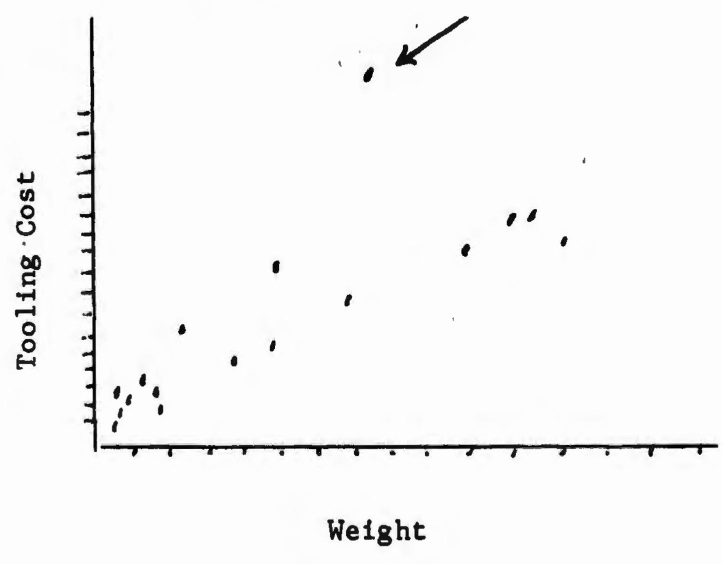


Figure 4-2

Figure 4-2 (Continued)



Another caution to be considered is in the consistency of the sample data. Suppose our scatter gram looked instead like this:



While it would otherwise have an apparently good linear relationship, this single point with a wide variance from the other points will considerably skew the final answer to the high side. Yet, to simply exclude this point from the analysis, the result may end up with an estimate that is too low. There is no hard and fast rule in cases such as this, except that the point must be investigated. Upon investigation it might be found that the weapon system (or some component) was plagued with unusual design or tooling problems which are not likely to recur. The analyst might also find that what was labeled as "tooling costs" really included other costs as well. In such cases it may be justifiable to not consider that point in the analysis. Whatever the conclusions, the final decision to include or exclude that point will be a subjective one, and oriented towards insuring that the data used is the best representation of the situation encompassing the new system.

To be useful, the data must also be consistent and comparable. In most cases the raw data, as collected, is neither. Therefore, before estimates can be derived, an adjustment must be made for yearly price changes, definitional differences, and units of measurement. As an example, weight can be in terms of gross weight or empty weight with a big difference between the two. As another example, labor costs rose 30% between 1953 and 1960. Therefore, these differences must be adjusted so that all elements in the sample are defined in common units and in dollars adjusted to a specific time period.

All these considerations take much time and effort and the example has not even gotten to the analysis yet. However, it is absolutely necessary that these cautions be observed carefully because all future conclusions in the analysis are based entirely on the sample data. Any errors, inconsistencies, or bias in the sample will introdue unnecessary error into what is already an imprecise analysis.

THE REGRESSION MODEL

Being satisfied that weapon system weight has the best relationship to cost and that the necessary cautions have been observed, the analysis may proceed. The equation of the regression model is

$$y = a + bX, \tag{1}$$

where y is the dependent variable and x is the explanatory variable. The symbols a and b are the constant and coefficient, respectively, of the equation estimated from the data. Here y could represent the cost of initial tooling and x could represent the weapon system weight. If it is assumed that b is greater than zero, the model indicates that heavier equipment will cost more than lighter equipment. When the values of a and b are known, it is possible to compute y (cost) for any given value of x (weight).

Least-Squares Estimating

Given Eq. (1), the basic problem in the first phase of the regression analysis is to derive estimates of the parameters a and b. This could be done simply by visually estimating the relating line, than determining the slope (b) and y intercept (a). The disadvantage though is that all people see things differently and very likely no two line estimates would agree. Therefore, it would be better to have a more precise and standard method of estimation. The standard procedure is the method of least-squares. The values of a and b are determined by the requirement that the sum of the squares of the deviations of the sample observations from the estimated line will be at a minimum. Symbolically, this minimum is expressed as

$$\min \sum_{i=1}^{n} (y_i - \hat{y}_i)^2, \qquad (2)$$

Where y_i is the ith observation and $\hat{y}_i$ is the value of y_i estimated from the equation

$$\hat{y}_i = \hat{a} + \hat{b}\, x_i \qquad (3)$$

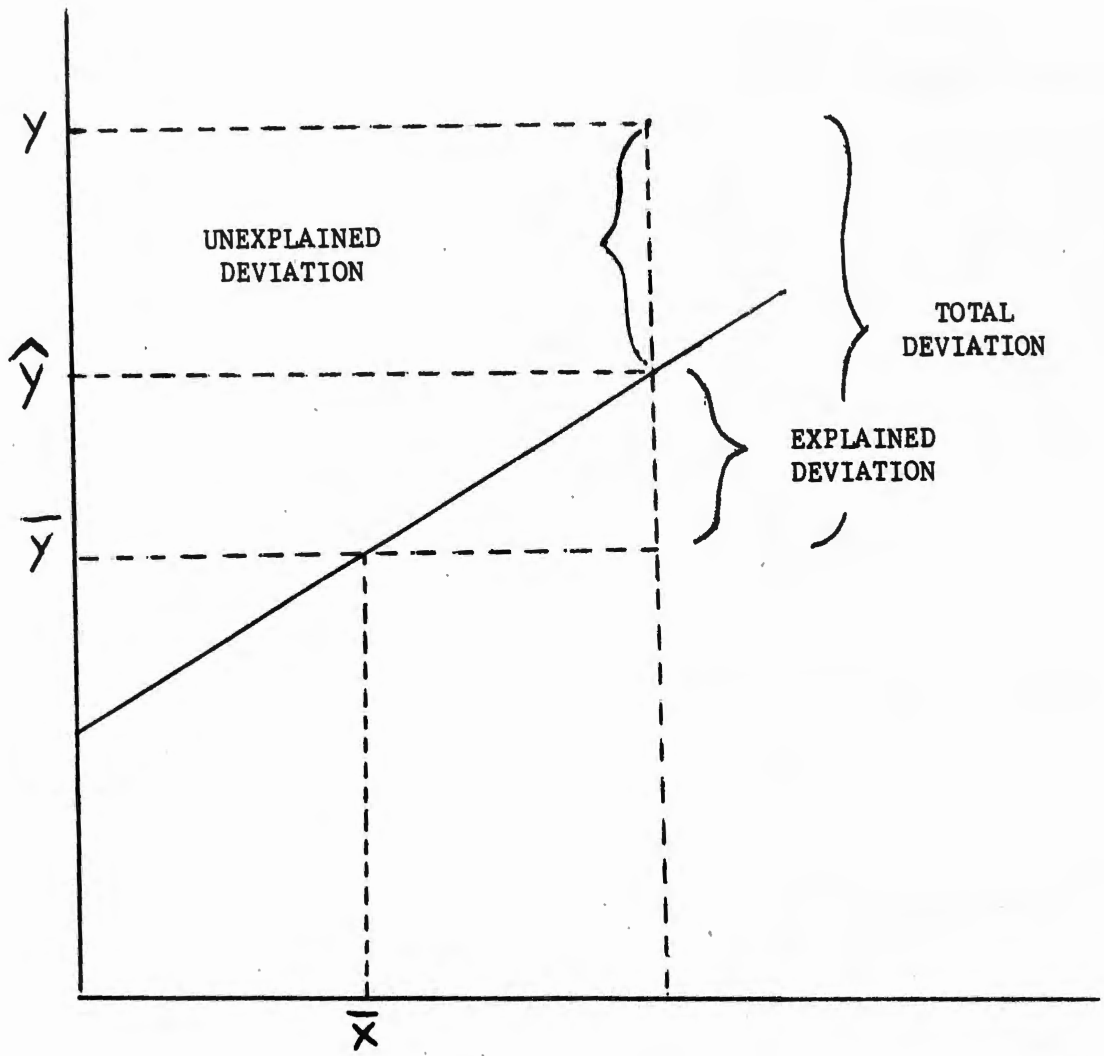
The carets over $\hat{a}$ and $\hat{b}$ indicate that $\hat{a}$ and $\hat{b}$ are least-squares estimates of the true but unknown values of a and b. Thus, $\hat{y}_i$ is the least squares estimate of y_i and the form $(y_i - \hat{y}_i)$ indicates the difference between each observed y_i and between each corresponding estimated value $\hat{y}_i$. This is illustrated in Fig 3, which shows the actual (y) and estimated ($\hat{y}$) value of the dependent variable that corresponds to a specific value of the explanatory variable x. The line shown in the figure is the line that represents Eq. (3). All of the estimated values of $\hat{y}_i$ fall on this line. The vertical distance from point A to point B is the difference between the actual value (y) and the estimated value ($\hat{y}$). The summation of all such differences that are squared (as illustrated in Eq. (2)) is the quantity to be minimized in estimating the line.

The minimum value for this sum is satisfied by substituting Eq. (3) in Eq. (2), taking the partial derivatives of Eq. (2) with respect to a and b, and setting the results equal to zero.

This process yields two equations that are called normal equations and that can be solved for a and b:

$$\Sigma y_i = n\hat{a} + \hat{b}\Sigma x_i \qquad (4)$$

$$\Sigma x_i\, y_i = \hat{a}\Sigma x_i + \hat{b}\Sigma x_i^2, \qquad (5)$$



Deviation of actual value from estimated value and sample mean

Figure 4-3

where y_i = cost of initial tooling in millions of dollars.

x_i = weight of weapon system in hundreds of pounds.

n = Number of items in the sample.

Σ = summation (e.g., y = the sum of all y's).

Assuming that the hypothetical data used in this example were reliable, we now have everything necessary for determining the equation of our model. Figure 4 contains the numerical values and totals required to solve the normal equations.

The costs are expressed in millions of dollars and weights in hundreds of pounds. Substituting those values into the normal equations, the following expressions are obtained for the sample data points:

$$1253 = 14\hat{a} + 811\hat{b}$$
$$101621 = 811\hat{a} + 61653\hat{b}$$

Solved simultaneously these give:

$$\hat{a} = -25.140$$

$$\hat{b} = 1.979$$

So the model is:

$$\hat{y} = -25.140 + 1.979x$$

The line representing this equation is shown here with the actual observations plotted on figure 5.

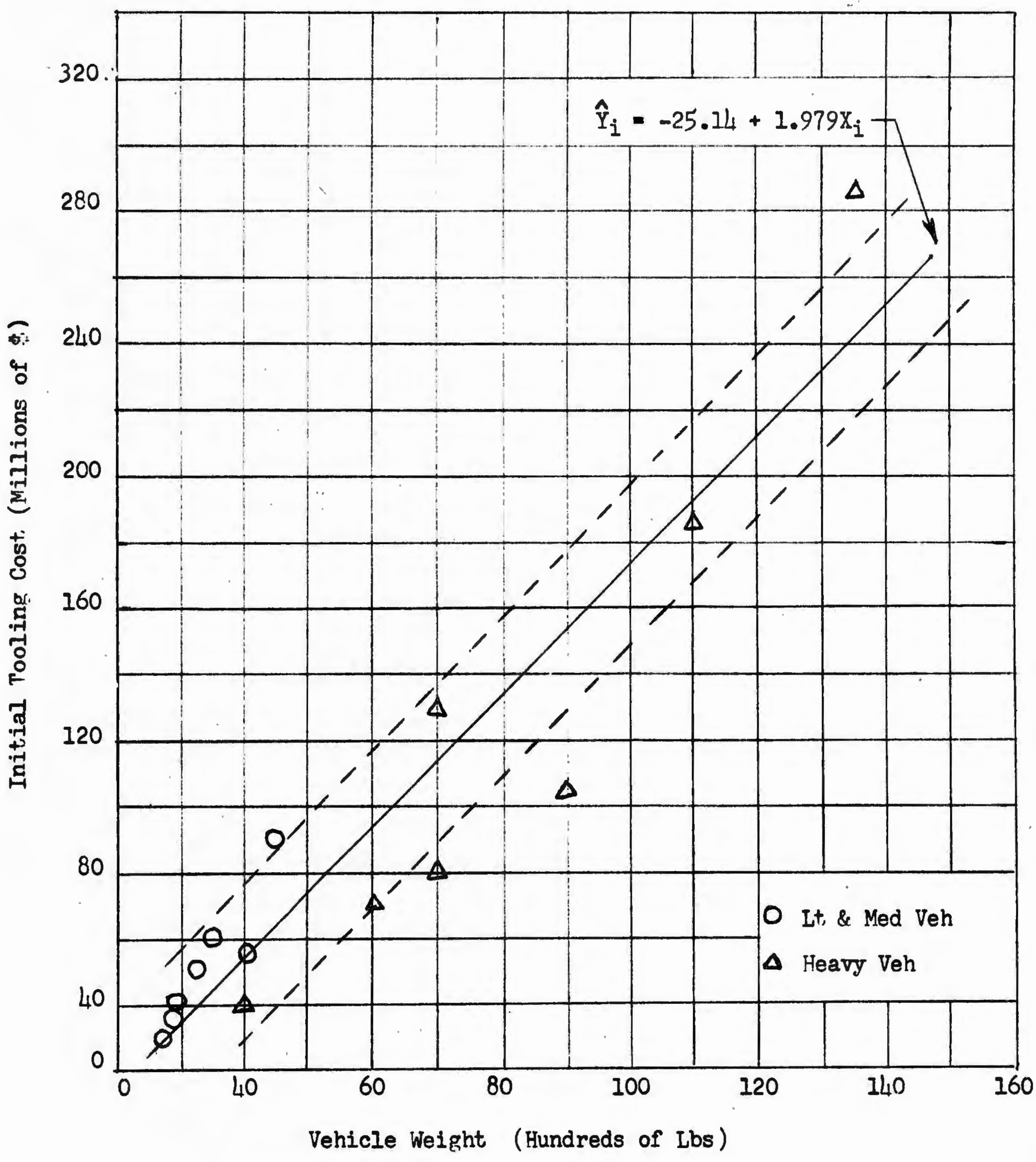
One now has the regression function - obtained by fitting a line to the scatter diagram. That is, point prediction of the expected tooling cost for the new weapon system could now be made but without being able to attach any degree of confidence in the estimate. The regression line in itself is insufficient since no sampling errors have been taken into account.

Data for Regression Analysis of
Initial Tooling Cost and Vehicle Weight

	X_i	Y_i	X_iY_i	X_i^2	Y_i^2	$(Y_i-\bar{Y})^2$	$\hat{Y}_i$	$(\hat{Y}_i-\bar{Y})^2$	$(Y_i-\hat{Y}_i)^2$	$(X_i-\bar{X})$
L-1	27	28	756	729	784	3782.3	28.3	3745.4	0.0	954.8
L-2	28	35	980	784	1225	2970.5	30.3	3504.6	22.1	894.0
L-3	29	40	1160	841	1600	2450.3	32.3	3271.8	59.3	835.2
M-1	35	60	2100	1225	3600	870.3	44.1	2061.2	252.8	524.4
M-2	32	50	1600	1024	2500	1560.3	38.2	2632.0	139.2	670.8
M-3	40	55	2200	1600	3025	1190.3	54.0	1260.3	1.0	320.4
M-4	45	90	4050	2025	8100	0.3	63.9	655.4	681.1	166.4
H-1	60	70	4200	3600	4900	380.3	93.6	16.8	557.0	4.4
H-2	135	285	38475	18225	[illegible]	38220.3	242.0	23256.3	1849.0	5944.4
H-3	70	130	9100	4900	16900	1640.3	113.4	571.2	275.6	146.4
H-4	90	105	9450	8100	11025	240.3	153.0	4032.3	2304.0	1030.4
H-5	70	80	5600	4900	6400	90.3	113.4	571.2	1115.6	146.4
H-6	40	40	1600	1600	1600	2450.3	54.0	1260.3	196.0	320.4
H-7	110	185	20350	12100	34225	9120.3	192.6	10629.6	57.8	2714.4
	811	1253	101621	61653	177109	64966	—	57468	7511	14673

$\bar{X} = \frac{\Sigma X_i}{N} = \frac{811}{14} = 57.9$ $\bar{Y} = \frac{\Sigma Y_i}{N} = \frac{1253}{14} = 89.5$

Figure 4-4



INITIAL TOOLING COST VERSUS WEAPON SYSTEM WEIGHT

Figure 4-5

MEASURING ERRORS

The scatter of observations about it relates inversely to the usefulness of the line as a tool for estimating the values of y from the values of x. The greater the dispersion of observed values of y about the line, the less accurate the estimates that are based on the line are likely to be. Looking at it another way, it can be said that the regression line is an estimate with error. Fortunately, this error can be measured and displayed in difference forms. This then is one of the advantages of the statistical approach over the analogy or engineering approaches.

One way to display the error is to do it in terms of the regression line itself. This is called the standard error of the estimate and it measures the average error of the regression line in providing estimates of y (cost) from given values of x (weight).

The standard error of estimate is defined as the square root of the unexplained variance of the y's:

$$SE = \sqrt{\frac{\sum(y_i - \hat{Y}_i)^2}{n - 2}} \qquad (6)$$

where the term "n-2" is defined as the "degrees of freedom."

For the equation $y = -25.140 + 1.979\,x$, the standard error of estimate is 25.01. This value has been plotted above and below the regression line in Figure 5.

This measure of reliability has been considered in the context of the regression equation in relation <u>to the sample observations</u>. This is usually not the context that is of greatest interest. Rather than being concerned with how well the regression equation describes the sample observations <u>per se</u>, the analyst is most often interested in using the estimating equation to predict values of y in the "population" or "universe" that the sample supposedly represents. While having described the sample well it cannot yet be extended to the new system which is not part of the sample. In the context of <u>prediction</u>, the standard error of estimate does not furnish a good measure of uncertainty or reliability of the estimating (regression) equation. In a formal sense, what would be desired is somewhat as follows. For a given value of the explanatory variable, say X_i, the estimating equation is used to obtain a predicted value of the dependent variable:

$$\hat{y} = \hat{a} + \hat{b}\, x_i \qquad (7)$$

It would now be necessary to put a boundary around y -- say $y + A$ -- such that there is a certain level of confidence that the established interval does indeed "bracket" the "true" value of Y in the population. The subject of "prediction intervals" discussed on page 4-3 and Footnote 3 of page 4-3 addresses this problem. Symbolically the prediction interval for a simple linear regression is represented as follows:

$$\hat{y} \pm SE(t)\sqrt{\frac{n+1}{n} + \frac{(x-\bar{x})^2}{\Sigma(x_i-\bar{x})^2}}$$

Where: SE = standard error as previously defined
t = value of the t statistic at the confidence level desired
$\underline{n}$ = size of sample
$\bar{x}$ = mean of the x_i's in the sample
x = the specified value of the explanatory variable used as a basis for obtaining y.

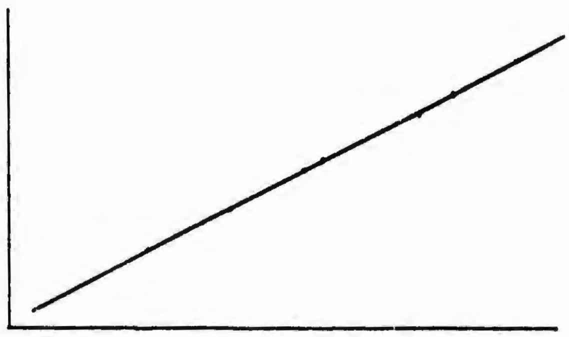
Of significance then is the fact that, to be objective, predictions based on regression analysis should include a confidence interval. That interval is highly sensitive to the level of confidence specified, the size of the sample, and the distance of X_i from X.

Another way of displaying the error involved in regression analysis is in terms of the regression coefficient itself. Previously, it was determined from the regression equation that b = 1.9789. This, of course, is a point estimate so, to display the error in these terms, it is requested to establish a confidence interval around b. One might find that a 95% confidence interval is from 1.5300 to 2.4278. This means of displaying regression analysis errors is not normally used in cost analysis studies however.

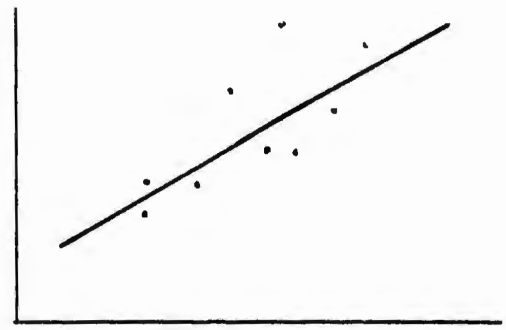
Up to this point, the discussion has been confined largely to statistical regression analyses -- developing an estimating (regression) equation and various measures of uncertainty pertaining to that equation. From an estimating point of view, this indeed is the most important part of the analysis.

CORRELATION ANALYSIS

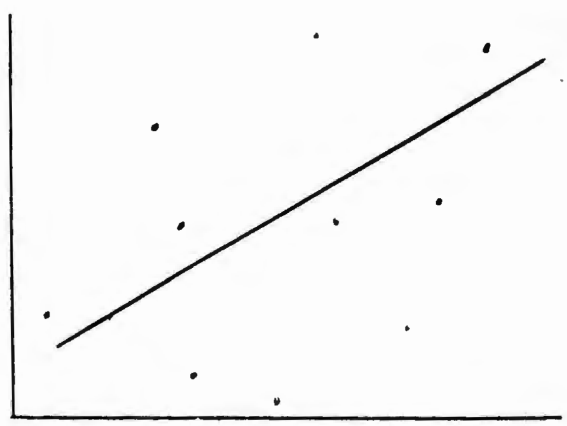
There is, however, another form of statistical analysis called <u>correlation</u> analysis. Correlation analysis is concerned with developing an abstract measure of the <u>degree of association</u> between the dependent variable and the explanatory variable (or variables). In simple linear regression, the most commonly used measure of degree of association is the correlation coefficient, denoted by r. The statistic r is constructed in such a way that it is bounded by the interval $-1 \leq r \leq +1$. The sign indicates whether the slope of the regression line is positive or negative -- i.e., whether the regression coefficient b is positive or negative. At the boundaries of the interval for r, there are the cases of perfect correlation: r = +1 (perfect positive correlation, see Figure 6), r = -1 (perfect negative correlation, see Figure 6). In these instances all of the sample points would lie exactly on the regression line. When there is no correlation between the variables whatsoever, r = 0, see Figure 6.



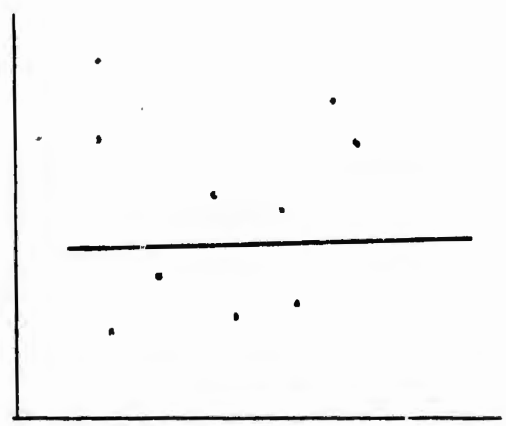
Perfect Positive Correlation
r = +1



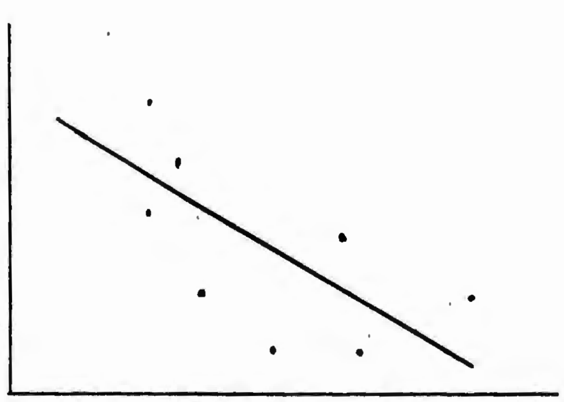
Strong Positive Correlation
r approximately + 0.80



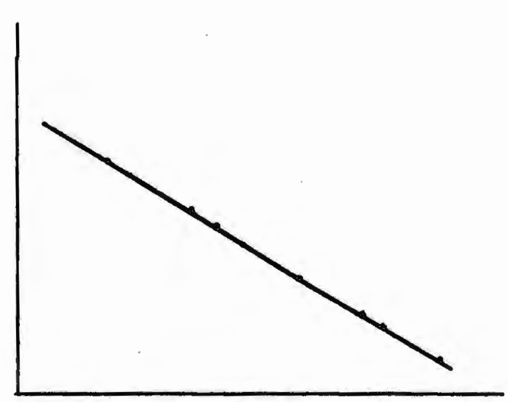
Weak Positive Correlation
r approximately + 0.20



No Correlation
r approximately zero



Moderate Negative Correlation
r approximately - 0.50



Perfect Negative Correlation
r = -1

Examples of Data Processing Given Correlation Coefficients.

Figure 4-6

While correlation is a somewhat different type of analysis from that discussed previously, it is nevertheless related in a definite way to regression analysis. In order to see this, recall the concepts of total variance, explained variance, and unexplained variance referred to earlier in the discussion of the standard error of estimate. Total variance pertains to the deviations of the sample Y's from their mean, and is measured by:

$$\frac{\sum (Y_i - \bar{Y})^2}{N} \qquad (8)$$

Explained variance refers to the deviations from $\bar{Y}$ of the computed $\hat{Y}_i$ values (calculated from the regression equation) corresponding to the values of X in the sample,1/ and is measured by:

$$\frac{\sum (\hat{Y}_i - \bar{Y})^2}{N} \qquad (9)$$

Unexplained variance is derived from the deviations of the sample Y_i values from the computed values of $\hat{Y}_i$, and is measured by:

$$\frac{\sum (Y_i - \hat{Y}_i)^2 \; \underline{2}/}{N} \qquad (10)$$

Intuitively one would think that the standard error of estimate might somehow be derived from the unexplained variance. From previous discussion, it was noted that this is indeed the case. The standard error of estimate (unadjusted) is the square root of the unexplained variance.

Similarly, one would intuitively think that the correlation coefficient (r) might somehow be derived from the unexplained variance. The correlation coefficient is in fact related to the explained variance.

1/ That is, for each value of X in the sample, a corresponding value of the dependent variable (Y) is computed from the regression equation Y = a + bX.

2/ A graphic portrayal of total, explained and unexplained variance is contained in Croxton and Cowden, op. cit., pp. 662-63.

It is defined as the square root of the proportion of total variance that is represented by the explained variance.1/ That is

$$r = \sqrt{\frac{\dfrac{\sum(\hat{Y}_i - \bar{Y})^2}{N}}{\dfrac{\sum(Y_i - \bar{Y})^2}{N}}} = \sqrt{\frac{\sum(Y_i - Y)^2}{\sum(Y_i - Y)^2}} \qquad (11)$$

Now the interrelationship among r, S, and the regression equation becomes more clear. The regression equation is used to determine the computed Y's, which are inputs to the calculation of both r and SE. Also, since r^2 is defined as a proportion of total variance, r and SE in a sense have an inverse relationship to one another.

Just as the confidence interval had to be adjusted for sample size -- particularly so in the case of small samples -- the correlation coefficient should also be corrected. In the case of simple linear correlation the value of r corrected for sample size is as follows:

$$r = \sqrt{\frac{\dfrac{\sum(\hat{Y}_i - \bar{Y})^2}{\sum(Y_i - \bar{Y})^2}\,(n-1)-1}{n-2}} \qquad (12)$$

As is obvious from this equation, the effect of the correction dampens out as n becomes larger. For very small samples, as in our illustrative example, the correction should most certainly be made.

Sufficient information is now available to compute the correlation coefficient. Adjusted for sample size the data is as follows:

$$r^2 = \frac{\dfrac{57468}{64966}\,(14-1) - 1}{(14-2)} = \frac{.8846(13)-1}{12}$$

$$= \frac{11.50-1}{12} = .8749$$

$$r = \sqrt{.8749} = .9354$$

1/ r^2 is sometimes referred to as the coefficient of determination.

The fact that r = .94 seems rather impressive. This represents a rather high correlation. But it is easy to be misled by high correlation coefficients. So much so, that in recent years there has been a trend away from the former emphasis on correlation analysis *per se* to regression analysis which stresses the derivation of structurally sound estimating relationships and of measures of the confidence that the user might have in the estimating equations. One reason is that the correlation coefficient is somewhat misleading. For example, a correlation coefficient of .70 may seem to be acceptable but it really implies that only 49% of the total variance is explained by the regression equation. Put in these terms, it may not be acceptable.

OTHER REGRESSION TECHNIQUES

This completes the example of a simple, 2 variable linear regression model. As one might expect, it is often true that a dependent variable is more accurately a function of two or more variables, rather than simply one. It may be possible then, to derive a more accurate estimate of the cost of a new system by considering not one, but several variables which will affect the new system by considering not one, but several variables which will affect the cost. In this case, a multiple regression model would be appropriate.

The approach taken is similar to that used in the simple regression model, except that the number of normal equations will be increased. If one understands the simple regression technique, multiple regression is easily understood. Because of this, and since multiple regression is adequately covered in most elementary statistics texts, it will not be formulated here.

Multiple regression also provides an excellent vehicle for sensitivity analysis - an area of increasing interest to cost analysts. As an example, a determination could have been made of the net effect on cost of changes in all three characteristics: weight, speed, and Load Capacity. Multiple correlation could have provided "net regression coefficients" which indicate the change in cost per unit change in each of the performance characteristics, holding the other two independent variables constant. It would then be known to which of the performance characteristics our cost estimate is most sensitive. Further analysis might then be in order to determine the probability of changes to the sensitive factor. That is, if cost is highly sensitive to weight, and if there is a good probability that the weight of the new weapon system may increase, we would be remiss in simply assuming a fixed weight.

Next, the analyst should be aware that many cost relationships are not linear, and that forcing non-linear data into a straight line simply introduces greater error into estimations. Curvilinear methods of regression should be used if: (1) logic of the association between two variables supports a curve rather than a line, and (2) the standard error of the estimates is less than for a straight line. The initial scatter diagram should provide the first clue that a curve rather than a line is a better model for use. Curvilinear regression techniques are covered in most elementary statistical texts and are similar to simple linear regression. The simplest solution technique is to convert inputs to logarithims and thereby change the problem into one which can be solved by the linear technique just gone through. Taking the anti-log of the final answer will provide a solution in non-linear terms.

Regression analysis can be laborious and time consuming if done by hand, as done here. Many of the computers available today are already programmed for simple and multiple regression problems and the practicing analyst will undoubtedly prefer their use. The use of computers is preferable since, especially in problems of any complexity, errors are reduced and time spent in computations arereduced. Some cautions are necessary though and those will be covered later.

REGRESSION SUMMARY

In summary, regression analysis is a powerful tool for establishing cost estimating relationships, <u>if used correctly</u>. Regression analysis provides three vital pieces of information which are of increasing interest to cost analysts at all levels. It provides a mathematical basis for making an estimation, a means of assessing the degree of uncertainty in the estimate, and it provides an excellent sensitivity analysis vehicle.

PITFALLS

Some factors to consider and pitfalls to be avoided when developing cost estimating relationships, or when reviewing someone else's CER's are as follows:

1. Be aware of the source of the estimate, and the purpose for which it is intended. Regardless of the integrity of the individual analyst, it should be expected that some personal or organizational bias may creep in. Contractors naturally want to sell their products or services, and their interests may be served by low estimates. Occasionally, some activities may be served by a high estimate. In this regard you could have an advantage if you have a broad range of historical cost data from several sources, while the same data may not be available to private contractors. Application of statistical analysis or simple analogy can give you an excellent means of checking estimates provided by other sources.

2. A simple check of the equations used in cost estimating relationships, along with common sense, will often indicate whether or not the relationship is a reasonable one. The pitfall to be avoided is that an equation may adequately describe one system but not be predictive of another. As an example, the following was developed by students at the Air Force Institute of Technology to describe the cost model for small missiles:

$$C = 8347.5 + 150.6W - 1149.1R$$

where C = cost of airframe plus guidance and control

W = weight

R = range

The use of this relationship to estimate the cost of a light, long range missile would lead to the conclusion that its cost would be less than a heavier, short range missile. This seems unlikely, so further examination of the model would be in order.

3. Consistency of data used is essential. When combining data for a regression sample, for instance, it is usually necessary to adjust dollar figures into constant dollars. Because labor and materials have not increased at the same rate it may be necessary to consider each separately. If actual expenditure for equipment still in the design stage will take place in the future, it may also be necessary to consider inflation factors. In the area of physical characteristics, one must further insure that such common terms as weight, speed, and distance are measured in like units. Often conversion is necessary to be certain that all elements of the sample are indeed compatible.

4. Care must also be taken to insure that historical cost data, which may be accumulated from several sources, truly reflects the actual costs incurred. In the above example, for instance, accounting differences among studies and contractors could easily result in wide variations to the costs actually included in "tooling costs".

5. Always insure that your answers are adjusted for sample size.

6. Finally, do not become so enamoured with an estimating model that you ignore the assumptions made in its development, and the reliability of the sample input data. A computer will furnish an impressive and detailed readout, even if the input data is unreliable. Carefully scrutinize sample data, data sources, and assumptions made in developing estimating relationships.

LEARNING CURVES

In concluding this section, a word should be said concerning learning curves, a particular type of parametric relationships. The learning curve supposition is based upon empirical observations that manhour labor inputs in the production process seem to vary inversely with cumulative output produced on a consistent basis (i.e., take a form represented by a power function). However, labor productivity is affected by technological changes as well as alterations in the level of utilization of factors of production. The precise manner in which labor inputs per unit of output change as a result of all these factors has not been formulated or generalized for the Defense industries.

The empirical justification for a power function learning curve as a description of the unit labor inputs is purely statistical in nature. The smaller the sample size, the less confidence can be placed in the estimates of the coefficients. In fact, the sample size may be so small that the assumption of a power curve relationship may be clearly unwarranted and only a guess by the estimator. Whatever the sample size obtained, however, the resultant sample regression must be used with care for prediction purposes. No probability statement can be made about a point prediction made from the sample data in relation to future production. Probability statements can be made only for interval estimates.

As an example of these difficulties, it is constructive to consider a case recently examined by A. R. Gallant and appearing in the December 1968 issue of the American Statistical Association Journal. The Data in Figure 7 gives the lot size, n*, and the total cost, TCv, respectively for five years. From this information the average cost per plane, y_v, for each lot can be obtained. Figure 8 gives the lot plot points for three alternative methods of obtaining lot midpoints. The "Asher method" refers to a procedure proposed in a Rand study on Cost/Quantity relations by Harold Asher. From the data in figure 8 least squares were computed. Figure 9 presents the alternative parameter estimates for alternative methods of computing lot midpoints. In addition, Figure 9 presents a set of coefficient estimates which were generated by Gallant based upon a probability model and which used an iterative procedure for solution.

The difference in slope between the median method of plotting midpoints and the Gallant iterative procedure is 0.73 percent. In addition, the probability estimates allow for tests of hypotheses and confidence interval statements. For the particular example of the data from Figure 7, the 50 percent and 90 percent confidence intervals are (-.728, -.617) and (-.842, -.502) or in terms of slope (60.4%, 65.2%), and (55.8%, 70.6%).

To see the effect that different unit curve estimating procedures might have on cost projections, a few extrapolations were obtained from the previous regression curves. Since slope values and tables of learning curve values are almost always quoted in interger values, Figure 10 shows projections for the Total cost of alternative buys of F-4B based on a slope value of 62% for the Median and Geometric Mean methods and a slope value of 63% for the Asher and Gallant methods. In addition, since we are only interested in the relative differences in total cost extrapolations and not their absolute magnitude, the entries in the table are expressed as percents of the Geometric Mean projections. As is well known, the nature of a power learning curve is such that significant percentage variations in total cost can result from much less significant percentage changes in slope, S. As is evident from the table, a 1% difference in slope may yield much larger percentage differences in total cost projections.

In addition to the different cost estimates generated by different least squares estimating procedures, further uncertainty concerning precise cost predictions is evidenced by the 90 percent confidence interval for the slope, S, derived from the probability model.

During concept formulation processes for <u>new</u> systems, there would appear to be no sound foundation for applying the learning curve philosophy. Thus its use at this stage of cost estimate derivation should be made only after an in-depth consideration of influencing factors. Complete justification for its use should accompany any such cost estimate.

Moreover, in considering the general usefulness and applicability of learning curves, for estimating costs at such times as system production has begun, it is appropriate to reflect on the conditions underlying its specification. The learning curve depicts the relationship between labor inputs and units of output as production affords opportunities to "learn" how to produce more efficiently.

F-4B FLYAWAY PRICES

In Millions of Dollars

year	v	number purchased (n*)	lot cost (TC_v)	cost per plane (Y_v)
1958	1	3	$ 165.927	$55.309
1959	2	15	156.981	10.465
1960	3	10	62.438	6.244
1961	4	85	320.238	3.768
1962	5	141	327.834	2.325
		254	$1,033.418	

Figure 4-7

ILLUSTRATION OF COMMON METHODS

lot (v)	cost per plane (Y_v)	median (X_v)	asher (X_v)	geometric mean
1	$55.309	2.0	1.753	1.817
2	10.465	11.0	9.691	10.040
3	6.244	23.5	23.275	23.320
4	3.768	71.0	64.691	66.360
5	2.325	184.0	177.741	179.300

(10) $\text{Log } Y_v = \text{Log } a - b \text{ Log } X_v$

Figure 4-8

ALTERNATIVE PARAMETER ESTIMATES

ESTIMATES	MEDIAN	ASHER	GEOMETRIC MEAN	GALLANT
a	69.45	63.16	64.83	61.59
b	- 0.6894	- 0.6762	- 0.6799	- 0.6726
s	62.01%	62.58%	62.42%	62.74%

50 percent confidence interval: b: (-.728, - .617)

s: (60.4%, 65.2%)

90 percent confidence interval: b: (-.842, -.502)

s: (55.8%, 70.6%)

Figure 4-9

Size of Projected Buy (np)	Median Method As A Percent of GM	Asher Method As A Percent of GM	Total Cost of np Units in Millions by Geometric Mean (GN) Learning Curve	Gallant Method As A Percent of GM
100	107%	111%	126.254	108%
200	107%	111%	229.812	109%
300	107%	112%	318.641	109%
400	107%	112%	397.009	109%
500	107%	112%	467.500	109%

SLOPE (S) FOR GEOMETRIC MEAN AND MEDIAN METHODS ROUNDED OFF TO 62%

SLOPE FOR ASHER AND GALLANT METHODS ROUNDED OFF TO 63%

Figure 4-10

It is primarily explained in terms of production workers repetition of labor operations in assembly and construction work. As an empirical description of reality, it is desirable to consider what this implies about the conditions of production. The Learning Curve measures the affects of learning on labor productivity under standard production conditions. Standard production conditions means that each unit of output is produced under the same conditions as every other unit of output. The learning curve is constructed and used under the assumption that there are no significant effects on labor productivity from alterations in the conditions of production in the form of the following: (a) Alterations in the rate of production; (b) Engineering modifications; and, (c) Changes in the level of technology. The only significant factor affecting labor productivity has to do with production experience accumulated (and the increased efficiency this implies). It is this set of circumstances which underlies the use of any learning curve. It must be recognized, therefore, that when the conditions of production change, the applicability of the learning curve may be called into question.

Engineering Changes: Engineering changes are defined here as all of the technological alterations in the product which is under production. If engineering changes are made which result in an alteration in the technical (performance) characteristics of the item being produced, it is only significant for the application of a learning curve to the extent that it changes the conditions of production. An engineering change may be minor in the sense that while it affects the technical and performance characteristics of the system, it does not significantly affect labor productivity per unit of output. For example, a modification of the avionics portion of an aircraft system may result in the substitution of a new component which will enhance the performance characteristics of the aircraft. It will not affect the learning curve nor avionics, however, if the conditions of production are not changed. This may be true even when the cost of the new component over the old may significantly alter the cost of the avionics portion of the system. Therefore, all engineering changes and modifications should be considered in light of how they affect the conditions of production. Engineering modifications may result in (a) a shift in the Learning Curve, (b) a change in the slope of the learning curve (rate of learning), or, (c) some combination of the preceeding two effects.

Production Rate Changes: Labor productivity will also be affected by the degree of plant capacity utilization and the costs involved in adjusting highly specific labor to fluctuations in output levels. The costs involved in hiring and training a firm's labor supply may effectively mean that the firm seeks to minimize labor losses and turn-overs. Consequently, changes in a firm's production rate or capacity utilization may be met with smaller fluctuations (in the same direction) in the labor force. A decrease in the rate of production which is not met with a corresponding reduction in the firm's labor force may result in an increase in labor manhours charged against particular units or lots of output. Therefore, the cost analyst must investigate the affect of production rate changes and adjust the learning curve if necessary.

Technological Change: A firm's method of production may change over time as a result of advances in technology yielding new ways of producing products more efficiently. Of course, labor productivity will be affected. For example, a new machine may allow for the installation and assembly of a missile motor to be completed with fewer manhours of labor than previously. This means that labor productivity has increased as a result of a substitution of capital for labor. Moreover, the change in technology may alter the number and extent of the opportunities to learn and hence may affect the rate of learning (slope of the learning curve).

IMPLICATIONS FOR COST ANALYSIS

The previous considerations imply that the cost analyst has a degree of leeway in the exercise and use of learning curves for any particular costing problem. Moreover, it is reasonable to expect that learning curves for a particular item of equipment will vary according to the type model and firm producing. Therefore, a cost analyst not privy to contractor data will have to rely either on acceptable learning curves for analogous items of equipment or an industry-wide average learning curve as a rough approximation.

A useful document for this purpose is the Defense Contract Audit Agency's compilation of Learning Curves. The pamphlet is entiled "Report on Improvement Curve Experience (DCAAP 7641.14), Revision I, April 1970. For each curve there is listed the nomenclature of the product, the contractor identification code, the base (dependent variable), the percentage slope, the number of plot points, the unit numbers included in the experience data and, where available, the estimated percentages of machine and assembly work.

All of the curves in the report were selected on the basis of the following criteria:

1. No curve was accepted where the slope was based on judgment, negotiation, or other standards.

2. No curve was accepted where significant production breaks or engineering changes required repositioning plot points.

3. No curve was accepted with less than a .7 coefficient of correlation obtained in fitting the curve to historical data.

4. No curve was accepted where experienced hourly (or cost) data were available on less than three lots or units.

Curve slopes contained in studies such as these should be used by analysts when a contractor's records are not available for the development of an appropriate curve.

ESTIMATING BY ANALOGY

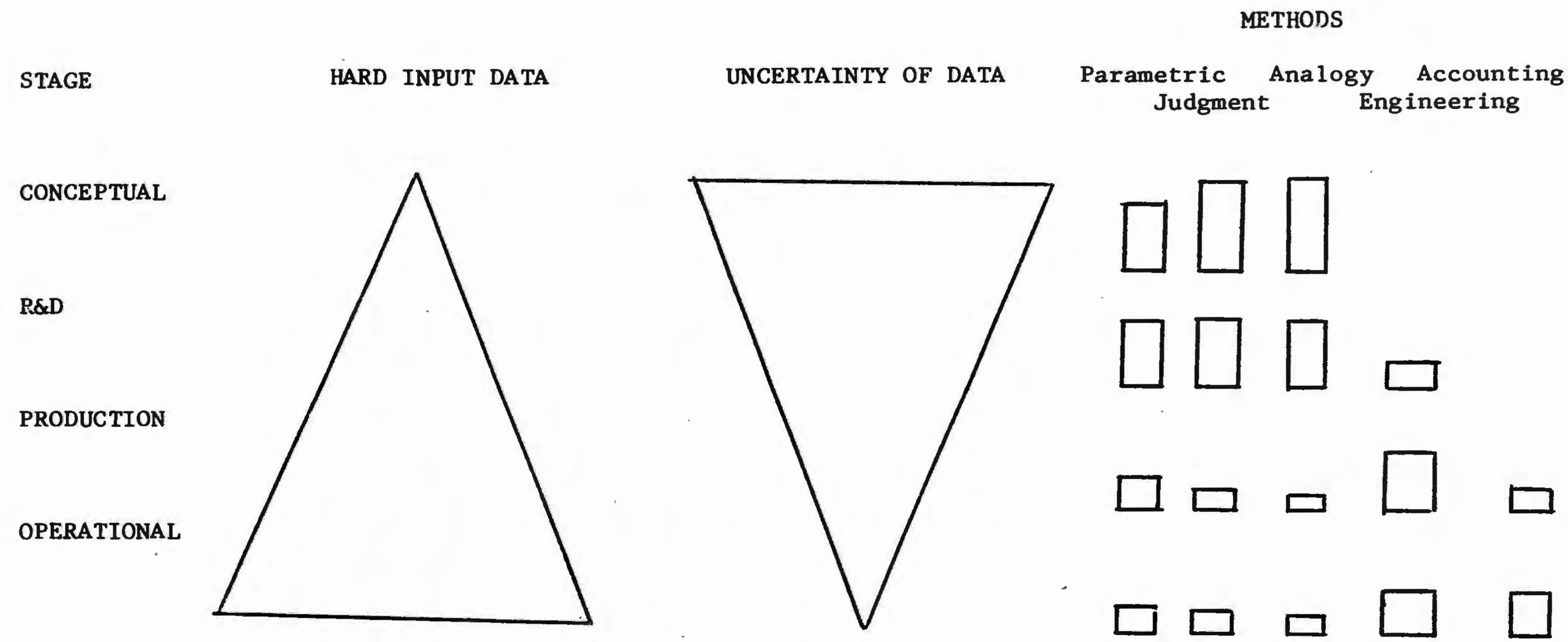
The method of analogy is based on direct comparisons with historical information on like or similar existing systems or components. It has been the most widely used method of analysis to date although surely not the most accurate. Thus, the current emphasis is on use of parametric techniques as previously discussed. The major drawback to the analogy method is that it is basically a judgment process and, as a consequence, requires considerable experience and expertise if it is to be done successfully. However, there are occasions when the system information available will not support any other method of analysis. Figure 11 shows the relation of the weapon system stage of development to the availability of data and to the methods of estimating used.

The analogue technique is based on the construction of relationships using cost data from logically similar systems. It is used when there is little or no historical information available on the specific item and/or when (although less justified) the cost estimate is required so quickly that an extensive data search is precluded. In the latter cases, it is a choice between an estimate being prepared by skilled cost analysts and the decision-maker having to decide without any cost data available to him.

There are two types of analogues which may be used. Similar products can be compred such as using cost data on commercial vehicles to estimate costs of tactical vehicles. Secondly, when a new concept or system must be costed, experience gained on a different product may be used. An example of this is estimating missile costs based on aircraft production experience. The accuracy of this type estimate depends on the experience and expertise of the estimator and the availability of a good analogy. Although useful for making rough comparison checks, this approach is often not appropriate for use by the government analyst since he will seldom have the detailed experience and expertise necessary to produce a sufficiently accurate estimate.

FIGURE 4-11

RELATION OF WEAPON SYSTEM STAGE
TO INPUT AND ESTIMATING METHODS



This, combined with the difficulty of determining the level of uncertainty in the estimate, makes the analogy approach difficult to apply for our purposes.

It is recommended that the greatest use of analogues be made in conjunction with cost estimates made parametrically. If resources permit, estimates can be made parametrically, by engineering methods and by analogy and all three can be comprared. Your most expert analyst should make the analogy estimate. A committee can then review the similarities and differences in the three estimates and choose the best one based on the amount of data available and the type of hardware being considered.

INDUSTRIAL ENGINEERING APPROACH

The industrial engineering approach consists of a consolidation of estimates from various separate work segments into a total project estimate. As an example, the estimated cost of production of a new model widget consisting of work contributions from 10 separate work divisions in a plant could well be a consolidation of 10 separate and detailed estimates each of which may be composed of several estimates itself. Figure 12 shows an example of an industrial engineering estimate of the cost of a steel center bracket. Observe the amount of detail and the number of estimates required for a relatively simple item.

Estimating by engineering methods is based on extensive knowledge of the system characteristics and, hence, are applicable to items at or near the production stage of the life cycle. It is necessary for the analyst to have a detailed knowledge of the system, the production processes, and the production organization. In using the engineering method, the system or item of hardware is broken down into its lower level components and estimates of each component are made. Parametric methods are usually used in estimating the costs of these components, and the results are combined with estimates of the costs of integrating the components to arrive at a total system cost. An advantage to this method is that it separates the parts of the system on which little data is available or which are new technological developments and required special treatment from those parts which can be treated more conventionally. Normally, however, the method has several drawbacks which most often result in underestimation:

1. The type detail required is not available to a government cost analyst, thus making this approach difficult to apply. The approach is often difficult to apply even at the corporate level. As an example, one large aerospace firm judges that the use of this approach to estimate the cost of an airframe requires more than 4000 separate estimates.

Figure 4-12

DETAILED LABOR COST ESTIMATE FOR FORMING A STEEL CENTER BRACKET

				Setup Charges			Operating Labor		
Department	Operation Number	Operation	Machine	Hours	Rate ($)	Cost ($)	Output per Hour	Rate ($)	Cost per 1000 ($)
20	16241	Setup	Niagara 462	1/2	3.40	1.70			
20	15081	Shear to length	Niagara 462				3000	3.40	1.13
20	16242	Setup	No. 4 Bliss press	2/3	3.40	2.27			
20	11571	Perforate and blank	No. 4 Bliss press				1100	3.30	3.00
20	16243	Setup	No. 4 Bliss press	1	3.40	3.40			
20	12951	Form	No. 4 Bliss press				450	3.30	7.26
18	14351	Tap	Tap wheel				900	3.15	3.47
18	16244	Setup	Plain mill	1/2	3.40	1.70			
18	14661	Mill slots	Plain mill				100	3.40	34.00
18	15541	File burrs	Hand file				95	3.40	35.70
07	16245	Setup	Speed lathe	1/4	3.40	.85			
07	11542	Burr 6 slots (and mill)	Speed lathe				600	3.15	5.26
07	16246	Setup	Multiple drill	1/2	3.40	1.70	900	3.15	3.47
07	11941	Countersink 2 holes	Multiple drill						
07	16247	Setup	Tapping machine	1/2	3.40	1.70			
07	16561	Tap 2 holes	Tapping machine				400	2.75	6.85
19	15151	Dull nickel plate					1000	3.50	3.50
						13.32			103.67

NOTE: This table is adapted from a detailed labor cost estimate published in L. P. Alford and John R. Bangs (eds.), Production Handbook, The Ronald Press Company, New York, 1953, p. 1045.

2. Inadequate allowance is frequently made for the costs of integrating the components into the whole.

3. In engineering estimates, some production labor estimates are made as percentages of the detail estimate and other cost elements are estimated as percentages of production labor. Thus the effect of a low estimate may be compounded.

For that reason some firms avoid the industrial approach when possible. The problem arises largely because each individual making his separate estimate often has insufficient information available to make a reliable estimate, and little means to evaluate inherent errors. This is especially true when a new product is involved and the estimator must work from sketches, blue prints, and word descriptions of an item which has not been completely designed. In these cases the complexity of the work can be easily overestimated or underestimated. Therefore, a cost estimate combined from as few as 10 separate estimates also combines the errors in each of those estimates and, in aggregate form, there is no means of evaluating the errors involved or the level of uncertainty in the estimate. For these reasons, the industrial engineering approach has been found to be difficult to apply, and often unreliable.

As in the section on "Estimating by Analogy" it is recommended that a combination of methods be used. The primary cost estimate should be made by parametric methods early in the life cycle and may be made by engineering methods as the system nears the acquisition stage. Secondary estimates can then be made by use of other methods. If a selection of the "best" estimate cannot be made by involved organizations then the various estimates with their rationales should be presented to the decision maker and he can select the "best" for the system under study.

EXPERT JUDGMENT

The analyst may appropriately seek the judgment of recognized experts at all phases of the estimating process by obtaining the advice of either in-house or contractor experts. The necessity of using experienced judgment to fill in gaps in data has long been recognized. However, too much judgment and too little mathematical analysis is often the case. The keynote in using judgment must be reasonableness tempered with large doses of impartiality. Judgment must only be employed by thoroughly experienced analysts and it must always be identified as what it is - a guess, albeit an educated guess.

Expert judgment may be defined as the comprehensive knowledge of a system by an individual or group that is required to reach a conclusion that is not directly supported by data. It is used to construct most

CER's particularly to check the behavior of the relationship when it extends significantly beyond the data base or where the data base is too small to be statistically significant. It is also used to adjust CER's, particularly to reflect costs of another technology. An example of this is adjusting a CER developed for a mild steel structure to cost an item with high tensile steel.

The use of expert judgment will continue to be necessary at times but it must be recognized that it is subject to large inaccuracies. The analyst who uses expert judgment in the preparation of CER's is well aware of its drawbacks since only he can evaluate the limitations of the data. The best use of expert judgment is as a means of cross-checking an estimate. A particularly good example of this is getting the expert and impartial judgment of a consultant to check what is felt may be a biased in-house estimate.

PROGRAM STRETCHOUTS

Program stretchout may be defined as an increase in the estimated length of time required to place a hardware system into the hands of troops. This stretchout occurs as a result of changes primarily within the development and production stages of the system's life cycle. Such stretchouts may be the result of either risk or uncertainty situations. Evaluation of this stretchout is currently handled in at least two separate manners and either may be considered appropriate depending on the situation at hand. First, within the development phase of system production the procedures of the Study of Trends and Escalation of Costs (STECPLOT) are applicable. Through this method the influence on costs due to increases in the time required to complete development is ascertained.[1/] Second, and also usable within the development phase but adaptable to other phases, is the procedure for determining the monthly rate of fund expenditure (usually during the peak funding requirement; e.g., SAM-D estimate) and applying this rate to any estimated increase in system completion time or system milestone intervals. Third, if time can be developed as an applicable, separate system parameter upon which to base a portion of total system cost, then program stretchout may be assessed during the parametric estimating process during the concept formulation stage of system development. The adequacy of any one or combination of these methods is essentially a matter for determination by the analyst performing the estimate. Research should be done to determine if there is a preferential method for treating program stretchout costing.

1/ See Chapter 10.

CHAPTER 5

MEASURES OF ESTIMATE VALIDITY

UNCERTAINTY AND RISK

The disadvantages of decision-making under uncertainty are well-known. However, the fact that complete knowledge is lacking does not alleviate the responsibility for using whatever knowledge is available to arrive at a decision.

In common English usage, the terms "risk" and "uncertainty" have the same connotation. In general, "risk" and "uncertainty" refer to the possibility that a particular characteristic of a project will turn out differently than forecasted or expected. However, in economics and decision-making the following distinction is made between the two words.

A. Risk - the dispersion of the probability distribution of the event whose value is being forecasted.

B. Uncertainty - the measure of the degree of lack of confidence that the probability distribution of the event being estimated is correct.

Risk then says that the value of an event cannot be estimated with certainty but that the value follows a certain probability distribution which is known. Thus, statistical predictions can be made about the particular value and by probability, the degree of confidence one has in a prediction can be measured. Uncertainty says that the value of an event cannot be estimated with certainty and that the value may follow a probability distribution which is not known nor certain.

If, under risk, a probability is unity or one, then there is decision under certainty. Thus, decision under certainty can be classified as a special case of decision under risk. It is on one end of the spectrum of risk. The other end, of course, would be the situation where there is complete ignorance about the probabilities, or decision-making under certainty. As one gains more information about a situation, there would be a move from the uncertain into the risk area.

Example 1: Through critical component sampling, the distribution of the shelf life of a missile has been determined as shown in the following table. The mean is 4.0 years and one can forecast that the shelf life of a missile that one plans to build that has similar critical components is also 4 years.

Distribution of Missile Life

Life (yrs)	% of Missiles With Indicated Life
2.0 - 2.9	10
3.0 - 3.9	37
4.0 - 4.9	41
5.0 - 5.9	11
6.0 - 6.9	1
	100

Assuming that this sample of shelf life represents the character of the underlying population, there is a risk of 47 in 100 that the shelf life of the missile will be less than 4 years. Or, it is expected that 47 out of 100 missiles will have a shelf life of less than 4 years.

In addition to this risk, it is uncertain as to how accurately the above sample represents the probability distribution governing the population of all missiles and their shelf-lives. Therefore, if one could quantify the degree of lack of confidence that one has in the sample shelf life distribution, then one might be able to quantify his predictions about shelf life. If, for example, one could say that one feels 90% confident about the distribution, then the statement might be made that the range of probability of shelf life being less than 4 years is 42.3 - 51.7 in 100. Risk is the variation from what is expected on the basis of the predicted probability distribution; the larger the variation from the expected value (average), the larger the risk. Uncertainty related to variation from the predicted outcome resulting from errors in determining exactly what the probability distribution is.

The reason why the differences between risk and uncertainty have been discussed is because different methods of problem evaluation apply to each. Another concept that is important to risk analysis is the definition of expected value. The expected value of an alternative is the average or mean value that the alternative would have in the long run.

Example 2: The shelf life from example 1 showed an expected or average number of years of 4. This means that if the analyst selects any missile, it is expected that the shelf life will be 4 years; or, another way of viewing it, upon averaging the life of a large number of missiles, this average life would be expected to be 4. Consider the following situation:

Alternative A		Costs		
	Outcome $	$20,000	$40,000	$75,000
	Prob of Outcome	.70	.20	.10

Alternative B		Costs		
	Outcome $	$15,000	$35,000	$100,000
	Prob of Outcome	.50	.45	.05

Expected Cost (Alternative A)	.70($20,000) =	$14,000
	.20($40,000) =	8,000
	.10($75,000) =	7,500
		$29,500
Expected Cost (Alternative B)	.50($15,000) =	$ 7,500
	.45($35,000) =	15,750
	.05($100,000)=	5,000
		$28,250

Given the above information, the decision-maker would select Alternative B based on its lower expected cost (assuming both alternatives have equal effectiveness). It should be noted, however, that while the expected value for Alternative B is $28,250, the probability of the program costing $28,250 is zero. The program can only cost $15,000, $35,000, or $100,000. The expected value must be understood as a long run average such that if the same program was conducted a very large number of times, say 1 million, that one would expect that 500,000 times the program would cost $15,000, 450,000 times to cost $35,000, and 50,000 times to cost $100,000. Upon averaging these outcomes, the average, expected value, or mean would be $28,250. However, government programs are conducted only once and one must question the validity of expected value alone as a decision-making measure.

Example 3: As another example of how expected value can be misleading, consider the following situation. A gambler is given the opportunity to bet $50,000 on the throw of a dice. If the dice shows a 6, the bettor wins 1 million dollars; if any other number comes up, he loses his $50,000. Thus, there are two alternatives:

Alternative 1 - Keep the $50,000
Expected value = $50,000

Alternative 2 - Bet the $50,000
Expected value = 1/6 (1,000,000) - 5/6 (50,000) = 166,667 - 41,667 = $125,000

Alternative 2 has the higher expected value and the dice is thrown once. What is the decision?

A millionnaire may accept this wager because $50,000 is a small percent of his fortune. However, most of us would not accept the bet. The point illustrated here is that decision-making with expected cost as the criteria is valid only when the maximum loss that it is possible to incur is not so great as to seriously affect the well-being of the spender.

Therefore, considering Alternatives A and B mentioned in example 2, even though B had a lower expected cost, there was the possibility under B for the program to cost as much as $100,000. Suppose Congress told the Army that if this program exceeded $80,000 in expenses, the Army budget would be cut in half next fiscal year. The Army probably would not be willing to take that 5% chance of Alternative B costing $100,000 for possible consequences such as this. They would probably choose Alternative A even though expected cost is higher.

It has been shown that consideration of expected value alone does not always lead to the correct decision. Other factors may also be relevant to a decision.

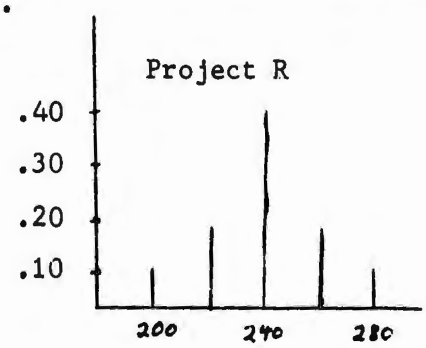
Example 4:

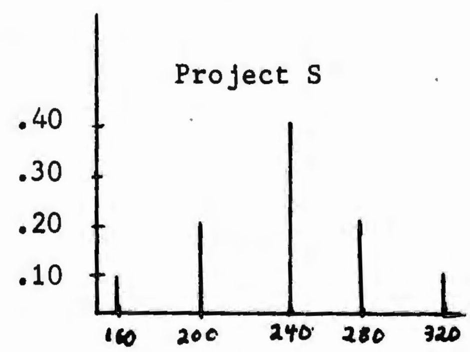
Project R Cost	Project R Prob	Project S Cost	Project S Prob
$200,000	.10	$160,000	.10
$220,000	.20	$200,000	.20
$240,000	.40	$240,000	.40
$260,000	.20	$280,000	.20
$280,000	.10	$320,000	.10

The expected costs of each alternative is the same yet the dispersion about the expected cost of Project S is greater. This dispersion in economics is the quantification of risk. Therefore, Project S is said to have greater risk than Project R and one would be more likely to select Project R.

Graphically:

Probability





What is illustrated here is the concept of risk as the dispersion about the expected value or average. The greater the dispersion, the greater the risk. In general, it could be said that for two alternatives with equal expected values, the one with the smallest risk (least dispersion from the expected value) is usually the most desirable.

Consider the following example:

Example 5:

Project J

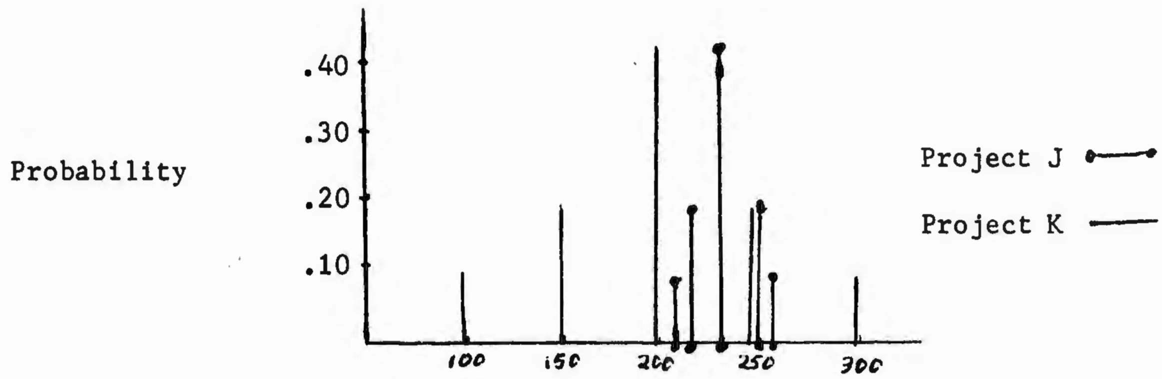
Cost	Prob
$220,000	.10
$230,000	.20
$240,000	.40
$250,000	.20
$260,000	.10

Exp cost $240,000

Project K

Cost	Prob
$100,000	.10
$150,000	.20
$200,000	.40
$250,000	.20
$300,000	.10

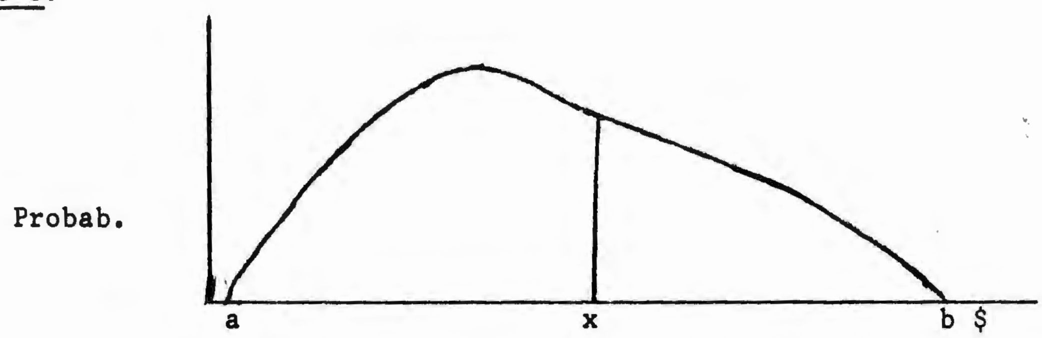
Exp cost $200,000



Project K has a lower expected cost than does Project J; however, it has greater risk involved because of the wider dispersion from the mean. A decision under these conditions is a difficult one and would depend on more information such as relative preferences for cost saving versus risk, the consequences of the program exceeding a particular cost, or other factors bearing on the acceptability of various outcomes.

To this point, the discussion has only been on <u>discrete</u> or <u>point</u> distributions of costs. Theoretically, one can look at costs that have continuous distributions.

Example 6:



The total area under the continuous probability curve is equal to 1 because all the possible outcomes are included. What the curve says is that if x is a cost, and the area between a and b is 1 and the area between a and x is, say, .75, then the probability that the cost will turn out less than x is .75; or conversely, the probability that the cost will be more than x is .25. Also, the probability that cost will be more than b is 0, more than a, 1.

In both discrete and continuous distributions, risk as defined as dispersion from the expected value and can be measured by using a common statistical measure called the variance, or its square root, the standard deviation. The standard deviation, σ , has the following mathematical definition:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}(X_i - \bar{X})^2}{N}} \qquad \text{Variance} = \sigma^2 = \frac{\sum_{i=1}^{N}(X_i - \bar{X})^2}{N}$$

Example 7:

Alternative 1

Costs	Probability
$ 2	.3
$ 5	.4
$ 7	.2
$10	.1

Expected Value = $5.00

$$\sigma_1 = \sqrt{\frac{(2-5)^2+(5-5)^2+(7-5)^2+(10-5)^2}{4}} = 3.1$$

Alternative 2

Costs	Probability
$ 1	.3
5	.4
7	.2
13	.1

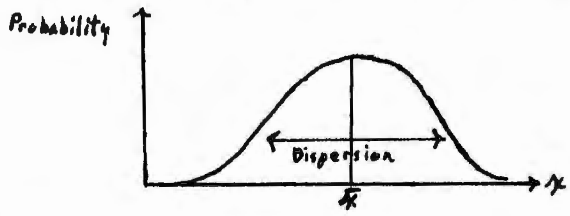
Expected Value = $5.00

$$\sigma_2 = \sqrt{\frac{(1-5)^2+(5-5)^2+(7-5)^2+(13-5)^2}{4}} = 4.6$$

It is obvious from examination of the Alternatives that Alt. 2 has the greater risk (dispersion) than 1; and the calculation of the respective standard deviations bears out this fact.

With continuous distributions, the concept is the same, the calculation is theoretically the same but since the distributions are continuous, the technique of integration must be used.

Continuous distributions can be shown as follows:



As in discrete distributions, they can be evaluated as to which decision should be made on the basis of risk and expected value.

The one case which was difficult to evaluate was the one in which one alternative had a greater expected cost than the other; but had a lesser risk attached to it. A possible method of evaluating such alternatives is to attach an "evaluator" to the standard deviation (risk factor) and take the sum of the expected cost plus the standard deviation times its evaluator. Whichever has the lowest statistic gets the decision.

Example 8: Consider Project J and Project K of example 5. Project K had less an expected cost but greater dispersion.

Project J		Project K	
Expected Cost	$240,000	Expected Cost	$200,000
Standard Deviation	14,140	Standard Deviation	70,700

Decision Statistic: Project J: 240,000 + e (14,140)
Project K: 200,000 + e (70,700)

If e is chosen to be approximately .71, then the statistic for both is equal. Therefore, our decision criteria would be as follows:

$e > .71$	Choose Project J
$e = .71$	Either
$e < .71$	Choose Project K

The evaluator "e" would have to be chosen subjectively and would depend on other factors such as time to complete program, relative performance, technical risk, etc. It should be obvious that if the upper cost range of the project with greater risk but lower cost is lower than the expected cost of the project with less risk, the former should be selected.

Let us now consider a case of how the concepts just explained can be used in a hypothetical situation.

Example 9: The Army plans to build a particular piece of equipment to perform a certain mission. The design engineers have developed two configurations that can be broken down into various components. At this point, the cost people in conjunction with the engineers estimate the most likely costs of each of the components for each design; and, in addition, estimate an upper and lower range for each of these most likely values. The results can be put in hypothetical tabular form as follows:

($000)

Configuration A	Most Likely Cost	Range	Configuration B	Most Likely Cost	Range
Component a_1	$12	$10-15	Component b_1	$31	$26-35
a_2	22	18-25	b_2	10	9-11
a_3	6	4- 8	b_3	8	5-10
a_4	5	4- 7	b_4	9	7-10
Total Cost	$55	$44-67	Total Cost	$58	$48-66

At this point, two important points must be noted:

1. The above costs are assumed to be random costs that approximately follow a Beta distribution (Based on a study on costs).

2. Central Limit Theorem (CLT) says "a new variable formed by the addition of independently distributed variables follows a normal distribution and its mean is the sum of the means of the component distributions and its variance is the sum of the variances of the component distributions." (NOTE: More than 4 or 5 independent distributions should be summed - 30 would be more suitable.)

To approximate the mean (expected costs) and variance of each component, the following formulae for Beta distributed random variables will be used.

$$\text{Mean} = \frac{A + 4M + B}{6}$$

$$\text{Variance} = \left(\frac{B-A}{6}\right)^2 \qquad \sigma = \frac{B-A}{6}$$

Where A = lower bound
B = upper bound
M = Most likely costs (Mode)

The following table is thereby constructed:

Configuration A

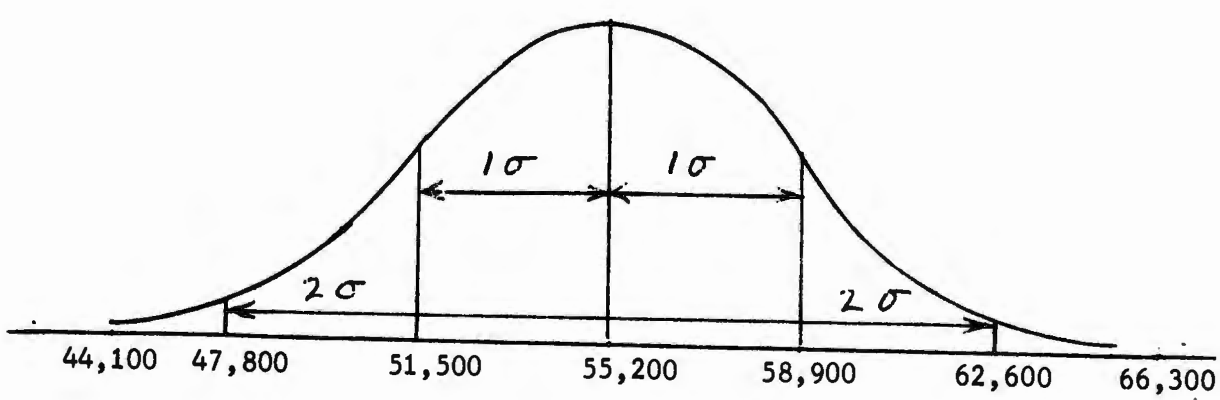
	Mean	Std. Dev.
Component a_1	12.2	.8
a_2	21.8	1.2
a_3	6.0	.7
a_4	5.2	.5
a_5	10.0	.7
Total	55.2	3.7

Configuration B

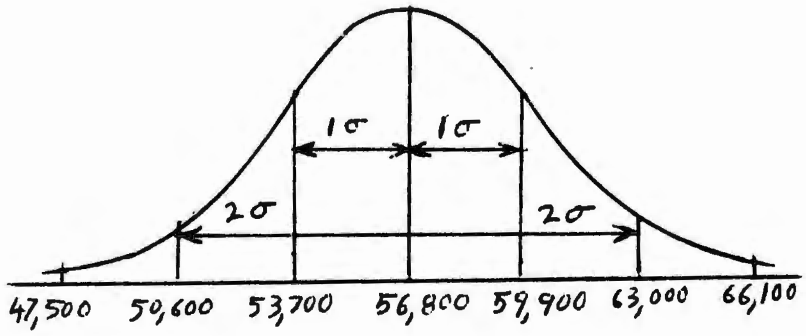
	Mean	Std. Dev.
Component b_1	30.8	1.5
b_2	10.0	.3
b_3	7.8	.8
b_4	8.2	.5
Total	56.8	3.1

By the central limit theorem, the total costs for each configuration approximates the normal distribution. Configuration A has a mean or expected cost $55,200 and standard deviation of $3,700; configuration B has mean of $56,800 and standard deviation of $3,100. A has smaller expected value but larger risk. Plotting the normal distribution for each of these configurations, the following graphs are drawn:

Alt. A



Alt. B



The properties of normal distributions are such that the area between the bounds of 1 standard deviation to either side of the mean is about 68% of total; between 2 standard deviations, about 95%, between 3 standard deviations, about 99.9%. What this means is that for configuration A, the probability of cost being less than $66,300 (3 standard deviations from the mean) is almost 100% (99.95%). In this case, it would be difficult to choose between the two configurations as relates to costs and cost risk, and other considerations would have to be brought to bear on the decision.

In another situation of this type, quantification of statistical cost risk would be carried out in a similar manner. One would consider the costs of components, sub-components, etc., estimate the most likely costs and ranges, sum up to the total cost, and using the CLT assume the total cost is approximately distributed according to a normal distribution with mean and variance as obtained as shown. As a result, one could make statistical risk predictions about the costs of the particular system being estimated. Of course, in the example used the results were based on the correctness of the assumed probability distribution. Uncertainty over the kind of distribution underlying cost estimates would invalidate quantitative predictions about risk.

It has been shown how cost risk may be quantified and evaluated in terms of statistics. As mentioned, the basic assumption of risk analysis is that the probability distribution is known. In most practical situations, roulette excluded, the probability distribution of events is not known for certain. Therefore, other methods of evaluation to deal with uncertainty have been developed. Unfortunately, a great amount of subjectivity is required and use of different methods will not yield consistent decisions.

In the situation where the probability of future outcomes is not known for certain, intuition would tell us to try to subjectively estimate the probabilities of the outcomes for each alternative. Then using the ideas of risk analysis, a decision may be made. This technique is called the Bayes Decision Rule.

Example 10: Outcome (Costs)

		S_1	S_2	S_3
Alternatives	A_1	2	4	6
	A_2	4	1	5

It is estimated that S_1 will occur with probability $= P_1 = .7$, S_2 with $P_2 = .2$ and S_3 with $P_3 = .1$. Using expected value as the decision criterion

$$\text{Exp } (A_1) = .7(2) + .2(4) + .1(6) = 2.8$$
$$\text{Exp } (A_2) = .7(4) + .2(1) + .1(5) = 3.5$$

Based on expected value criterion choose A_1 (lowest cost). It is, of course, not certain that the probabilities assumed are true. Varying the probabilities and outcomes leads to simulation and sensitivity analysis, which is discussed later in this chapter.

A second technique used to cope with uncertainty is called the LaPlace Principle. The LaPlace Principle assumes that all outcomes have equally likely chances to occur. Again, compute expected value and/or standard deviation and evaluate.

Example 11: Using the same alternatives and outcomes as in example 10, assume the probability of each outcome S_i is 1/3. Then: $\text{Exp } (A_1) = \frac{12}{3} = 4$

$\text{Exp } (A_2) = \frac{10}{3} = 3.3$

Select A_2 for lowest expected cost.

Another method used is called the Minimax Criterion. This method is used when complete uncertainty about the probability distribution exists and subjective estimates are impossible. The Minimax Criterion simply says "examine the highest (maximum) cost that can occur for each alternative; and select the alternative that has the lowest (minimum) of these costs." The philosophy is pessimistic and attempts to set an upper bound on costs.

Example 12:

Outcomes (Costs)

		S_1	S_2	S_3	Maximum Costs
Alternatives	A_1	4	1	3	4
	A_2	1	1	5	5
	A_3	2	3	3	3

Alternative A_3 has the lowest of the maximum costs under this criterion and would be chosen.

Similar to the Minimax Criterion is a fourth technique called the Minimum Criterion. This technique is used if the analyst is optimistic. Essentially, the minimum cost for each alternative is examined; and the alternative with the lowest (minimum) of these minimums is chosen.

Example 13:

Outcomes (Costs)

		S_1	S_2	S_3	Minimum Costs
Alternatives	A_1	4	1	3	1
	A_2	1	1	5	1
	A_3	2	3	3	2

Select either A_1 or A_2 using minimum as the criterion.

Still another technique, exotically named the Minimax Regret Criterion, can be employed. If one alternative is chosen and another alternative would have given us a lower cost under the outcome that actually occurs, one would regret the fact that the costs could have been lower. The maximum potential regret can be measured by subtracting the estimated cost for each alternative under each outcome from the lowest estimated cost for each alternative under the given outcome. The analyst then lists the largest potential regret for each alternative. Finally the analyst chooses the alternative with smallest potential regret.

Example 14:

		Outcomes (Costs)			Regret Matrix			
		S_1	S_2	S_3	S_1	S_2	S_3	
Alternatives	A_1	4	1	3	-3	0	0	-3
	A_2	1	1	5	0	0	-2	-2
	A_3	2	3	3	-1	-2	0	-2

Choose A_2 or A_3 since they show (in absolute value) the minimum amount of regret.

To again illustrate the techniques just presented and also to show how each of these different criteria can lead to different decisions, consider the following example:

Example 15:

		S_1	S_2	S_3	S_4	Bayes*	LaPlace	Mini Max	Mini Min	Regret
	A_1	2	3	2	4	2.9	2.75	4	2	-2
Alternatives	A_2	3	1	2	5	2.8	2.75	5	1	-3
	A_3	5	2	2	2	2.6	2.75	5	2	-3
	A_4	2	2	1	5	2.7	2.50	5	1	-3

* Assumes for Bayes $P_1 = .2$, $P_2 = .3$, $P_3 = .2$, $P_4 = .3$

1) Bayes says select A_3

2) LaPlace says select A_4

3) Mini Max says select A_1

4) Minimum says select A_2 or A_4

5) Regret says select A_4

The disadvantages of making decisions under uncertain conditions are obvious. Depending upon one's subjective judgment, a different decision can be made under each criteria.

It will be advantageous to review some earlier definitions at this point. In economics and decision theory, a rigorous definition of uncertainty is desired. Uncertainty attempts to measure the degree of confidence the analyst has that the probability distribution chosen is correct for the event being estimated. The value of the event cannot be estimated exactly and this value follows a probability distribution not known for certain. It is the variation which is found in the probability distribution and caused by errors in forecasting the precise nature of the actual probability distribution. On the other hand, the rigorous definition of risk says that it is possible to describe all the outcomes of the situation and to assign meaningful objective numerical probability weights to each such outcome. The value of the event cannot be estimated exactly but under risk the value follows a particular probability distribution which is known.

In practice, it is not usually realistic for cost analysis to follow these rigorous definitions and differentiations at the current time.

It is possible to use such techniques as the Bayes Decision Rule, the LaPlace Principle, the Minimax Criterion, etc. to evaluate "uncertainty" as defined above; however, the use of such techniques is not recommended because they are too highly dependent on judgment and particularly because the use of different techniques can lead to different decisions. In most cases, it is necessary to translate a problem of decision-making under uncertainty to a problem of decision-making under risk. See Figure 1 for a general approach which bounds uncertainty and attempts to make it more specific. The analyst thus has three choices:

1. Treat the decision as one under uncertainty - this course is not recommended.

2. Acquire data or perform experiments so that the decision is translated to one under risk. This course is often blocked by such practicalities as lack of time and money.

3. Transform the decision to one under risk by obtaining probabilities subjectively assigned by expert judgment. It is recognized that this course introduces further uncertainty but it may be and often is the only course available. Such judgment must be based on past experience with systems similar to the one being costed. It is also to be emphasized that the basis for the judgment must be fully documented and made a permanent part of the cost estimate.

It is also recommended that uncertainty be quantified as objectively as possible in all cases. All cost estimates should include a section giving the point estimate (most likely value) and a probable high-low range for the estimate with a 90% confidence level. That is the probability that the actual system cost will be equal to or greater than the high value is 5% and the probability that the cost will be equal to or lower than the low value is 5%. A qualitative paragraph may also be desirable but it should not be the only uncertainty evaluation offered.

The level of detail an uncertainty evaluation presents is also a matter of judgment. Generally, aggregated cost uncertainties should be presented in RDTE, recurring investment, non-recurring investment, and operating cost categories. However, early in the life cycle it may be realistic to only present a system uncertainty estimate and range. Later in the development cycle, it may be valuable to also highlight the uncertainty associated with a particular cost element. An overall system uncertainty evaluation should also be included.

APPROACHES TO UNCERTAINTY

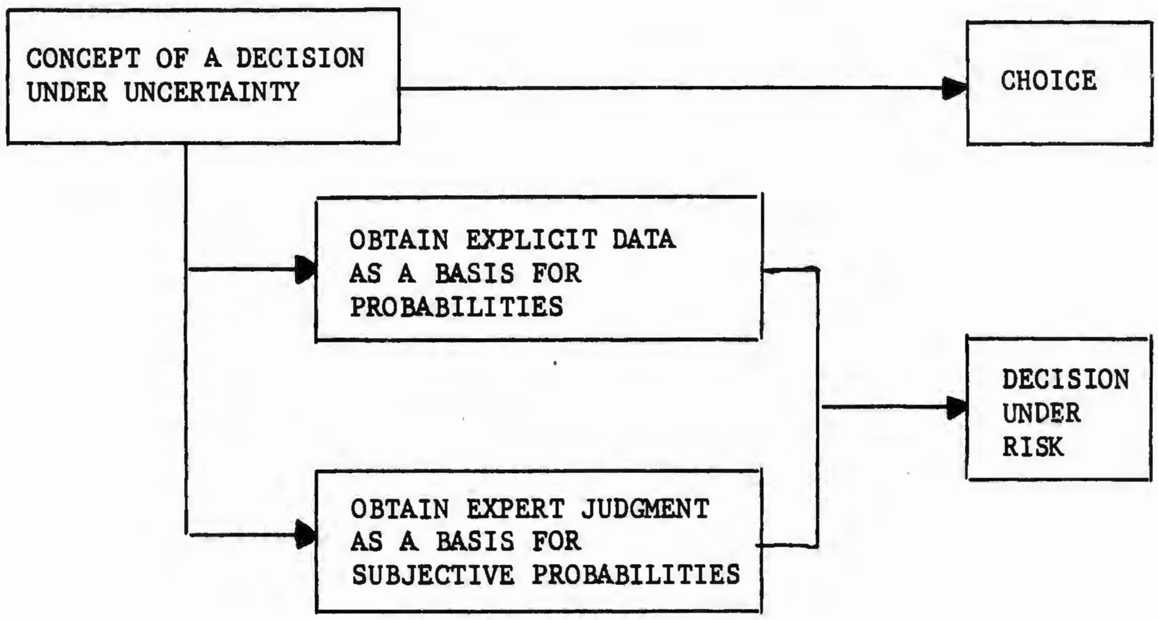


Figure 5-1

This may be arrived at using Monte Carlo[1/] or asymmetric[2/] estimating techniques.

The use of standard statistical techniques (confidence intervals, t-test of significance of the standard error, etc.) to deal with uncertainty often cannot be justified. Usually the sample size is too small and a normal distribution for the underlying population cannot be assumed. However, the standard deviation may be useful measure of uncertainty if there are five or more data points. When CER's are used in the estimating process, the uncertainty section should definitely include a standard error of the estimate.

The value of the Monte Carlo technique has not yet been evaluated in fact. It seems to be valuable provided the analyst has some confidence in the validity of his inputs and provided he has extensive computer time available. There are also hand-computational techniques for determining cost ranges whether the distribution is symmetric or asymmetric.

Sensitivity analysis has been cited as a valuable technique for uncertainty evaluation. It is useful in identifying the cost sensitive system elements but does not produce a set quantitative measure of uncertainty. This issue is further discussed in a succeeding section of this chapter dealing with sensitivity analysis.

In carrying out an estimate under conditions of great uncertainty, it may be desirable to recommend special tests or other methods in order to define the estimating problem in terms of quantifiable risk, and, in any study addressing uncertainty, the presentation of the analysts' qualitative evaluation of the following four topics is of particular importance:

1. How much uncertainty exists.

2. What steps can be taken to reduce uncertainty.

3. How much will it cost to reduce uncertainty.

4. How much uncertainty will be reduced as development progresses.

1/ "A Monte Carlo Simulation Approach to Cost Uncertainty Analysis," M. F. Gutowski, et al, RAC-TP-349, Research Analysis Corporation, 1969.

2/ "Adding Costs Est. that are not Symmetric About the Most Likely Value," Sutherland, Draft RAC-CR-23, Research Analysis Corporation, 1970.

The reduction of uncertainty by acquiring knowledge occurs as development progresses, and the fact that development produces information about costs, about performance, and about availability dates has important implications for the conduct of cost analysis. It is now of key interest to decision makers whether it would pay to buy more information; that is, to undertake development up to some later stage, before a final choice is made.

As an example of this situation consider a problem of deciding on a course of action with respect to a future ICBM capability. There are two promising alternatives: (1) Missile A, which uses a storable liquid propellant, and (2) Missile B which uses a solid propellant. To simplify things assume that the operational dates of the system and the capability that must be available are fixed. What is wanted then, is to achieve the given capability during the given time period at a minimum cost--where cost is defined to include all costs of development, procurement, and operation. When confronted with this problem, the decision maker is, of course, uncertain about which of the two alternatives will in fact yield the **minimum** cost. Assume, for the sake of a simple example, that his best judgment about probable costs of Missile A and Missile B, based on the information available to him, is summarized in Figure 2. This figure, in other words, portrays his personal estimates of the probable costs of these two missile systems.

In brief, our decision maker is convinced that Missile A will cost either \$8 billion or \$10 billion and that these two are equally probable. Similarly, he is convinced that Missile B will cost either \$7.5 billion or \$13.5 billion, once again with equal probability.

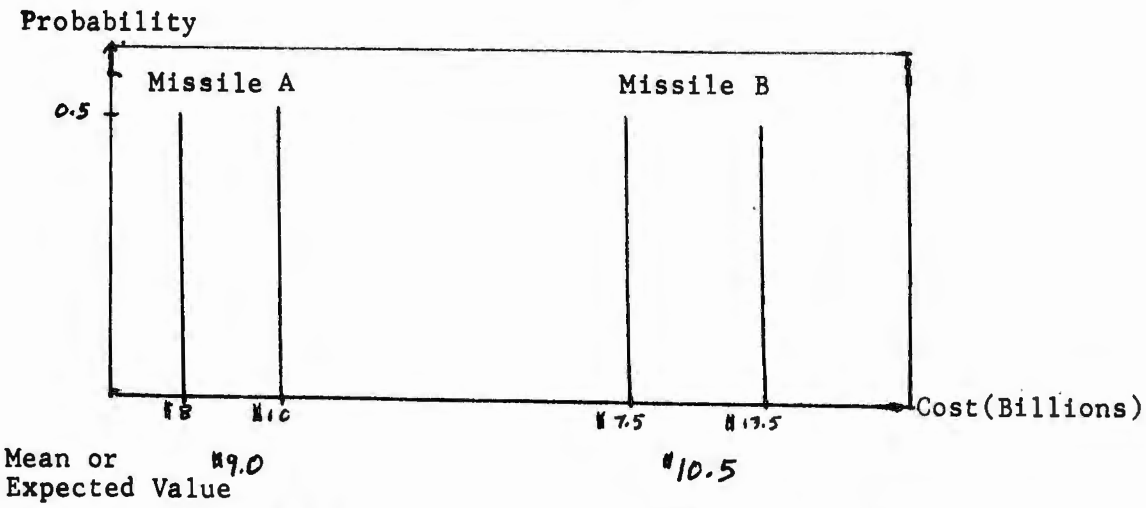


Fig. 5-2 Probable costs of Missiles A and B

Given the information shown in Fig. 2, the decision maker might simply assume that the rational choice is to select the system with the lowest expected cost. In other words, he would choose Missile A on the grounds that if he makes such decisions repeatedly he would expect an average cost of $9.0 billion for Missile A as opposed to $10.5 billion for Missile B.

Given our decision maker's estimates of probable costs, there are four possible states of the real world that can exist. These are shown in Figure 3. The figures in the table represent the four possible combinations of costs for Missile A and Missile B which could occur, given the probable cost estimates shown in Figure 2.

Figure 5-3

State of the world	Cost of Missile A (billions of $)	Cost of Missile B (billions of $)
S_1	8.0	13.5
S_2	10.0	13.5
S_3	8.0	7.5
S_4	10.0	7.5

When our decision maker is first confronted with the problem, of course, he does not know which of these four situations is in fact true. If he chooses Missile A, that is, if he chooses on the basis of expected costs, and if either S_1 or S_2 is the true state of the world, the choice of Missile A will have been best. But if he chooses Missile A, and either S_3 or S_4 is the true state of the world, then he has chosen wrongly.

He would very much like to avoid choosing wrongly, but if he cannot get more information as a basis for his decision, he cannot improve on a straightforward choice of Missile A. It is at this point that the second observation cited earlier about the nature of development becomes relevant. The reason we undertake development is precisely to get information--information that will reduce uncertainty. If our decision maker has an opportunity to improve on the reliability of his cost estimates through partial development, he may then be able to improve on the results he would get by simply choosing Missile A.

To illustrate this, take the extreme case and see how much it would be worth to find out with certainty which of the four situations in Figure 3 is the true state of affairs. Assuming that Missile A is the best choice in the absence of such knowledge, it is now asked how much the decision maker would be willing to pay to determine which of these four states will actually exist. In order to answer this question let us first suppose he is told which of the four will prevail. When he is told that either S_1 or S_2 is true, he will choose Missile A just as he did before, because this will give him the lowest cost. But, when he is told that S_3 or S_4 is true he would choose Missile B in order to minimize costs. Naturally, at the time he has to make his decision, he never really knows which of the four will turn out to be true. In fact, he regards each as equally likely--to each he has assigned a probability of 0.25 that it will be the one that actually exists. Therefore, his average or expected savings if B were chosen rather than A is 0.25 x \$0.5 billion = \$0.125 billion with respect to state S_3 plus 0.25 x \$2.5 billion = \$0.625 billion with respect to state S_4, or \$0.75 billion in all. In other words, knowing which of the four situations actually holds true is worth \$0.75 billion to our decision maker, and if there is any way he can get this information at a cost of less than \$0.75 billion, it will be rational for him to do so. To be more specific, if he can determine the costs of the two alternatives by carrying both into development, he can afford to spend up to \$750 million on one of the missiles, even though it is eventually cancelled.

In the real world the problems faced in making development decisions are clearly much more complex than in this simple example. But, this particular example shows why, in making development decisions, it is necessary to take into account more than a single point estimate of how much particular systems will cost. A thorough analysis of alternatives open to the decision maker, including obtaining more information, requires an evaluation of the uncertainty surrounding cost estimates for alternative hardware configurations.

In conclusion, no one technique for the evaluation of uncertainty can be recommended at this time. For the most part, cost analysis studies in the past have either ignored uncertainty or been too qualitatively oriented in their uncertainty evaluations. It is recommended that future cost analysis studies use and present all quantitative techniques which the analyst can justify, however judgmental they may be. Thus, in the future, there will be a basis for evaluating the relative merits of the various techniques which is not now available. The problem of uncertainty will always be present in estimating the costs of future weapon systems. However, attempts to reduce it and to find the best methods for evaluating it must be made.

SENSITIVITY ANALYSIS

Sensitivity analysis determines the significance of a given variable within some prescribed range of interests, and it attempts to answer the following questions: How does the cost of a system vary as a result of changes in the configuration of the system, changes in its deployment plan, changes in operational use, and so on? To what elements (considering operational assumptions as well as hardware specifications) is the total cost of the system especially sensitive or insensitive?

All cost analyses should have sections in which the quantitative results presented are open to question. Sensitivity analysis identifies and varies such factors in magnitude to analyze how the final study results are influenced by possible variability in the questionable factors. It changes each of the study parameters while the others are held constant to analyze how a small change in the one parameter can affect the total cost. Such an analysis can be very valuable and can be a useful technique for dealing with some of the problems of uncertainty-the more so because statistical methods for deriving confidence limits and other criteria of uncertainty cannot be applied generally to cost estimates. In studying proposed future systems, numerous uncertainties must be recognized together with their impact on system costs. Studies of system historical data have shown that perhaps the most important reason for differences between early estimates and final costs is that the configuration of the system ultimately obtained differs considerably from that envisaged early in the program. Cost sensitivity analysis deals explicitly with cost differences related to differences in system configuration, and it can therefore provide a range of system costs which is likely to be a more realistic guide than a single, most probable cost. Sensitivity analysis highlights potential problem areas and produces a concentration on the most important cost factors. The areas of greatest uncertainty are found and where these are costly areas, options are readily identified for future research and experimentation.

An example of sensitivity analysis is a study done by the US Army Missile Command Cost Analysis Group. Congress was questioning the possibility of using the SHILLELAGH missile, an anti-tank missile designed to be fired by a tank, in a ground mode rather than the TOW missile which was designed for ground operation. The costs of the two alternatives were to be considered with the most inexpensive one being selected. The SHILLELAGH missile had been produced for five years longer than the TOW and had undergone a price decrease due to competition among possible manufacturers. It was calculated that competition effected a step down in the learning curve of about 29%. TOW also was planned to be made competitive and therefore based on SHILLELAGH experience, a 29% factor was used. However, it was expected that this assumption was very likely to be questioned, so a cost sensitivity analysis was conducted. The competitive cost reduction factor had no probability distribution associated with it, so costs were computed for factors of 0%, 10%, 20%, 29%, and 35%. Even the 0% competition, the total TOW program cost less than the total SHILLELAGH program and an unequivocal decision could then be made.

Figure 4 shows sensitivities and insensitivities revealed by costing various configurations of a ballistic missile system.*

1. The system cost is relatively insensitive to increases in payload; that is, a considerable increase in payload can be obtained for relatively small increases in cost. The explanation is that a number of the expensive components of the system change little with increases in gross weight of the missile (e.g., guidance and control systems, ground support equipment, and installations items associated with fire control and flight vehicle guidance).

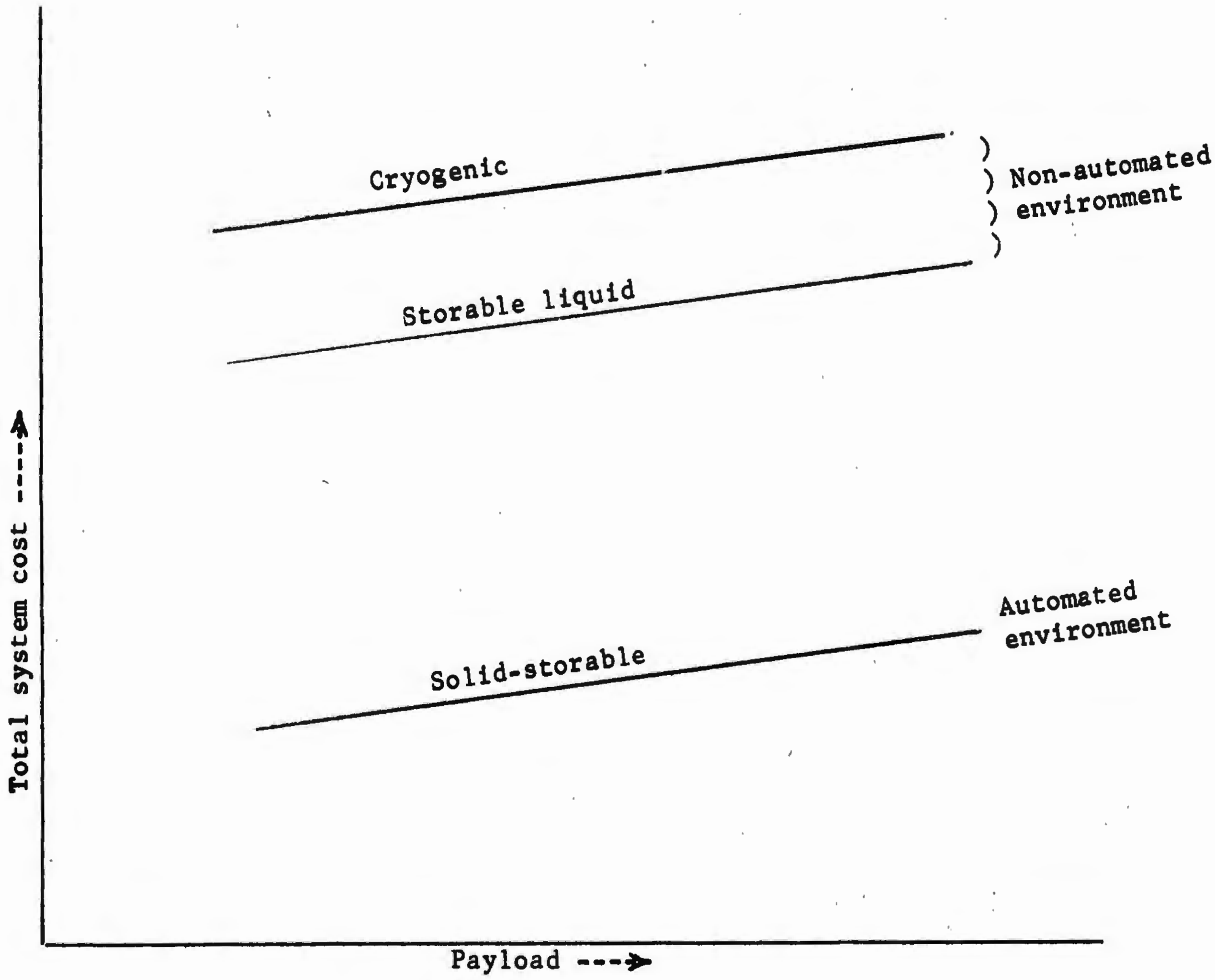
2. The system cost is relatively sensitive to type of propellant used. The explanation is that the use of solid or storable liquid propellants eliminates the need for the expensive storage and transfer facilities and equipment required by cryogenic propellants.

3. The system cost is relatively sensitive to the automation of the ground environment. The explanation in this case is that an automated environment requires less launch site checkout equipment and personnel and personnel facilities.

Figure 5 illustrates a boost-glide system* which is initially quite sensitive to increases in the weight of the warhead. The cost curve shows that the sensitivity decreases with increasing warhead weight, so that after a point substantial increases in weight could be bought for only moderate rises in system costs.

Figure 6 displays (on a slightly different scale) the major elements of cost which contribute to the total cost curve shown in Figure 5. From this breakdown, it is apparent that the cost of the operational flight vehicles is the most important element in the total cost curve, although other elements also contribute to its change of slope.

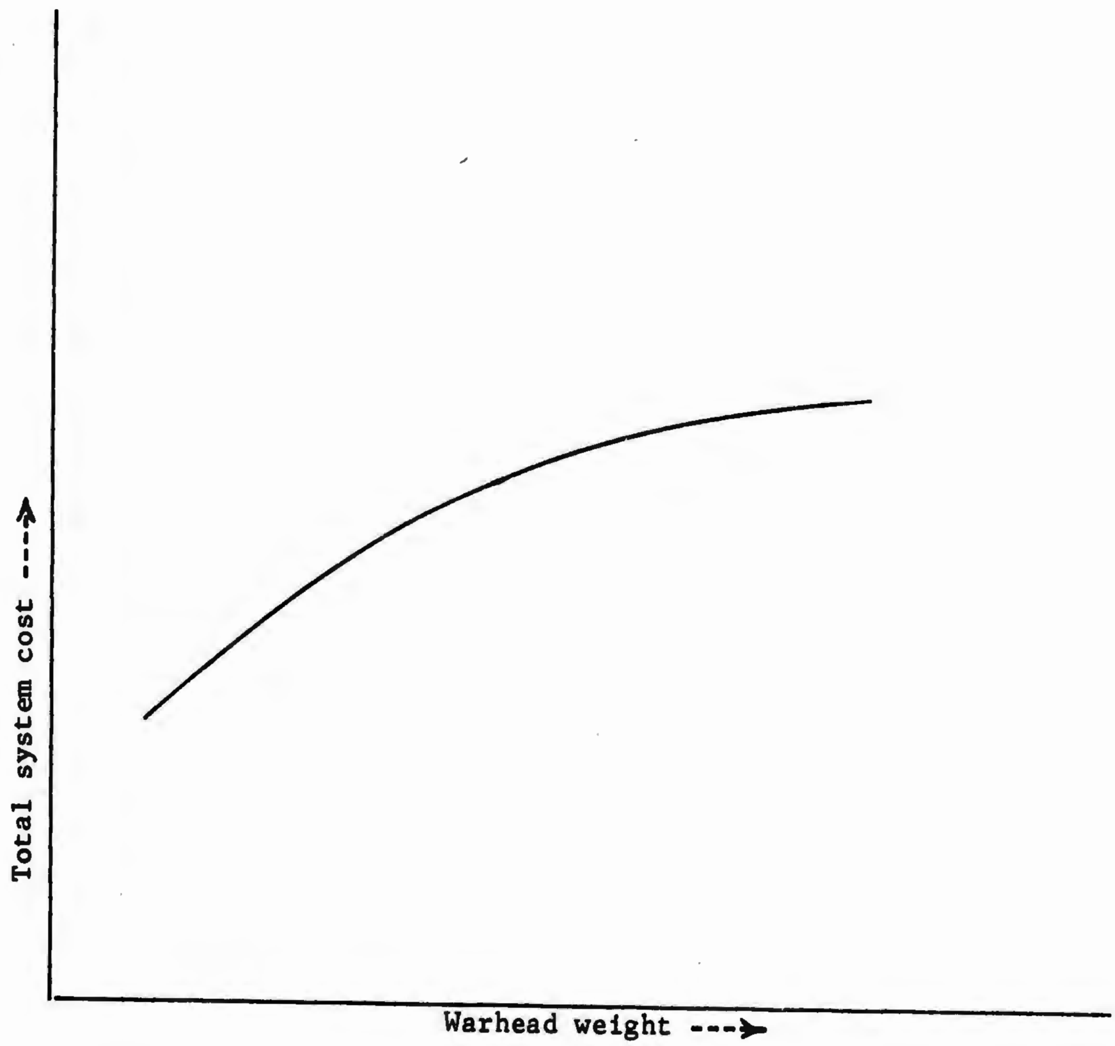
* Example from <u>System and Total Force Cost Analysis</u>, by David Novick, The Rand Corporation, April 1961.



Missile system cost vs payload for
various types of propellants and
ground environments

(Fixed number of ready missiles)

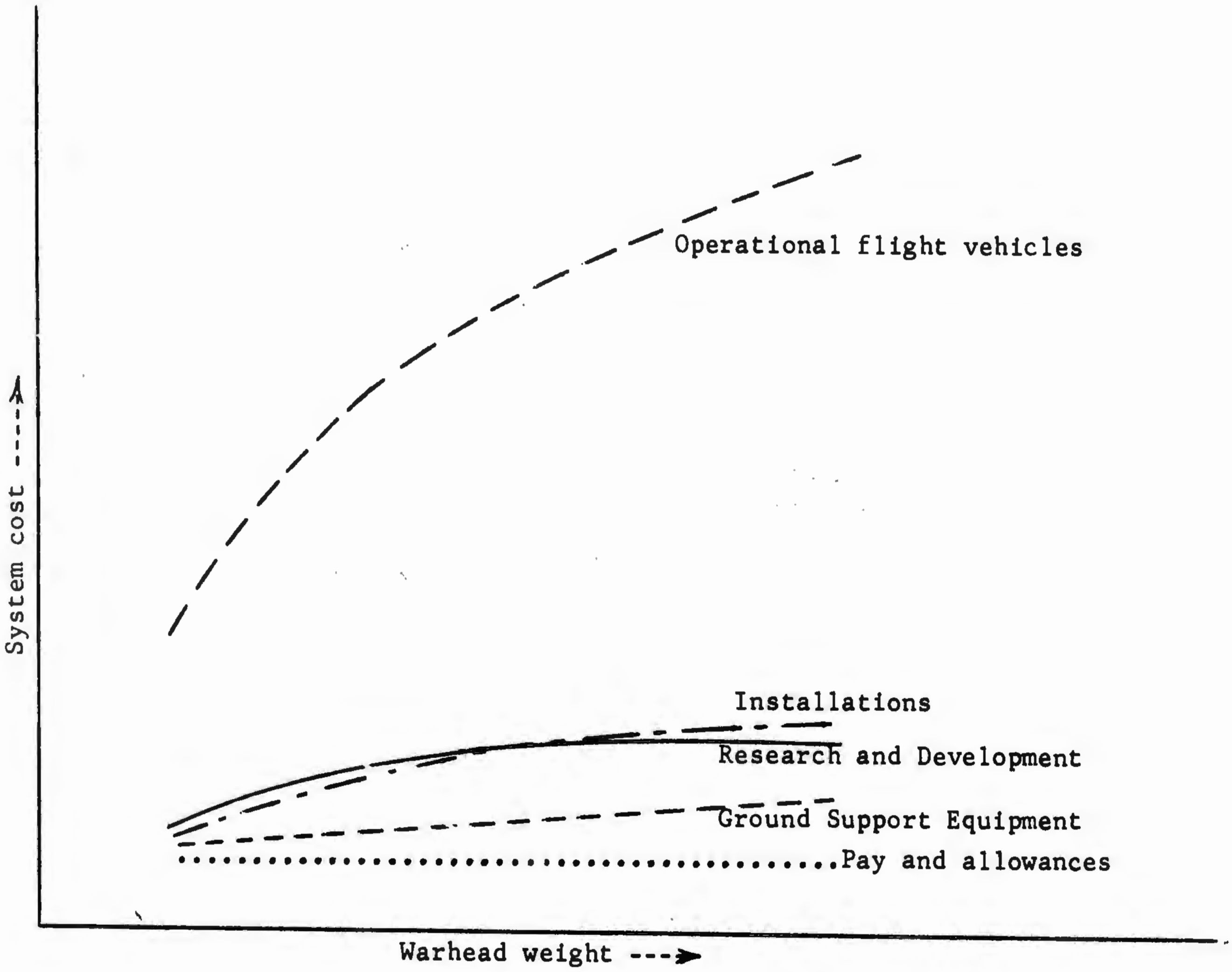
Figure 5-4



Boost-glide system cost vs
warhead weight

(Fixed ready vehicle force)

Figure 5-5



Major elements of cost in Figure 5-5
(Shown on a slightly different scale)

Figure 5-6

Figure 7 illustrates a case in which the total cost of a system initially decreases and then increases as one of the system characteristics is altered toward higher values. The system includes a number of satellites in orbit, and as their altitude is increased, the cost of the system falls markedly at first, primarily because the change in altitude makes it possible for fewer satellites to do the job. But after a point this saving is counterbalanced by the increasing costs of other components: the larger boosters, more sensitive instrumentation, and more powerful communication equipment needed for the greater altitudes. The point is that the cost implications of the system are fully revealed only by costing a wide range of system configurations. Not only can the slope of the cost curve suggest possibilities of advantageous tradeoffs between cost and system characteristics; in some cases, points of minimum cost can be located apart from points of minimum performance.

In conclusion, some guidance for the inclusion of sensitivity analysis in future cost analysis studies can be presented. Each cost analysis should include a separate section on sensitivity analysis. It should isolate the sensitive variables and present the effects on cost due to variations in the value of the sensitive variables. The selection of which areas to study for sensitivity is generally obvious to experienced analysts associated with a system. The analyst must also be responsive to requests by decision-makers to vary the assumptions. In general, the effects of changes in buy quantities as well as variations in a minimum of three other sensitive parameters should be used in the sensitivity analysis at this point in time. As sophisticated data processing becomes more available, the full range of the element estimated should be explored. For ease of use, the results of the sensitivity analysis should be summarized and presented in table or graph form.

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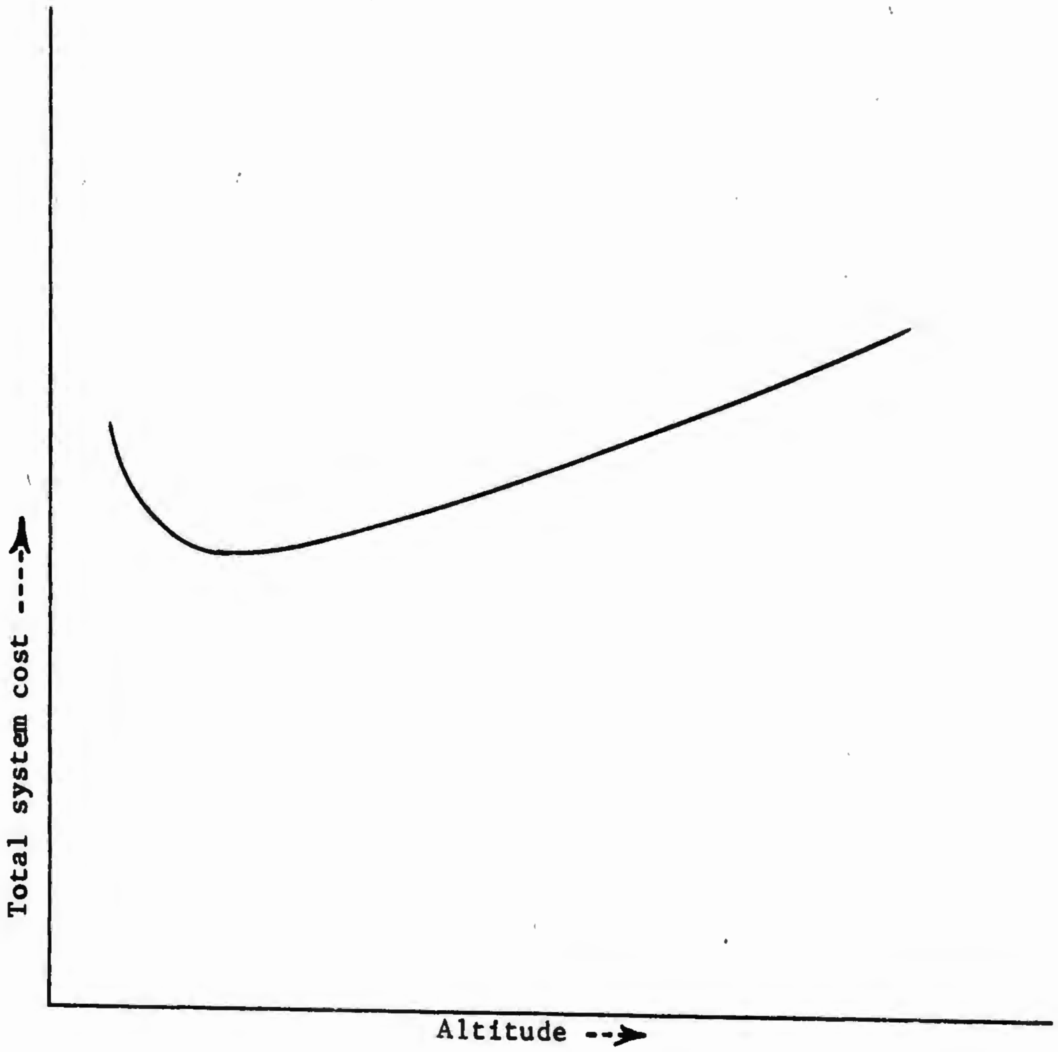
4. Naylor, T. H., Balintfy, J. L., Burdick, D. S., and Chu, K., Computer Simulation Techniques, Wiley, New York, 1966.



Satellite system cost vs altitude

(Fixed job to be done)

Figure 5-7

CHAPTER 6

ECONOMIC CONSIDERATIONS

<u>Economic analysis and cost estimating</u>.

Economic analysis concerns the evaluation of alternatives. It is clear that any attempt to evaluate alternative proposals or courses of action in terms of objectives, costs, and benefits must include a consideration of cost information. Hence, cost estimates play an integral role in any economic analysis. This chapter covers certain economic considerations that may affect cost estimates rather than the general subject of economic analysis. The concepts and procedures to be followed in conducting economic analyses are described in Army Regulation 37-13, "Economic Analysis of Proposed Army Investments".

<u>Time-phasing</u>.

Most cost estimates must be time-phased. Not only is it necessary to know how much a proposed system will cost, but it is also necessary to know when the expenditures will be made. There are several reasons for this. First, planning costs must ultimately be programmed into a budget. Second, time phased cost estimates are required in order to make trade-offs among projects which have differing expenditure patterns over time. Third, if inflation is to be considered, the distribution of expenditures over time must be known.

<u>Inflation</u>.

Definitions:

There has been considerable confusion over the terms "constant" and "current" dollars. The following definitions are in accordance with generally accepted usage:

<u>Constant Dollars</u>. The phrase "constant dollars" is always associated with a base year (e.g., FY 71 constant dollars) even though the base year may not always be specifically stated. An estimate is said to be in constant dollars if costs for all work are adjusted so that they reflect the level of prices of the base year. A constant dollar estimate is what would be paid if price levels had always been the same and always remained the same as in the base year.

Current Year Dollars. Current Year Dollars are current to the year the work is performed. When prior costs are stated in current year dollars, the figures given are the actual amounts paid out. When future costs are stated in current year dollars, the figures given are the actual amounts which will be paid including any amount due to future price changes. The "current year" in "current year dollars" does not refer to the year in which the estimate is made or any other single year.

The use of constant dollars.

The use of constant dollars in budget requests has two major benefits. First, constant dollars may be useful in the consideration of resource requirements over time. Here, the use of constant dollars removes distortions which are attributable only to price level changes. Second, using constant dollars aids in the attempt to control inflation since the expectation that inflation will continue adds greatly to inflationary pressure.

The use of current dollars.

When inflation occurs between the time a budget request is submitted and the time funds are actually expended, there will be a gap between how far the funds were supposed to go and how far they actually go. Hence, the use of current dollars also has certain advantages for use in budget and programming documents. A major advantage is in developing estimates which more realistically reflect likely expenditure levels. Since cost estimates have been proven overly optimistic in the past, inflated estimates can serve to reduce overruns by showing a more realistic initial estimate.

Policy on inflation.

Only limited policy guidance on inflation has been announced. OMB is firmly adhering to its requirements for constant dollars. DOD, however, is making increasing use of current dollars in its internal planning process. Several items of policy have been clearly defined and should be closely followed. The broad form of this policy is summarized below. More detailed instructions are included as annexes.

General instructions have been issued for inclusion of price escalation in certain cost estimates for research and development, procurement, and construction. This detailed guidance is inclosed as annex 1.

Specific guidance has been issued for use in the preparation of Selected Acquisition Reports (SAR's). This guidance is provided in annex 2 and should be used for SAR preparation and only for SAR preparation.

Cost data in constant dollars must be maintained in all cases. Since the costs of all systems must ultimately be programmed into the budget cycle, constant dollar costs must be readily identifiable.

The use of current dollars in cost estimates is encouraged whenever it will aid in planning and programming or whenever it may serve as an effective form of sensitivity analysis (subject to the limiations expressed in the detailed guidance in annexes 1 and 2).

Care should be exercised to avoid double counting when estimating unbudgeted price increases. For example, if part of a system involves expenditures under a fixed price contract, these costs should not be inflated.

Present Value.

Economic analysis is applied to alternative courses of action. The emphasis is on comparison in a decision-making environment. This broad concept of economic analysis means that the resultant decision is to take into account the relevant benefits and costs of all appropriate alternatives. Moreover, the decision maker is assumed to maximize efficiency in terms of these two empirically oriented concepts. The cost side in any economic analysis blends in with, and is a part of, any typical costing exercise and has been treated in other parts of the handbook under sections dealing with "estimating techniques" and the construction of LCCE's. The problem is usually presented to the cost analyst in a rough and general form with the requirement to conduct an economic analysis. Within this general framework, the analyst has the option of structuring the alternative courses of action. Relevant costs and benefits must then be calculated and estimated.

Economic analysis expands cost analysis activities by examining the effects of the time-value of money on the investment decision. Once cost/benefit estimates have been generated, they must be time-phased to allow for the consideration of alternative expenditure patterns. The time-value of money is appropriately considered by computing present value costs. Present value costs are to be computed by applying the appropriate 10 percent discount factors to the time-phased expenditure amounts. The Present Value costs are then obtained as the sum total of the discounted costs.

The present value of the alternative is the money cost which would be required to finance the alternative --- when 10 percent could be earned by investing the funds until required for expenditure. If 10 percent interest can be earned, then this represents the "opportunity cost" of capital. Assuming equal benefits, the alternative whose present value cost is least is the more desirable, because it implies a more efficient allocation of resources. The lower present value cost means that resources are allocated more efficiently in the sense that fewer current resources must be diverted to satisfy the requirement. The particular approach to any economic analysis (i.e., equal cost; equal benefit; unequal cost; unequal benefit) will be dependent upon the specific nature of the problem. No one approach is inherently superior and all are logically equivalent.

ANNEX 1

GENERAL INSTRUCTIONS FOR INCLUSION OF PRICE ESCALATION IN CERTAIN COST ESTIMATES FOR RESEARCH AND DEVELOPMENT, PROCUREMENT, AND CONSTRUCTION

1. References:

a. DODI 7045.10, "Five Year Defense Program Procurement Annex," 14 April 1970.

b. DOD Manual 7110.1-M, "Manual for Preparation of Budget Estimates, Operating Budgets, Financial Plans and Apportionment Requests, and Related Support Material," dated 23 August 1968, as changed 13 August 1970.

c. AR 37-100, "Army Management Structure."

d. ASD(C) Memorandum, 30 June 1970, Subj: Weapon System Costing.

2. Applicability.

a. This instruction applies to cost estimates appearing in the Five Year Defense Program (FYDP), the budget, Development Concept Papers (DCP), Selected Acquisition Reports (SAR), the Program Objectives Memorandum (POM), and related items. Specific implementing instructions for these documents will be provided as appropriate.

b. This instruction applies to the following costs with the exception noted in 2b(5).

(1) Procurement costs for all systems (line items) listed specifically by name in the FYDP Procurement Annex in Activities 6, 7, and 8 (Tactical and Support Vehicles, Communication and Electronics Equipment, and Other Support Equipment) if the procurement cost exceeds $5 million in any year without the inclusion of anticipated price changes and in Activities 1, 3, and 5 (Aircraft, Missiles, and Tracked Combat Vehicles) regardless of cost. The FYDP Procurement Annex is prepared in the same manner as the PEMA Line Item List (Exhibit P-1) but covers the same time period as the FYDP. Procurement cost is as defined in reference 1b. This is the same procurement cost as is shown in the SAR and is the sum of the individual system line and its associated initial spares in the FYDP Procurement Annex and in the P-1. This instruction does not apply to modifications, component improvement, replenishment spares and items listed in the aggregate (except initial spares identified with systems to which this instruction does apply).

(2) RDTE costs for systems reported under the SAR. RDTE costs for other systems listed by name as program elements or major projects within program elements in the FYDP will be included in the future as instructions from HQ DA may direct.

(3) Costs of Major Construction (Budget Program 6100.0000 and Budget Accounts 6800.2000 and 6800.3000 within Military Construction, Army, Budget Accounts 8511.0000 and 8512.0000 within Military Construction, Army National Guard, and Budget Account 8612.0000 within Military Construction, Army Reserve).

(4) Costs of Construction of New Family Housing Units (Budget Project 1810.0000 within Family Housing Management Account, Defense - Transfer to Army).

(5) As an exception to 2b(1) through 2b(4) costs of compensation of government employees are not intended to be covered by this instruction even though they may be included in the above four categories.

3. Types of Price Escalation. A distinction is drawn between the following two types of anticipated price changes:

a. Specific data: Specific data is applicable to a given system or project and consists of contract provisions, labor agreements, productivity, and quantity changes and considers the extent to which materiel is on hand or under fixed price contract. This data is based on events which have occurred or will definitely occur rather than a general expectation or extrapolation of changes. Specific data is the type of data which has been used as the basis for including anticipated price changes in prior budget requests.

b. Price Level Indices: A price level index forecasts the general level of prices. The following indices have been provided by the Assistant Secretary of Defense (Comptroller):

	Procurement	RDTE	Family Housing And Construction
FY 1970	96.6	95.1	94.0
FY 1971	100.0	100.0	100.0
FY 1972	102.6	103.8	104.8
FY 1973	104.5	107.5	109.2
FY 1974	106.1	110.8	113.3
FY 1975	107.5	114.1	117.3
FY 1976	108.9	117.5	121.4
After FY 1976, add the indicated annual increase, compounding	1.3%	3.0%	3.5%

The FY 1971 index should be considered as the price level prevailing in about the fourth quarter of Calendar Year 1970, or the average price level prevailing in FY 1971.

4. Policy. In the documents to which this instruction is applicable, estimates of costs specified in paragraph 2b will reflect the best estimate of the amounts ultimately to be paid, specifically incorporating anticipated changes in future prices. Wherever practicable, this will be accomplished on the basis of specific data applicable to a given system as defined in paragraph 3a. In other cases, it will be necessary to base the estimates on forecasts of changes in price levels. In such cases the indices given in paragraph 3b, and only these indices, will be used.

5. Time Phasing of TOA Expenditure.

a. In projecting prices, it should be noted that the TOA reflected for a particular year must reflect the price escalation over the span of years during which that TOA will be expended. For example, FY 1972 TOA might reflect escalation from FY 1972 through FY 1975, taking account of the time phasing of outlays on firm contracts for the system involved.

b. When price escalation is based on indices, the indices should ideally be applied to dollar amounts assigned to years on an accrued expense basis. To apply indices to a given year's TOA, that year's TOA should be time-phased on (or near) an accrued expense basis and indices should be applied against this time-phasing to arrive at the escalated TOA for the original year. Inclosure 1 provides standard factors by appropriation for the time-phasing of expenditures of a given year's TOA. These factors should be employed unless there is specific information available supporting a different expenditure pattern. Inclosure 2 provides an example applying indices to $1 million of FY 72 PEMA TOA with expenditures time-phased by the factors shown in Inclosure 1. This example assumes that the basic estimate to which indices are applied is in FY 71 constant dollars; existing estimates not in FY 71 constant dollars would have to be adjusted to FY 71 constant dollars before the procedure shown in the example could be employed. Since the amount of price escalation to be added to each year's TOA is sensitive to the time phasing of the expenditures of that year's TOA, offices preparing estimates should maintain the capability to reproduce the time phasing of each year's TOA expenditure used in applying indices.

6. Double Inclusion of Price Escalation.

a. For each system or project, anticipated price changes based on specific data should be included in costs for which they are available and price escalation based on indices should be included in those costs for which specific data on anticipated price changes is not available.

b. In cases where price escalation to cover several years is to be included, it may be appropriate to base price changes in the near future on specific data and employ indices to cover the remaining time period. In general, it is expected that anticipated price changes for the budget year would be based on specific data while price indices would be used for years farther beyond the budget year.

c. To avoid double counting, care must be taken that a single cost within the estimate for a given system or project is not increased once because of specific data and then again because of indices covering the same time period as the specific data.

7. Visibility of Price Escalation.

a. In order to maintain comparability with costs not including anticipated price changes, it is desirable that the amount of price escalation included within an estimate and the basis for the price escalation be stated either along with the estimate or in appropriate backup.

b. Since the practice of escalation by indices is subject to errors having large effects on costs, records will be maintained of the amount of price escalation included in estimates that is based on indices. Particular care in recording price escalation based on indices is required in systems or projects where both specific data and price indices are employed.

8. Other Cost Estimates. Estimates of costs not covered by this instruction will be prepared as they have been in the past and as other instructions may provide.

ESTIMATED EXPENDITURE RATES FOR A GIVEN YEAR'S TOA (AS A PERCENT OF THAT YEAR'S TOA)

APPROPRIATION	IN FIRST YEAR	IN SECOND YEAR	IN THIRD YEAR	IN FOURTH YEAR	IN FIFTH YEAR
PEMA (Other than Ammo)	16.00	44.00	28.00	9.00	3.00
RDTE, Army	51.00	38.00	7.50	2.10	1.40
MCA	10.00	50.00	25.00	10.00	5.00
MCA, R	5.00	51.00	29.00	8.00	7.00
MCA, NG	1.00	34.00	45.00	14.40	5.60

CALCULATION OF PRICE ESCALATION BY INDICES - TIME PHASING OF TOA

FY 72 PEMA TOA Without Price Escalation
(FY 71 Constant Dollars) = $1,000,000

FISCAL YEAR	PRICE INDEX	EXPENDITURES OF FY 72 TOA ON AN ACCRUAL BASIS (AS APPROXIMATED BY PROJECTED DISBURSEMENTS)	
		In FY 71 Constant Dollars (i.e., without price escalation)	In Current Year Dollars (i.e., with price escalation)
FY 72	102.6	160,000	164,160
FY 73	104.5	440,000	459,800
FY 74	106.1	280,000	297,080
FY 75	107.5	90,000	96,750
FY 76	108.9	30,000	32,670
TOTAL		1,000,000	1,050,460

FY 72 TOA PEMA with price escalation (Current Year Dollars) = $1,050,460

ANNEX 2

INSTRUCTIONS FOR CALCULATIONS OF PRICE ESCALATION IN THE SELECTED ACQUISITION REPORT (SAR)

1. References:

a. General Instructions for Inclusion of Price Escalation in Certain Cost Estimates for Research and Development, Procurement, and Construction, dated 4 September 1970, COMPT-CA(R).

b. Composite Indices for Simultaneous Application of Standard TOA Expenditure Rates and General Price Level Indices, dated 15 September 1970, COMPT-CA(R) (Inclosure 4).

2. General: The provisions of reference 1a will be followed in preparing estimates for Selected Acquisition Reports. The use of Price Escalation Worksheets and of a Price Escalation Summary for the SAR are described below. These instructions do not alter the formats used in the SAR proper as it is forwarded to OSD and Congress. Additional lines are required in the Fiscal Year Display to show the amount of future price escalation included. Previous estimates in the SAR have included price escalation on the basis of various assumptions. Amounts previously included in SAR estimates for future price escalation will be removed and only future price escalation based on these instructions will be reincorporated in the SAR.

3. Applicability: The types of cost to which these instructions apply are defined in paragraph 2b of reference 1a. It should be noted that these instructions do not apply to Additional Procurement Costs. The provisions of reference 1a will be applied in the SAR to the Current Estimate, the FYDP Estimate and under Contractor Costs, to the Government Estimate of Price at Completion. The Planning Estimate, Development Estimate, and Contractor Costs (other than the Government Estimate of Price at Completion) are matters of record and cannot be changed by the Project Manager because of the new policy regarding anticipated price changes. Headquarters DA will furnish the FYDP Program and reflect as a separate line entry the price escalation to be shown as a memo entry. The same principles that are applied to price escalation for the FYDP estimate and the current estimate will be used to compute the price escalation for the FYDP program.

4. Price Escalation Worksheet (Incl 1):

a. The Price Escalation Worksheets are for the Project Manager's use in preparing his estimates. Although the worksheets need not be submitted along with the SAR, they must be available for submission to Headquarters DA in the event that the estimates must be revised or the procedure for handling price escalation must be reviewed.

b. At the top of the format enter the name of the Project, the estimate (Current Estimate and stub item, FYDP Estimate, or Government Estimate of Price at Completion), Appropriation, and the fiscal year of the Total Obligational Authority being estimated ("FY70 and prior", FY71, FY72, FY73, FY74, FY75, FY76, or "To Complete"). Separate worksheets may be used for each fiscal year within "FY70 and prior" and "To Complete".

c. Under "Year of Expenditure" enter as column headings the fiscal years in which expenditures will occur from the TOA of the fiscal year being estimated. The projected expenditures of the TOA will be time phased in these columns in order to apply indices.

d. Portion not subject to further escalation. Since indices will not be applied to amounts appearing in this section, expenditure time phasing is not required. Only sunk costs, costs arising from signed contracts which establish a price which will not change due to inflation, and compensation of government employees will be listed in this section. Government personnel compensation will be priced as provided for in Budget Formulation Directives (i.e., approved FY71 pay rates will be used for future years). Note the effect of the update to FY 71 pay rates on the line indicated.

e. Specific Data: Contracts with Escalation Clauses:

(1) In order to predict the price of the work at completion covered by a contract with an escalation clause, it is necessary to use the levels which will actually be assumed by the price indices on which the contract's escalation clauses are based. The OSD indices, adjusted as described below, will be treated as the actual future values of standard indices appearing in escalation clauses. By taking the contract price of the work financed by a given year's TOA (including any earned incentives or portions of the target-ceiling price spread) and adding the reimbursement for inflation resulting from execution of the escalation clause, the estimate in current year dollars for the TOA expended on the given work is obtained.

(2) The OSD indices will be adjusted to put them in the same base year as the standard indices appearing the the escalation clause allowing for the latest historical value of the standard indices.

Typically, contract escalation clauses are based on Bureau of Labor Statistics (BLS) indices for labor, materiel, subcontract and so forth. These indices are on a calendar year rather than fiscal year basis, and the latest historical annual averages for these indices are from CY 69. Calendar year OSD indices with a base year of CY 69 are provided at Inclosure 3. In order to obtain index numbers to use in determining the effect of an escalation clause, multiply the historical CY 69 value of the standard index by the index numbers from Inclosure 3. If the CY 73 value for a BLS index were required for an escalation clause dealing with PEMA funds, the historical CY 69 BLS index would be multiplied by the CY 73 procurement index from Inclosure 3. Similarly, if the CY 74 value for a BLS index were required for an escalation clause dealing with RDTE funds, the historical CY 69 BLS index would be multiplied by the CY 74 RDTE index from Inclosure 3.

(3) The Price Escalation Worksheet will be filled out in the following manner. Each contract with an escalation clause will be handled separately (as a, b, c, ...). For each contract, list the contract number and in the total column enter the price of work at completion including the allowance calculated for the escalation clause. This allowance should be shown as a memo entry "Future Price Escalation". Projections and calculations required to determine the effect of the escalation clause should be done on a backup sheet attached to the worksheet.

f. Portion subject to escalation by indices:

(1) This section of the format will be used for costs which are not covered elsewhere.

(2) In the space provided for "Conversion to FY 71 Constant Dollars", note how the portion subject to escalation by indices is brought to FY 71 constant dollars. The update of older estimates not in FY 71 constant dollars should be done by use of the OSD indices in paragraph 3b, reference 1a, unless the use of historical data can be supported by documentation. If the OSD indices are used to conver to FY 71 constant dollars, this calculation should be done here.

(3) On the line "FY71 Constant $" enter the cost in FY71 constant dollars of all work to be accomplished with funds from the FY of TOA which is subject to escalation by indices. These costs <u>must</u> be in <u>FY71 constant dollars</u>. The amount shown on this line must be time-phased as to expenditure (with the exception noted in paragraph 4f(4)). Enter the price indices from reference 1a on the line labeled "OSD Index (FY71 = 100)". Multiply the amounts in FY71 Constant Dollars by

these indices, enter the products on the line "Subtotal Current Year $" and enter the sum of the time-phased current year dollar amounts under the Total Column. Show the difference between "FY71 constant dollars" and "Subtotal Current Year Dollars" as a memo entry "Future Price Escalation."

(4) If the standard expenditure rates given in Inclosure 1 to reference 1a are used to time-phase the expenditure of TOA, then the specially developed composite indices described in reference 1b (Inclosure 4) can be used (without calculating the time-phasing of TOA) to convert TOA for FY71 and outyears, expressed in FY71 constant dollars, directly into current year dollar totals. Instead of entering the time-phasing of expenditures calculated from the standard expenditure rates, enter the notation "standard expenditure rates used", and enter the TOA in FY71 constant dollars in the Total Column. Enter the composite index number, chosen from reference 1b for the fiscal year of the TOA, in the Total Column on the line labeled "OSD Index (FY71 = 100)." Multiply the TOA in FY71 constant dollars by the composite index number and enter this amount on the line "Subtotal Current Year Dollars."

g. Totals: At the top of the worksheet, in the space marked "Total" show the sum of the subtotals from sections 1, 2, and 3. Show the sum of the memo entries from sections 2 and 3 as "Future Price Escalation."

5. Fiscal Year Display (Inclosure 2): Upon completion of all worksheets, the dollar amount of future price escalation within each dollar entry in the Current Estimate and the FYDP Estimate of the Fiscal Year Display will be entered as indicated on the attached sample Fiscal Year Display.

6. Price Escalation Summary: Only the results of the price escalation computations will be included in the SAR as forwarded to OSD. An Inclosure (no more than one page, preferably one paragraph) to the Fiscal Year Display will summarize the logic and results of the following computations for the FYDP Estimate, the Current Estimate, and the Government Estimate of Contract Price at Completion:

a. The update of the constant dollar base from FY 70 constant dollars to FY 71 constant dollars.

b. The price escalation computations for the FY 72 budget covering the projected update of the FY 71 constant dollar base to current year dollars.

c. The future year cost increases for price escalation (the program from FY 73 through completion of acquisition).

7. Variance Analysis and Changes from the Previous SAR:

a. Changes and variances due to causes other than implementation of this instruction on price escalation will be accounted for in the 30 Sep 70 SAR on the basis of the pricing policy followed in the 30 Jun 70 SAR. In the variance analysis, price escalation amounts should be included in the cost growth category "Economic Change." The "Remarks" column should include subtotals of historic inflation (the inflation which has been accounted for as a result of updates of the SAR constant dollar base through FY71) and projected price escalation (the price escalation for the budget year and future years).

PRICE ESCALATION WORKSHEET
($ MILLIONS)

					TOTAL	FUTURE PRICE ESCALATION
PROJECT	ESTIMATE(STUB ITEM)	FY OF TOA	APPROPRIATION	DATE		

BREAKDOWN	YEARS OF EXPENDITURE	TOTAL
1. PORTION NOT SUBJECT TO FUTURE ESCALATION		
(CONVERSION TO FY71 PAY RATES)		
SUBTOTAL		
2. PORTION SUBJECT TO SPECIFIC DATA		
a. CONTRACT # (FUTURE PRICE ESCALATION)		
b.		
.		
.		
SUBTOTAL		
(FUTURE PRICE ESCALATION		
3. PORTION SUBJECT TO ESCALATION BY INDICES		
CONVERSION TO FY71 CONSTANT $		
FY71 CONSTANT $		
OSD INDICES (FY71 = 100)		
SUBTOTAL CURRENT YEAR & (FUTURE PRICE ESCALATION)		

WEAPON SYSTEM
FISCAL YEAR DISPLAY
PROGRAM ACQUISITION COSTS AND ADDITIONAL PROCUREMENT COST

DATE
REPORT AS OF:

PROGRAM ACQUISITION COST ($ Millions)	FY70 & Prior	FY71	FY72	FY73	FY74	FY75	FY76	TO COMPLETE	TOTAL ESTIMATE
DEVELOPMENT ESTIMATE									
RDTE									
PEMA									
MCA (if applicable)									
CURRENT ESTIMATE									
RDTE									
Escalation									
PEMA									
Escalation									
MCA (if applicable)									
Escalation									
FYDP									
RDTE									
Escalation									
PEMA									
Escalation									
MCA (if applicable)									
Escalation									
FYDP ESTIMATE									
RDTE									
Escalation									
PEMA									
Escalation									
MCA (if applicable)									
Escalation									
ADDITIONAL PROCUREMENT COSTS									
CURRENT ESTIMATE									
FYDP									
FYDP ESTIMATE									

OSD INDICES ON CALENDAR YEAR BASIS

	Procurement	Research and Development	Family Housing and Construction
CY 1969	100.0	100.0	100.0
CY 1970	103.5	105.3	106.5
CY 1971	106.7	110.0	112.5
CY 1972	109.1	114.0	117.5
CY 1973	110.9	117.8	122.2
CY 1974	112.5	121.4	126.6
CY 1975	114.0	125.0	131.1

The CY 1969 index should be considered as the price level prevailing in about the second quarter of Calendar Year 1969 or the average price prevailing in CY 1969.

These indices when adjusted for the historical CY 1969 value of the indices appearing in an escalation clause will be used to predict the effect of the escalation clause. This procedure is necessary since no valid projection of standard indices (e.g., Bureau of Labor Statistics Indices) is available. The OSD indices have been specially developed to apply to DOD activities. The index numbers to be used in calculating the effect of escalation clauses will in effect be treated as "projections" of standard indices, but it must be realized that these "projections" are only a combination of the last historical year of the standard index and the OSD indices for the future. Even though a detailed analysis of the standard indices would reveal differences between the most probable future values of standard indices and the values "predicted" with OSD indices, the later will be used.

COMPOSITE INDICES FOR SIMULTANEOUS APPLICATION
OF STANDARD TOA EXPENDITURE RATES AND GENERAL PRICE LEVEL INDICES

1. Reference: General Instructions for Inclusion of Price Escalation in Certain Cost Estimates for Research and Development, Procurement, and Construction, dated 4 September 1970, COMPT-CA(R).

2. Given an amount of money in FY 71 constant dollars as TOA for a given year, the time phasing of this amount by standard expenditure rates and application of price level indices (both provided in ref 1) represents a simple, but time consuming, arithmetical problem. The direct approach is to multiply the TOA by each year's standard expenditure rate to arrive at expenditures for each year in FY 71 constant dollars. Each year's expenditure is multiplied by that year's price level index to arrive at yearly expenditures in current year dollars. These yearly expenditures are summed to arrive at the required TOA in current year dollars (i.e., with price escalation).

3. The general formula for this calculation is as follows:

$$Y_i = B_iA_1X + B_{i+1}A_2 X + B_{i+2}A_3 X + B_{i+3}A_4X + B_{i+4}A_5X$$

Where:

X is TOA in FY 71 constant dollars

Y_i is TOA in current year dollars with expenditures beginning in year i.

A_1 through A_5 are the standard expenditure rates given in ref 1.

B_i through B_{i+4} are the OSD price level indices for fiscal years i through i+4.

Note that the above formula simplifies to:

$$Y_i = X\ (B_iA_1 + B_{i+1}A_2 + B_{i+2}A_3 + B_{i+3}A_4 + B_{i+4}A_5)$$

$$= X\ C_i$$

Where $C_i = B_iA_1 + B_{i+1}A_2 + B_{i+2}A_3 + B_{i+3}A_4 + B_{i+4}A_5$

Thus, if the factor C_i (called herein the composite index for fiscal year i) is available, the calculation is reduced to one multiplication.

4. The table on the following page shows the composite indices (by appropriation) for each fiscal year. Multiplying a TOA amount in FY 71 constant dollars by the composite index for a given fiscal year and appropriation automatically raises that TOA amount to current year dollars allowing for time phasing (by standard rates) of expenditures beginning in the year of authorization.

COMPOSITE INDICES FOR SIMULTANEOUS APPLICATION OF STANDARD TOA EXPENDITURE RATES AND GENERAL PRICE LEVEL INDICES 1/

	PEMA	RDTE	MCA	MCA,R	MCA, NG	FHMA
FY 71	103.2	102.4	106.9	107.4	108.7	
FY 72	105.0	106.1	111.2	111.7	112.9	Not
FY 73	106.6	109.6	115.3	115.8	116.9	Available
FY 74	108.0	113.0	119.4	119.8	121.0	
FY 75	109.4	116.3	123.6	124.0	125.2	
FY 76	110.9	119.8	127.9	128.3	129.6	
After FY 76 add the indicated annual increases, compounding	1.3%	3.0%	3.5%	3.5%	3.5%	

1/ These composite indices are to be applied only to estimates of TOA expressed in FY 71 constant dollars. With one multiplication, they convert FY 71 constant dollars to current year dollars assuming the time phasing of expenditures by standard rates. These factors are derived from the general price level indices and standard expenditure rates given in reference 1.

CHAPTER 7

PRESENTATION OF THE ESTIMATE

The presentation, both written and oral, of the procedures, findings, conclusions, and recommendations of a cost analysis study to the decision maker and other interested persons is as important as properly performing the study itself. This phase in the completion of a study program can mean the difference between having a project continued or dropped, or its findings accepted or rejected.

Keeping this in mind the writer must organize his thoughts and material. The mere undertaking of a project will require both intermediate and final reports, and all of the same steps in the systematic accomplishment of the project or study are involved in the writing of the project report. These steps are:

Stating the problem. This is undoubtedly the crux to the entire study process. If the wrong problem is addressed, then time, money, and purpose for the study will be wasted.

Defining the scope. Limits as to what can be presented within the space of time allotted must be recognized.

Planning the Research,

Collecting the Information, and

Analyzing the Information: For the purposes of cost analyses presentation these last three steps involve having the report preparer sit down with the study working papers and (1) deciding what needs to be included in order to show how the study conclusions were reached, (2) culling this information out of the working papers, and (3) determining how to best set this information down on paper.

THE USERS: Following the accomplishment of these steps the writer then needs, prior to commencing the actual writing task, to consider the controls which will be influencing the way in which he will put words down on paper. This control takes the form of the audience--the decision-making office that will read the report and use the material it contains.

After determining who the audience is to be, the writer then has a basis for making decisions all along the line, including decisions on such things as the length of the report, the format, the writing style, and the comprehension level of the reader. Knowing the audience also includes knowing how the report will be used. For cost analysis reports, the use will almost exclusively be as an aid in making decisions. Many, if not most, of these reports will ultimately be used by one or more individuals within the decision-making office. Several questions about these people should be answered in order to aid report preparation. These questions include:

What are their jobs?

How familiar are they with the subject?

What are they interested in?

What are the key questions they need answered?

Do they need to be filled in on some background information or have terms defined?

The more one knows about these individuals the better one can make the report.

Finally, one slight complication needs mentioning. The report may in fact be used by more than one audience--in other words a primary audience and a secondary audience. The primary audience is seldom a problem but the secondary audience can be elusive. It may be one person or a hundred. He may use the report next month or pull it out of a file two years from now. This being the case it is impossible to anticipate the entire range of backgrounds of this type audience. The report usefulness to the secondary audience can however be maximized by the conscious use of the four traits of good writing previously mentioned.

THE REPORT: Having determined who the audience, or if possible, the audiences will be, the writer can then prepare the report itself. The preparation of the results of cost analysis studies differs somewhat from other subjects in that the majority of the material may be numbers, numerical comparisons, and mathematical relationships. The writer will find that tables are useful in presenting numbers and numerical comparisons, while statements of formulas or graphs will best portray the mathematical relationships. Tables have the advantage of clarity, comprehension, explicitness, and economy of space. Care must be taken however, that the tables are properly constructed, complete, emphasize the proper comparisons, avoid extraneous data, and are properly labeled. While on the subject of numerical presentations, an additional point needs to be made. Numerical data is easy to check by readers and nothing will damage the credibility of a study more than a simple arithmetic error. The reader is likely to think, "if this guy can't even add and subtract, how can he make a good cost analysis?" The study and logic may otherwise be flawless but the credibility will be decreased.

In the area of graphics, a frequent shortcoming in cost analysis is that the writer fails to properly state why a graph or chart is relevant or how it fits into his analysis. Often one simple sentence will provide the necessary connection.

Due to the increasing cost growth of weapon systems over initial estimates, strong interest in several areas of cost analysis has developed. Specifically, Congress, and thus DOD, wants to know more about the influences of risk and technical uncertainty upon cost. In addition to the detailed analysis of these influences, sensitivity analysis including sensitivity to possible changes in assumptions must be included as a major section or sections in the physical organization of the report. Passing references to these topics are no longer adequate. The full report is comprised of two major volumes--the Executive Summary and the Detailed Report. The Executive Summary should be an abbreviated document restating the findings and conclusions and summarizing the supporting material. Particular attention should be made in pointing up any reservations connected with the study parameters and assumptions.

A general format would look as follows:

EXECUTIVE SUMMARY

I. TABLE OF CONTENTS

II. SYSTEM OVERVIEW

A. System Description

B. System Peculiar Definitions or Aspects

C. Study Objectives

D. Assumptions

III. FINDINGS AND CONCLUSIONS

IV. SUPPORTING SUMMARIES

   A. Assumptions

   B. Variance Analysis

   C. Uncertainty/Technical Risk/Sensitivity Analysis

A Detailed Report format aimed specifically at Weapon/Support system studies but modifiable to force studies is given below.

DOCUMENTATION FORMAT

I. TABLE OF CONTENTS

II. BACKGROUND

   A. Authority for Study

   B. System Overview

      1. System description

      2. System status in the life cycle management plan

      3. System peculiar definitions or aspects

III. STUDY OBJECTIVES AND ESSENTIAL ELEMENTS OF ANALYSIS (EEA)

   A. Objectives

   B. Essential Elements of Analysis

IV. STUDY PARAMETERS, ASSUMPTIONS

   A. Parameters

   B. Assumptions

V. DATA SUMMARIES

VI. VARIANCE ANALYSIS

VII. UNCERTAINTY/TECHNICAL RISK/SENSITIVITY ANALYSES

   A. Cost Estimating Uncertainty

B. Technical Risk Cost Impact

C. Sensitivity Cost Impacts

VIII. FINDINGS AND CONCLUSIONS

ANNEXES:

ANNEX 1--METHODOLOGY (RATIONALE)

ANNEX 2--DATA INPUTS (IN-HOUSE, OTHER SOURCES)

ANNEX 3--GLOSSARY

ANNEX4--BIBLIOGRAPHY

A brief explanation of each paragraph will assist in understanding the contents of each paragraph.

DOCUMENTATION FORMAT

I. TABLE OF CONTENTS - Self-explanatory.

II. BACKGROUND

A. Authorization for Study

This section contains the letter of transmittal and the authorization or directive which initiated the study. Background information that may provide perspective should also be included in this section.

B. System Overview

1. System Description

This section is intended to provide the reviewer with a perspective of the overall system. As a minimum, this description includes the operational concepts, major hardware item functions and description, system performance characteristics, maintenance concepts, and, where applicable, mobility and air transportability requirements, and other areas believed to be necessary.

2. System Status in the Life Cycle Management Plan

This section contains a brief description of the system life cycle management plan with emphasis placed on the current status of the system within the plan. The life cycle management schedule, the milestone schedule, and the major decision points should be addressed in the above context.

3. System Peculiar Definitions or Problems

This section lists and defines those definitions or problems which are peculiar to the system.

III. STUDY OBJECTIVES AND ESSENTIAL ELEMENTS OF ANALYSIS (EEA)

A. Study Objectives

This section of the report will exhibit the reasons that promoted the conduct of the study and the study objectives. This discussion should include a reference to the status of the system within the life cycle management plan and identification of the decisions that will be influenced by the study.

B. Essential Elements of Analysis (EEA)

This section should list the EEA that the study investigated. These EEA are the major issues or decisions involving system life cycle costs that are directly related to the study objectives. They address the major decision or "what if"? questions which can be anticipated.

IV. STUDY PARAMETERS, ASSUMPTIONS

A. Study Parameters

This section contains the initial guidance for the study. It states the place of the weapon system in the DA plan and a general tactical employment concept. It also includes the basis of issue contained in the Table of Allowances, Table of Organization and Equipment, Manning Table and Equipment List, or other similar authorization which provides the basis of the study and specifies the number of items issued to an individual, a unit, a military activity, or for a unit piece of equipment. This section includes the total quantity to be procured, the production rate and schedule, the build-up rate and time period, and the delivery schedule. If more than one total production quantity is considered, then the production rate, schedule, and delivery schedule for each total quantity is specified. The maintenance plan and requirements are discussed to include maintenance float, combat consumption, mobilization reserve, and basis of issue of special equipment. The initial provisioning policy and factors broken out between PEMA and stock fund are provided. Ammunition requirements are identified as to type, basic load, initial provisioning factors, interface with other weapon systems, training ammunition requirements for introductory training, annual training allowances, and quality assurance requirements. Operating cost assumptions include the Table of Organization, primary weapon crew size, annual operating factors, such as mileage, ammunition expenditure, time between overhaul, maintenance plan, replacement training plan, annual training program, and accession factors.

B. Assumptions

This section should include a complete listing of the statement of assumptions and the source or justification for each assumption.

V. DATA SUMMARIES

This section consists of a narrative description of the wrok breakdown structure (WBS) used, and cost tables and formats prepared in accordance with AR 37-18.

VI. VARIANCE ANALYSIS

This section contains all data necessary to explain changes between this cost estimate and previous cost estimates, if applicable.

VII. UNCERTAINTY/TECHNICAL RISK/SENSITIVITY ANALYSES

A. Cost Estimating Uncertainty

This section should be devoted to the explanation and quantitative display of confidence ratings and levels pertaining to the study cost estimates. Uncertainty may be due to many factors (resulting in both measured and estimated uncertainty) and the cost analyst must consider all aspects to arrive at final measures of confidence. The confidence ratings may be obtained by engineering judgment or statistical analysis-preferrably a combination of both.

B. Technical Risk Cost Impacts

This section addresses the potential error in cost estimates due to the degree of uncertainty surrounding selected technical aspects of the program. Advanced systems concepts usually are based upon assumptions that certain state-of-the-art advancements will make necessary devices or techniques available at specific times or after the expenditure of specific amounts of resources in the system development process. Each such assumption introduces a risk that a level of performance capability, a cost, or a schedule cannot be attained as planned. Possible consequences are severe time delays, extreme cost increases, major program redirection, or, in extreme cases, program termination. Comprehensive development planning requires the identification of high risk areas and definition of alternative courses of action that can be pursued if the desired results are not achieved. For example, if a new engine fails to perform as anticipated, what would be the cost impact of going to a conventional engine? The cost estimator accounts for this technical risk by calculating the estimated cost of the alternative courses of action.

C. Sensitivity Cost Impacts

This section addresses the impact of the cost fluctuations in the program due to a change in a study parameter or assumption. For example, what is the cost impact of the addition of one battalion of equipment? What would be the cost impact of a one-year R&D slip? What would be the total cost impact of a change in the production/procurement rate? In effect, what is the impact on the Life Cycle Cost Estimate (LCCE) and study results which result from changes in the critical assumptions which were established as the basis for the estimate?

VIII. FINDINGS AND CONCLUSIONS

This section will summarize and present the cost implications by category of costs. Particular attention will be given to abnormalities, areas of concern (risk or sensitivity), and adequacy of inputs. Conclusions presented should address any applicable statements concerning the study parameters and assumptions used. The Resource Management Corporation (RMC) study, "Guidelines for Presentation of Army Cost Analyses" Draft Report UR-125, May 1970 should be used as a guide to develop graphic charts.

ANNEXEX TO THE DOCUMENTATION FORMAT

ANNEX 1: METHODOLOGY

The rationale should be included in each of the four life cycle categories of R&D, Investment (Non-recurring), Investment (recurring) and Operating Costs. It should be a detailed description of the procedures (methodology) used to determine the element cost in the WBS (parametric, engineering, catalogue price, etc.). It identifies the costing rationale used for each WBS element. It specifies the sources of all cost statistics and/or learning curves used in costing each WBS element. A detailed explanation of how learning curves and first unit cost were determined will be shown. Where a computer is used, it guides the reviewer through the program logic using sample calculations. It provides the clear, logical, basic, defensible origin of all cost numbers.

ANNEX 2: DATA INPUTS

This section should include copies of the exact inputs which were provided by the in-house directorates (RDT&E, P&P, Maintenance, Quality Assurance, etc.) and other commodity commands for use in the study. If deviations were made by the study conductors in manipulation of the actual data inputs, the rationale for making the changes should be explained.

ANNEX 3: GLOSSARY

This section should describe all major terms and acronyms.

ANNEX 4: BIBLIOGRAPHY

This section should show all source material by organization, date, summary of data or information obtained, person contacted; his name and telephone number.

THE REVIEWER:

Having gone directly from the writer to the organization of the report he was writing, one needs to return to what is a very important step in the production of a cost analysis study. This is the job of the reviewer. Before a report reaches the publication phase it will be reviewed by someone other than the writer for completeness and clarity. The writer can, therefore, help this process along if he knows what the reviewer will be looking for (aside from the obvious miscalculations and misspellings). The type of information which will generally be looked for in cost studies is covered in the Research Analysis Corporation (RAC) publication, "Guide for Reviewers of Studies Containing Cost-Effectiveness Analysis" (AD 618 892). While this is aimed, as the title indicates, specifically at cost effectiveness the following list of "selected questions" taken from that study is most pertinent. If the writer's work provides positive answers to these and perhaps other applicable questions posed in the RAC document then a minimum of rewriting will be required.

"SELECTED QUESTIONS"

Is the problem stated in the real problem?

Are the assumptions unduly restrictive?

Are any feasible and significant alternatives omitted (if alternatives are applicable)?

Is the study adequately documented?

Are the facts stated correctly?

Are the cost estimates relevant?

Are incremental costs considered?

Is an amortized (if applicable) cost used?

Are the models (cost) adequately identified and explained?

Are the models or methodology intuitively acceptable?

Are all criteria used consistent with higher echelon objectives?

Have all the significant ramifications been considered in arriving at the findings and conclusions?

Are the conclusions intuitively satisfying?

THE ORAL REPORT

Oral briefings on cost analysis results are to present information and not to sell a system. The material presented forms a portion of the basis upon which a decision can be made and if the system is a good one it will sell itself. The briefing of study results will also save time. It saves the decision-maker's time in that being well constructed and organized, the main facts, implications and conclusions resulting from the cost analysis are quickly and concisely revealed. This greatly simplifies a difficult subject by culling out all extraneous back-up material and verbage.

BRIEFING REQUIREMENTS

Just as in preparing the written report, the reason for an oral briefing must be analyzed. We have already accomplished one step in this process by defining the presentation of cost analysis results as an informational type of briefing. This begins to shape the material and data to be included. To finalize the amount and type material needed the briefer must next determine to whom the briefing will be given. It may be someone who is one or two steps higher in the chain of command or it might be someone outside of the organization. In each case the amount or type of general information included will be a little different. Just as in the writing of the report it should be determined as nearly as possible just what the audience wants or needs to know. If one briefs his immediate superior the methodology and logic by which he arrived at specific numbers might have to be discussed and/or defended while at higher echelons of management such topics probably would be inappropriate. Another point to determine is when the briefing is to be given. Usually this will be mentioned at the time the requirement for the briefing is assigned. This information will define the amount of time available to prepare the material and the type of graphics that can be produced. If the date of the briefing is far enough in the future a graphics department can put together neat, professional Vu-graphs and charts. However, should the briefing be that afternoon or the next day or so then perhaps rough charts are the best that can be prepared. This should not concern the person preparing the briefing since it is the information presented that is important. A fourth item in the analysis process is to answer the question, "Where is the briefing to be given?" The answer will have a direct bearing on the type of graphics used. Should the appointed place of presentation be other than "home base" then perhaps more Vu-graphs will be required, or rough instead of finished charts. These can sometimes be made at the place the briefing is to be given, thus reducing the amount of material that needs to be carried from one place to another.

After completing the analysis of the requirements for the briefing, the preparer can begin to go through the study material and select that data and only that data which is necessary to present a clear and complete picture of the study. Too much data will either bore the listener or lead him into tangent subjects which may destroy the purpose of the briefing. Thus, what the briefer must aim for is to summarize the analysis--hitting only the salient points. He must direct and control the presentation so that questions concerning details can be brought up after the briefing itself is concluded. It must be kept in mind however, that the material covered should contain enough information so that important details aren't hidden.

Specifically, cost analysis briefings should include as appropriate:

PURPOSE OF THE ANALYSIS. This is required in each case. Unless guidelines are laid out, lack of direction may lead to a compilation of unorganized facts.

DESCRIPTION OF THE SYSTEM. This tells the audience what the data covered pertains to and how one piece of information relates to another.

STATUS OF LIFE-CYCLE AND ENVIRONMENT. The status will inform the listener what has been accomplished up to that point in time and whether the same "rules" apply as when the study began.

MORE DETAILED PURPOSE OF THE ANALYSIS. Such a statement or explanation may or may not be necessary. Such an additional requirement could be appropriate if the original study was altered after system investigation had already begun.

METHODOLOGY USED IN ANALYSIS. In keeping with the philosophy of presenting just the salient facts, an explanation of the methodology used should be included only if requested by the person or persons being briefed or if some new or unusual technique was added to existing methodology.

RESULTS OF THE ANALYSIS. This is the main body of the briefing. Here the data used, the inter-relationships developed and the findings and conclusions are stated. Again, enough information should be given that details are not hidden. However, too much information may detract from the main study purpose.

PROBLEMS, UNCERTAINTIES AND SENSITIVITIES. Finally, all problems, uncertainties and sensitivities must be identified and stated. Not to do so may lead a decision-maker (audience) who uses cost analysis results in combination with other information to reach an erroneous conclusion.

The use of graphics both in written reports and in briefings allows numerical data to be conveniently summarized and compared. They are also useful in uncovering important facts that might be overlooked in written text or tabular presentations of data. To use a chart effectively, three basic steps should be followed:

1. SELECT one specific type that will be most appropriate--one which explains the desired relationships and shows the trends.

2. DESIGN it to focus attention on the specific point the chart is intended to emphasize.

3. CONSTRUCT the chart in such a way that it is easy to read and understand. Caution must be maintained so as to avoid putting too much information on the chart.

Finally, the sequence of the oral presentation must be in a logical order consistent with the study. The "big facts" of the analysis should be presented early to draw attention to them quickly. These should be reinforced with the lesser facts throughout the presentation. To wrap up the briefing the conclusions are then listed so as to complete the study picture. Thus successful, boil down to a careful evaluation of:

THE PURPOSE

THE AUDIENCE

THE FACTS TO BE PRESENTED

Careful analysis of each of these three areas before beginning to speak will assure that the presentation is not only a medium of service to the listeners, but to the briefer as well.

CONCLUSION

In summary:

1. The steps in successful report writing proceed logically from getting in a good attitude for writing, to finding out all about the audience(s), to finally writing the report so as to facilitate the purpose(s) of this audience(s).

2. An executive summary volume to a cost analysis is very helpful to the decision maker by summarizing these topics and presenting pertinent facts and conclusions in a clear and concise manner. This document should be cross-referenced with the detailed main report in order that specific cost questions can be answered if required.

3. The same three steps mentioned above also apply to preparation of an oral briefing on the study. The presentation should address the problem and strictly avoid extraneous material. Annex 1 is a briefer's check list used by the US Army Management School and is a helpful detailed guide. Conscious use of the ideas presented in this chapter, and more particularly by the entire handbook, will aid in the success of any cost analysis undertaken.

U. S. ARMY MANAGEMENT
SCHOOL

OPERATIONS RESEARCH/SYSTEMS ANALYSIS
EXECUTIVE COURSE

CHECK LIST - BRIEFING TECHNIQUES

1. WHY BRIEFINGS?

   a. Save time; of an executive.
   b. Simplify; make a difficult subject easy.
   c. Sell; information or decision, and in either case, yourself.

2. BRIEFING REQUIREMENTS

   a. Get requirement in writing. If received verbally, put in writing and check with originator.
   b. Determine, from an analysis of the requirement:
      WHO gets the briefing? This sets the level of your presentation.
      WHAT does he want to know? Or, in your opinion, what does he need to know?
      WHEN is the briefing due? This tells you how much time is available.
      WHERE is the briefing to be given? Get as favorable a location as possible.
      WHY is the briefing required? Dig out the "why" if not readily apparent.
      HOW should the briefing be presented? Do it like "WHO" wants it. Use "rough" charts or vu-graphs. Vu-graphs should be used only if time permits their preparation.

3. SELECT DATA. Use only that necessary to your presentation.

4. BOIL TO "BONES". Or, what are the salient points?

5. CHART "BONES" AS OUTLINE. In preparing your "roughs"

   a. Layout - you don't have to be an artist. Anyone can make rough charts.
      (1) Make your layouts on a GI tablet - Then check with your supervisor before starting "rough" charts.

(2) Use both sides of ruler to draw lines for lettering on your rough charts.
(3) Letter each line in pencil first, then use MAGIC MARKERS or crayon.
(4) Leave plenty of white space top, bottom, sides, and between lines.

b. Lettering
(1) Plain
(2) Minimum height 1¼". The chart must be legible to everyone in the room.
(3) Maximum - 2 or 3 colors. Suggested:
(a) Headings - RED
(b) Text - Black, key words underlined in red.

c. Content
(1) Omit EXTRANEOUS matter. If you don't refer to it in your presentation, it's extraneous.
(2) Present SIMPLY.
(3) Graph RELATIONSHIPS. Reduce tabular data to vectors, to facilitate detection of trends by inspection.

d. Sequence
(1) Logical Order - Normally, abbreviated staff study sequence (problem, assumptions, facts, discussion, conclusions, recommendations; headings unnecessary).
(2) Hit "big sell" early. Inspire confidence with "big" facts first.
(3) Reinforce heavily with lesser facts.
(4) End with Conclusions and Recommendations, as appropriate.

6. REVIEW PURPOSE - Make sure your conclusions or recommendations do in fact accomplish your purpose.

7. PRIVATE REHEARSAL - With your final charts, builds up your confidence.

8. REHEARSE - With a Critical Audience - Better be shot down by friends privately than by higher authority, in public. Don't be sensitive.

9. MAKE NECESSARY CHANGES - A chart is a medium of communication not a work of art, and rough charts are easily changed, by "patching" your mistakes.

10. FINAL PRESENTATION

a. Preparation - Get there early. Have all aids ready.
b. Have documentation available for ready reference.
c. Introduce yourself if the audience does not already know you, and state your purpose.

d. Talk from charts not to them. Use pointer.
e. Oratory not needed. Speak clearly in your natural voice. You MUST, however be audible to everyone in the room.
f. Be sincere - You can't sell it if you don't believe in it.
g. End with Conclusions and Recommendations, as appropriate.
h. Answers - Don't dodge. Answer only when you know the answers. Otherwise, you destroy confidence.

11. SUMMARY

a. Briefings: Save time, simplify, and sell.
b. Obtain written requirement.
c. Select only pertinent data.
d. Boil data to "Bones".
e. Chart "Bones" as outline.
f. Follow staff study sequence.
g. Load with your ace.
h. Rehearse with critical audience.
i. Presentation is narrative built around charts which tell your story.

12. CONCLUSION: Briefing SUCCESSFUL if:

a. Informational - You have made your points.
b. Decision - You have the desired answer.
c. You deserve an accolade if everyone in audience could give briefing, using your charts.

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CHAPTER 8

COST GROWTH

Cost growth is the net change, which can be positive or negative, of a currently estimated or actual amount from a base figure previously established. The base must relate to a program, project, or contract and be clearly identified including source, approval authority, specific items included, specific assumptions made, date, and amount.

Deputy Secretary of Defense Packard has defined cost growth and listed nine categories that will be used in the Department of Defense. These terms should be used in all cost studies to identify any cost growth which may have occurred since previous cost estimates. Categories of cost growth are as follows:

1. Engineering Change - An alteration in the physical or functional characteristics of a system or item delivered, to be delivered, or under development, after establishment of such characteristics.

2. Quantity Change - A change in quantity to be procured, computed at the original price after making appropriate and consistent adjustments for cost-quantity relationships (e.g., improvement curves), thereby excluding that portion of the current price attributable to changes in any other category.

3. Support Change - A change in support item requirements (e.g., spare parts, training, ancillary equipment, warranty provisions, Government-furnished property/equipment, testing, etc.).

4. Schedule Change - A change in a delivery schedule, completion date, or immediate milestone of development or production.

5. Unpredictable Change - A change caused by Acts of God, work strikes, Federal or State law changes, or other similar unforeseeable events. Unforeseeable events include contractual actions without consideration pursuant to PL 85-804 for (1) essential contract performance and (2) correction of mistakes. Formalization of informal commitments under PL 85-804 are not included under this category but should be reflected under the other categories, as appropriate.

6. Economic Change - A change due to the operation of one or more factors of the economy. This includes specific contract changes related

to economic escalation. This also includes changing real dollar amounts in program estimates to reflect (1) revised economic impact or (2) definitized contract amounts.

7. Estimating Change - A change in program or project cost due to refinements of the base estimate. These include mathematical or other errors in estimating, changing the base year of the constant dollars, revised estimating relationships, changing from constant dollars to real dollars, etc.

8. Contract Performance Incentives - A net change in contractual amount due to the contractor's actual performance being different than was predicted by performance (including delivery) incentive targets; as differentiated from cost incentive targets; established in a EPI or GPIF contract. This category also includes any changes in amounts paid or to be paid a contractor due to (1) award fee for performance accomplishments under a cost plus award fee contract or (2) the sharing provisions of a value engineering incentive clause included in any type of contract.

9. Contract Cost Overrun (Underrun) - A net change in contractual amount over (under) that contemplated by a contract target price (FPI contract), estimated cost plus fee (any type cost reimbursement contract) or redeterminable price (FPR contract) due to the contractor's actual costs being over (under) target or anticipated contract costs, but not attributable to any other cause of cost growth previously defined. Offsetting profit or fee adjustments attributable to cost incentive provisions, if any, shall be considered in determining the net contract cost overrun (underrun).

A cost estimate must provide visibility to higher-level reviewers and decision-makers. A better presentation and backup for cost estimates will provide greater visibility and thus help to identify low estimates. Reviewers will look for reasonableness in the estimate. Reasonableness is based on a judgment made by comparing cost histories of current and past programs. Since it is accepted that a price cannot be placed on an unknown, it is not realistic to expect the first cost point estimate made on a system which is in the conceptual stage to be one hundred percent accurate. The uncertainties arising from lack of data and new technology will never be completely overcome.

CHAPTER 9

COST EFFECTIVENESS

INTRODUCTION 1/

Cost effectiveness analysis is a method of study designed to reveal information necessary for an intelligent appraisal of alternative courses of action. In most cases where technology, costs, and goals are numerous and complex, a standardized methodology cuts through the irrelevant features of a study and exposes the relevant aspects for systematic comparison. The objective of the Army management process is to develop weapon systems which are optimum in terms of performance capability to meet currently foreseen needs for the resources applied.

DISCUSSION

Cost effectiveness is based on the economic principle that all material decisions involve the choice of how best to allocate scarce and limited resources among unlimited and competing requirements, responsibilities, or goals. Even in the most basic military planning, cost effectiveness is as old as weapons systems themselves. But the increasingly complex

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1/ The subject of cost effectiveness analysis is one with wide and complex ramifications in the determination of the "best" course of action from several alternatives. Each analysis of this type must be built up from a consideration of the particular problem at hand. Appropriate measures of effectiveness will differ according to the primary mission of the force or equipment being studied. The costs to be considered also must be carefully scrutinized since costs determined to be common to all systems under study may not be able to be eliminated (ignored). This is because one system may be sensitive to the common cost whereas the other systems may be insensitive. The discussion contained in this chapter is a broad overview and to obtain a more definitive appreciation of the subject the reader should refer to the several references (as well as others) listed below. A Primer of Cost Effectiveness, Research Analysis Corporation, AD 816 751; Models in Cost-Effectiveness Analysis, Research Analysis Corporation, AD 622 109; A Beginning to Cost-Effectiveness Analysis, Research Analysis Corporation, AD 422 374; The Critical Region in Relative Cost-Effectiveness, Resource Management Corporation, AD 820 657; System and Cost Effectiveness Manual for System Developers, Lockheed Missiles and Space Co., AD 867 397; The Total Cost Approach to Cost Effectiveness Within The Logistics Priority System, AFIT, AD 863 834; and System/Cost Effectiveness Notebook, Communications and Systems, Inc., Vol I - AD 854 651, Vol II - AD 854 652.

relations between weapons systems as the state-of-the-weapon-art advances requires a simultaneous advance in the methodology used to analyze the concurrent costs and effectiveness. The state of the cost effectiveness art must be sufficiently advanced to objectively embrace all relevant aspects of possible alternative systems. This advance in analytical capability is, in fact, nothing more than a systematic (organized) set of guidelines to follow to obtain detailed cost effectiveness studies of alternative projects. These studies provide benefits through the universal dimensions of comparability and visibility, exposing the relevant aspects on a basis which warrants genuine comparison without fear of oversight or mistake. This becomes, then, a major management tool to achieve the goal of controlling the selection, development, and utilization of a system in an optimum manner throughout its life-cycle. The organized manner by which the manager assembles these inputs is cost effectiveness analysis and may be illustrated in outline form as seen in Figure 1.

A cost effective situation can be defined as any situation where the expended resources (funded costs) were, in fact, effective in achieving the project goal. But for every defined goal, there is usually more than one means to achieve that goal, and each may also be cost effective as defined above. The problem is to select that method which is the most cost effective. To do this, the goal must first be specified and agreed upon. To attempt to reach a goal without first clearly specifying the goal itself would be inconceivable to the decision maker, so every plan necessarily includes the desired goal. Then the expected costs associated with each alternative path must be developed and assigned to each alternative. This now brings the alternative costs and the desired goal into view. This describes a simple array of cost effective alternatives without considering the possibility of tradeoff analysis, a technique which raises cost effective techniques to a higher level of sophistication which will be considered later. Figure 2 illustrates a simple cost effective relationship between three linear alternatives. The key to understanding cost effectiveness analysis in this case is merely deciding upon the desired level of output. Once this goal has been selected, the rational economic choice is clear. If output level M is selected, the least-cost alternative to achieve that output is Alternative A. This is determined by Alternatives C and B each having a higher level of total costs associated with that level of effectiveness. From this we have arrived at a relationship, or ratio, between cost and effectiveness. Notice that the desired effectiveness has been held constant, while varying the cost level as among alternatives A, B and C.

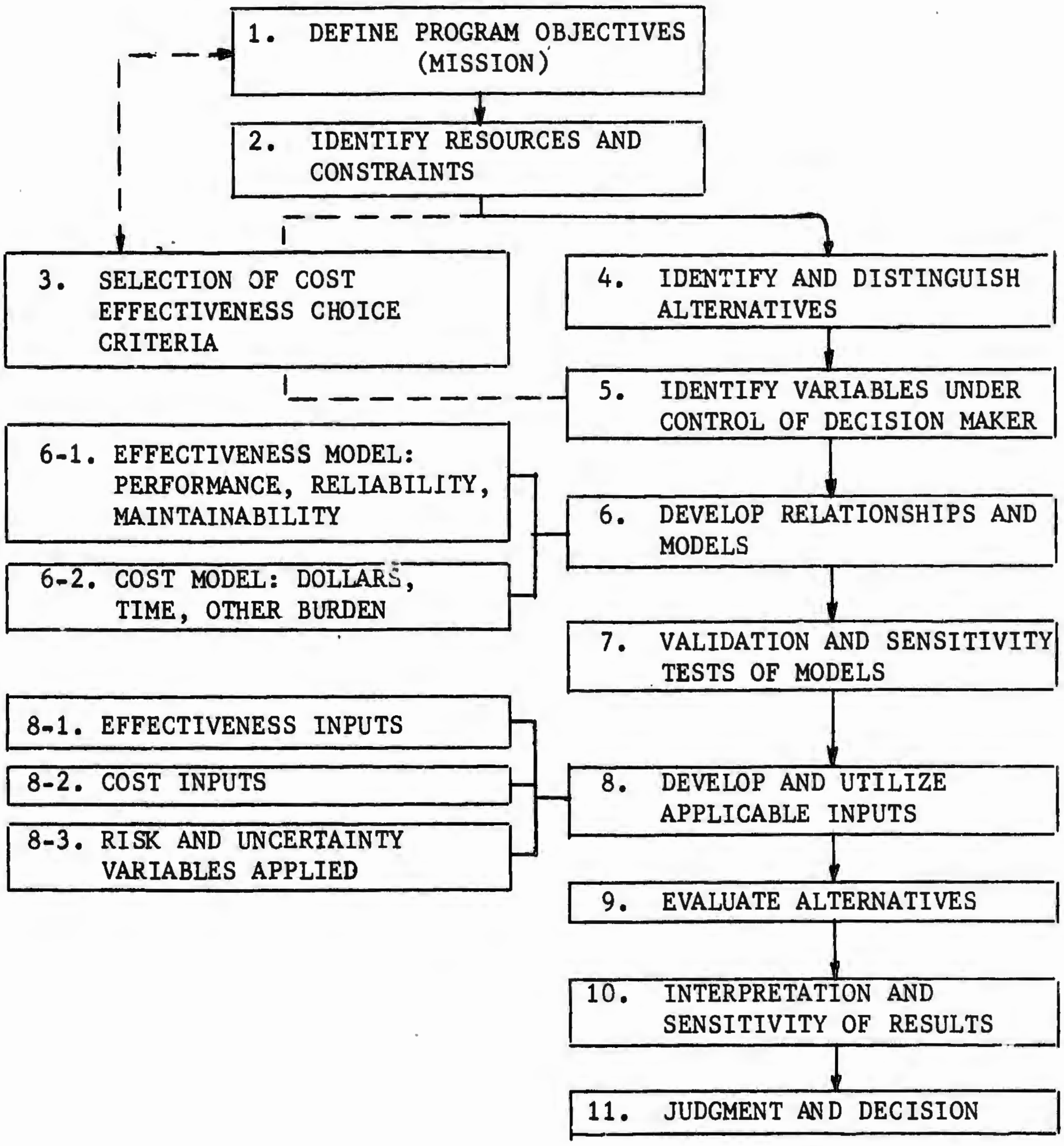

1. DEFINE PROGRAM OBJECTIVES (MISSION)
2. IDENTIFY RESOURCES AND CONSTRAINTS
3. SELECTION OF COST EFFECTIVENESS CHOICE CRITERIA
4. IDENTIFY AND DISTINGUISH ALTERNATIVES
5. IDENTIFY VARIABLES UNDER CONTROL OF DECISION MAKER
6-1. EFFECTIVENESS MODEL: PERFORMANCE, RELIABILITY, MAINTAINABILITY
6-2. COST MODEL: DOLLARS, TIME, OTHER BURDEN
6. DEVELOP RELATIONSHIPS AND MODELS
7. VALIDATION AND SENSITIVITY TESTS OF MODELS
8-1. EFFECTIVENESS INPUTS
8-2. COST INPUTS
8-3. RISK AND UNCERTAINTY VARIABLES APPLIED
8. DEVELOP AND UTILIZE APPLICABLE INPUTS
9. EVALUATE ALTERNATIVES
10. INTERPRETATION AND SENSITIVITY OF RESULTS
11. JUDGMENT AND DECISION

Figure 9-1

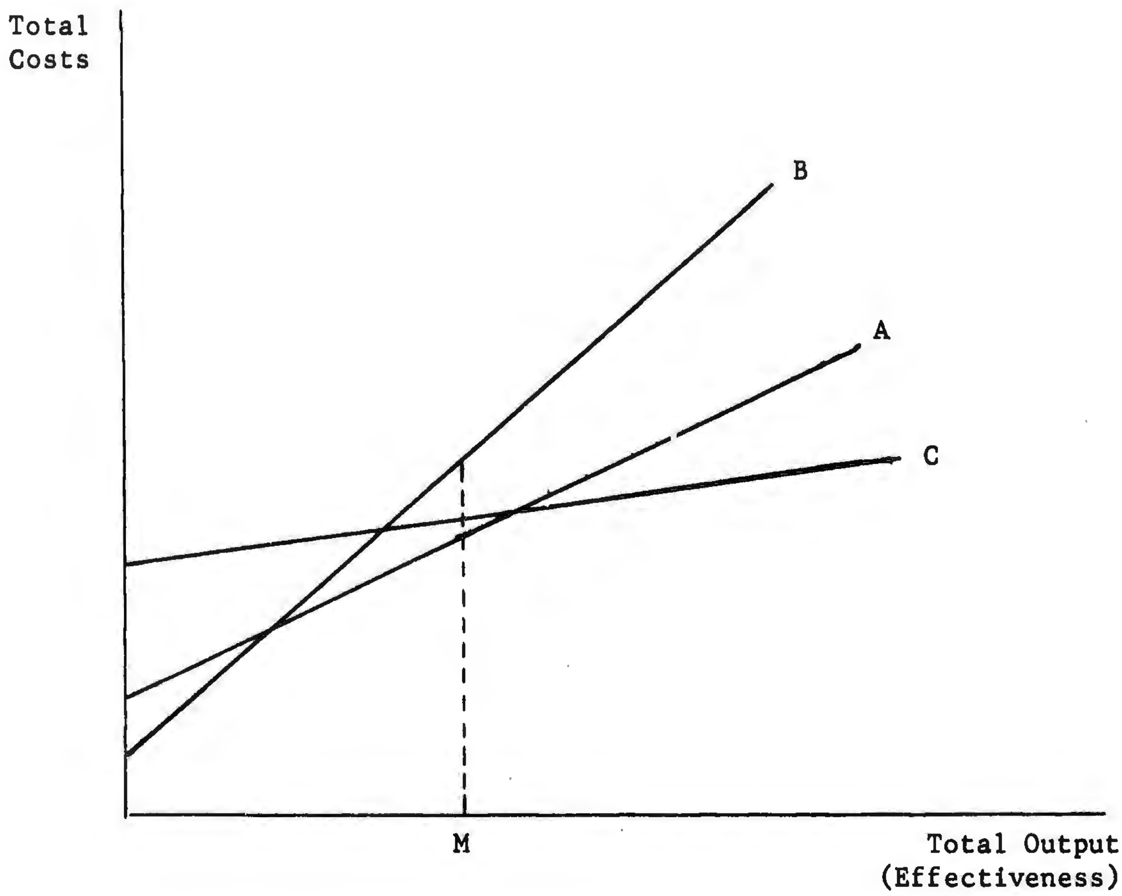


Figure 9-2

Looking closely, it is seen that the ratio of cost to effectiveness in Figure 2 between Alternative A and Output M is less than either Alternative B or C. Thus Alternative A has the lowest cost effective ratio for Output M of the three simple alternatives considered. The ratio, like the graphical treatment, also enables the analyst to identify and isolate the best situation from among those which are all satisfactory, that is, merely good. After the alternative with the lowest cost effective ratio has been identified, the decision maker can be more fully informed and can select the most likely means in terms of efficiency and availability to achieve his goal. It is emphasized again that in constructing these ratios that effectiveness is held constant. Otherwise, inconclusive results could be reached.

While this process of analysis describes the most logical course for optimizing resource use, it is also recognized that in certain situations the starting point of analysis would be from the cost side rather than the output side. In this case, the decision maker would be handed a list of the resources (expendable costs) at his disposal, and his task would then be to maximize his output (effectiveness), rather than minimize his costs. In this case, it is recognized that the best a decision maker can do is to "sub optimize", that is, to optimize (maximize) within the constraint of his apportioned resources. In many ways, this method is analogous to the relation between the "grand plan" and its "sub plans". The overall scheme is decided upon at the highest levels, and a rough apportionment of budgeted resources to component agencies is selected. The agencies receiving their budgets must coordinate and synchronize their movements to maximize the effectiveness of their share of the "grand decision".

Finally, in situations where the project goal is not clearly visible, due to uncertainty regarding the exact nature of the competition, such as enemy threat, another variation in cost effectiveness techniques occurs. In this case, the goal itself may be treated as not fixed, and subject to tradeoff considerations. There might be, for example, a range of acceptable goals, going from least acceptable to most acceptable with any of these alternative levels of output acceptable, where the choice would be less clear than before. Since each alternative goal would probably have alternative and different cost estimates, it becomes apparent that the more ambitious goal would have a higher cost than the next most ambitious goal and so on. In cases such as these, it is probably better to select a goal, under uncertainty, which appears to be most likely to satisfy the conditions of competition, and then choose the least cost alternative.

SUMMARY

At best, cost effectiveness analysis provides information, not policy. It furnishes needed answers to relevant questions rather than justifying any particular goal. In essence, it seeks to outline alternative paths and the costs which would be incurred along each. As such, it cannot be expected to make a decision, but rather to assist the decision maker toward an enlightened choice. In order for this goal to be achieved, all the data used to estimate costs (cost analysis) and effectiveness must be accurate and reliable.

CHAPTER 10

A NEW TECHNIQUE TO ANALYZE R&D ESTIMATES: STECPLOT 1/2/

THE PROBLEM

In the early stages of designing a complex weapon system there is difficulty in estimating the eventual cost of the Research and Development (R&D) program. This problem has become more and more apparent as the Department of Defense finds its early estimates on most weapon systems at the root of cost overruns. The following reasons largely contribute to this problem:

1. Engineers are naturally optimistic about solving technological problems of a new system.

2. There is insufficient identification of technical and management risks and the planning required to reduce these risks.

3. There are changes over time in the configuration of the system being developed, usually toward a more complex system, due to initial inadequate definition of the requirements.

4. Appropriations usually don't materialize in the amount and with the timing desired by the engineers.

5. The program stretches out because of technical problems, funding problems and too optimistic a schedule with too much concurrency.

1/ Adapted by CPT B. J. Kadets and CPT C. D. Billings from Horace Schow's "Macrobehavior of Development Costs and Estimates (STECPLOTS)," Washington, DC, US Army Materiel Command, 1968.

2/ Research and development cost estimates have historically been optimistic resulting in cost overruns as the development program progresses. This consistent underestimating is caused by the procedures of making an estimate and the development framework. A new technique to evaluate research and development cost estimates is presented and described with a case study of Army missile development programs. The basis of the evaluative technique is the analysis of the trend of research and development cost estimates on the assumption that a median level of past disturbances will persist in the future. The technique is applicable to any research and development estimating procedure where data on past performances is available as a data base.

6. The cost estimating procedure used reflects the above problems and understandably underestimates costs.

The characteristics of the R&D process make cost estimating difficult and cost analysts are continuing to search for more satisfactory costing techniques. The most frequently used technique is to estimate the level of effort required to complete the objectives of the R&D program within given time constraints. This approach assumes that either the state-of-the-art is sufficiently advanced, or can readily be advanced, to the extent necessary that some estimable amount of effort will achieve the breakthroughs required. Apparently this technique is not very satisfactory since R&D estimates tend initially to be low as shown in Table I. The data in Table I was collected from Army Management review reports termed Army Selected Acquisition Reports (SAR's) and from the offices of Project Managers. An Army R&D program is financed primarily from the Research, Development, Test and Evaluation (RDT&E) appropriation account and several program estimates are displayed in Table I. This data shows that the range of growth in the RDT&E estimates was from 12% to 425% while the average rate of growth was 134%.

In R&D Cost Estimates of recent weapon systems, Army analysts defined the components and their subcomponents of a weapon system to as detailed a breakout as was possible in order to isolate the system's components. Then a contractor estimate was obtained for each identified component. This systematic breakdown of a weapon system enabled the analysts to identify many separate items for the first time. Where the contractor had no estimate for a newly discovered component, Army engineers made their own estimate. In certain instances, the Army analysts believed that the contractor estimates at the component level were optimistic and raised the figure. The total package was then summed, spread by planning factors over the proposed R&D time schedule, and presented as the cost estimate for the R&D phase of the system.

Under today's environment, Defense cost overruns are closely scrutinized. Therefore, cost estimating techniques which inherently result in cost overruns are clearly unacceptable. The methodological problems inherent in this process need to be examined and solved. In the final analysis, the technique described above used contractor estimates at the lowest identifiable component level which were modified by Army analysts where necessary. It is assumed that the contractor's estimates were also based on a level-of-effort-funding.

TABLE I

RDT&E ESTIMATE GROWTH

System	Original RDT&E Estimate $M 1/	Current RDT&E Estimate $M 1/	(Increment/Original Est) Percentage Growth in RDT&E Estimate %
CHEYENNE	125.9	201.8	60
GAMA GOAT	5.1	9.5	86
SHERIDAN	32.0	35.8	12
M6CA1E2	6.1	13.9	128
MBT-70 2/	101.4	259.6	156
TACFIRE	25.4	69.7	174
LANCE	132.1 3/	447.5	239
SAM-D	554.7 4/	1,006.0	81
SHILLELAGH	111.3	152.6	37
DRAGON	42.1 5/	95.4	127
TOW	49.5 6/	106.1	114
PERSHING 1A	58.3 7/	116.9 9/	100
IMPROVED HAWK	20.7 8/	108.6 10/	425
Average percentage growth in RDT&E estimate (Increment/Original Estimate)			134

1/ 31 Mar 70 Selected Acquisition Report unless otherwise indicated.
2/ US share of Joint R&D program.
3/ April 62 Missile B Weapon System Proposal.
4/ August 65 Trade Off Study.
5/ March 65 MAW Technical Development Plan.
6/ September 62 Technical Development Plan.
7/ September 65 Program Change Request.
8/ December 62 Technical Development Plan.
9/ January 69 Project Manager Master Plan.
10/ April 70 Life Cycle Cost Study.

This paper presents a new technique to evaluate R&D cost estimates that are constructed by the work breakdown method described in the preceding paragraphs. This analytical tool, called STECPLOT analysis, evaluates RDT&E cost estimates through a macroeconomic view of the estimate. The term, STECPLOT, arose from a "Study of Trends and Escalation of Costs."1/

THE TECHNIQUE

The basis of the STECPLOT technique lies in the analysis of the trend of RDT&E Cost Estimates made during the R&D phase of various weapon systems. A study of various weapon systems indicates general regularities in the RDT&E estimates as the R&D phase moves toward completion. These regularities, which form the basis of the technique, can be expressed graphically by using a graph whose axes are normalized to a 100% scale as shown in Figure 1. The abscissa represents a development program's time period and the ordinate represents the program's expenditure; both expressed percentage-wise. Through this normalization procedure R&D programs of different lengths and costs are comparable since both costs and time are expressed in percentage terms.

An important assumption in using the STECPLOT approach is that the particular system being estimated follows the trend of previous systems. This allows evaluation of the status of the system being considered on a comparative basis with the history of other systems. It should be noted that this comparison is not always valid. Systems may not follow previous trends for reasons peculiar to a particular system. Therefore, complete dependency on the technique without further analysis is not desirable. However, considering our present inability to forecast the occurrence of the causes of cost growth and their impact, the assumption that a median level of past disturbances will persist in the future is a reasonable assumption.

Past disturbances of R&D programs are reflected in the analysis via time and cost variables.

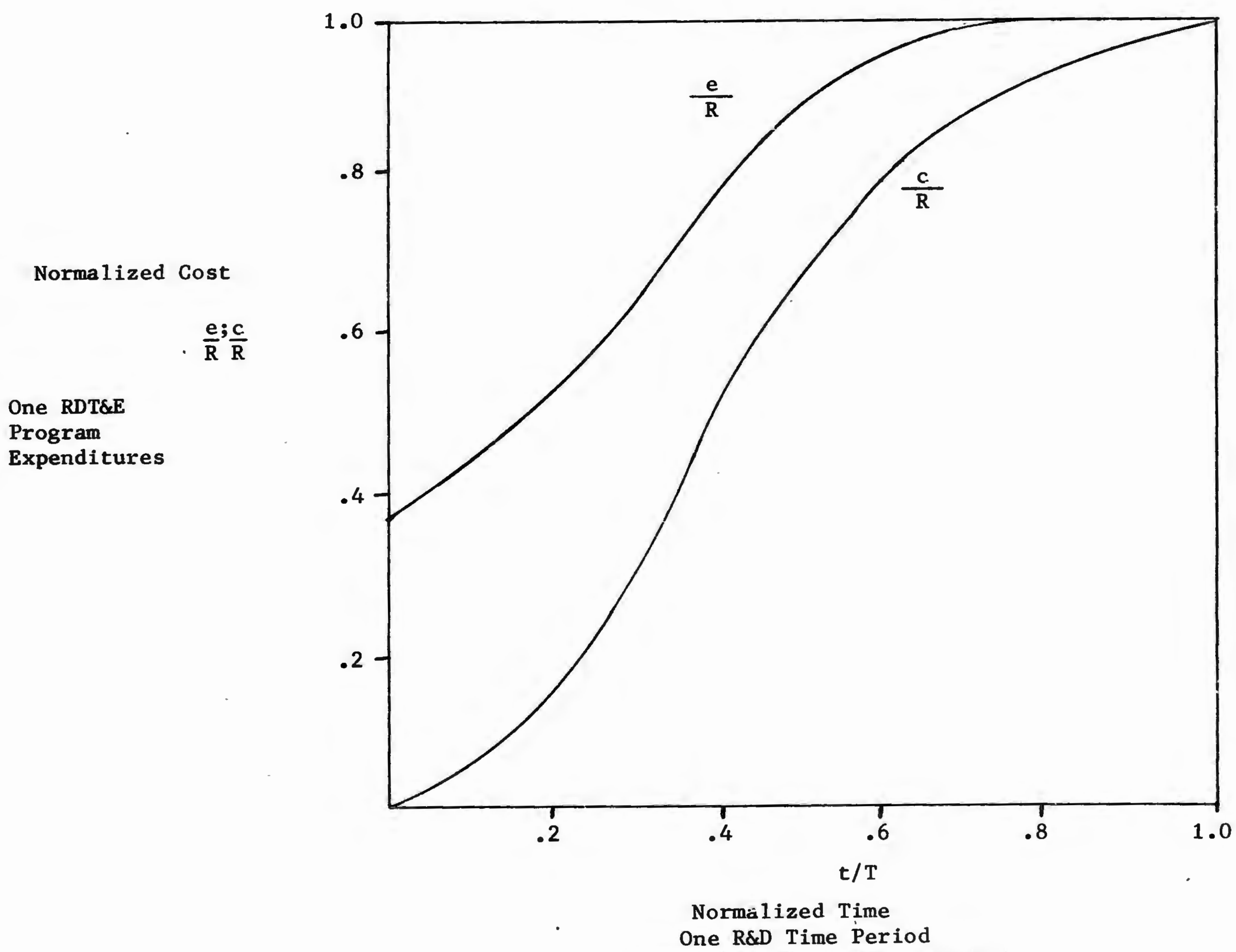
1) T = Total development time from beginning to completion;

2) t = Elapsed time of the development program, $o \leq t \leq T$;

3) e = An estimate of total RDT&E cost, R, made at a point in time with elapsed time, t, $o \leq t \leq T$;

4) c = Known cumulative RDT&E monies expended upon completion of the development phase.

1/ Horace Schow, Macrobehavior of Development Costs and Estimates (STECPLOTS), Washington, DC: US Army Materiel Command, 1968.



NORMALIZED GRAPH FOR STECPLOT

Figure 10-1

5) R = The known amount of RDT&E costs expended upon completion of the development phase.

Note that T is a known time for systems that have completed development, but an estimate of total time for systems that have not completed development. The variable e is known from the beginning of the program, t = o, to the end of the program, t = T, for systems that have completed development and is the actual expenditure upon completion of development, e = R when t = T. For systems that have not completed development, the "e's" are known from the beginning, t = o, to t = present time where t is still less than T.

In terms of the above variables, the abscissa of the graph is the variable t/T, or percentage of development time completed. The ordinate is a cost percentage; therefore, it can express either the accuracy of the RDT&E estimate, (e/R), at an elapsed time, t/T, or the percentage of total RDT&E monies expended, (c/R), at an elapsed time, t/T.

The first curve considered is e/R as a function of t/T. This curve can be labeled the "accuracy curve." It indicates how accurately the estimator estimated the eventual total RDT&E costs at different normalized points in time. An example will suffice to show how this curve is derived.

Suppose system A completed its development phase after 3 years and a cost of $100 with the estimates, e, of RDT&E cost, R, made over the 3 years as shown in Table II:

TABLE II

EXAMPLE OF RDT&E ESTIMATES OVER TIME

t (years)	0	1	2	3
e at each t	$30	$50	$90	$100

T = 3 years and R = $100

From this information accuracy factors can be derived at various points of the R&D program as shown in Table III:

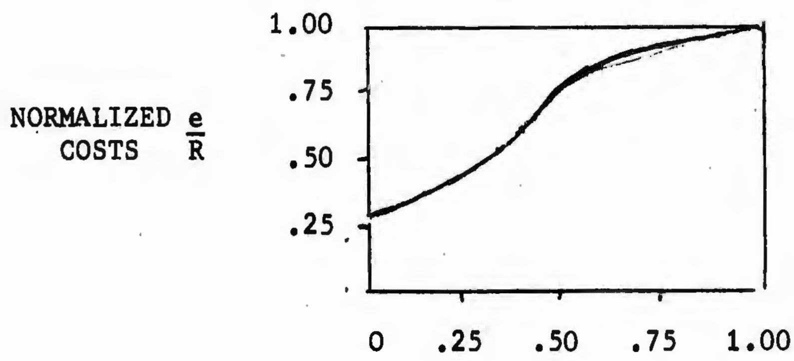
TABLE III

EXAMPLE OF ACCURACY FACTORS OVER TIME

t/T	0	.33	.67	1.00
e/R	.30	.50	.90	1.00

The time ratio, t/T, indicates the percentages of the R&D program time completed when an estimate was made and the accuracy factor, e/R, indicates what percent that estimate was of the eventual cost. For example, when the R&D program began, the RDT&E estimate was $30, but the eventual cost was $100; therefore, at t/T = 0 the accuracy factor was $30/$100 = .30. When the program was 2/3 completed, at the end of the 2nd Year, the estimate was $90, but the eventual cost was $100; therefore, at t/T = .67 the accuracy factor was $90/$100 = .90.

Plotting e/R as a function of t/T, Figure 2 is obtained from Table III.



NORMALIZED TIME t/T
GRAPH OF TABLE III
FIGURE 10-2

At 33% completion time, the estimator was 50% accurate in his estimate of final RDT&E cost. Interpolating, at 50% completion, it is predicted that the estimator would have been 75% accurate.

The second curve considered is the distribution of the actual cumulative expenditures as a function of time. That is, c/R as a function of t/T. For example, assume System A's expenditures as shown in Table IV.

TABLE IV

EXAMPLE OF CUMULATIVE RDT&E EXPENDITURES OVER TIME

t	0	1	2	3
c	$0	$30	$80	$100

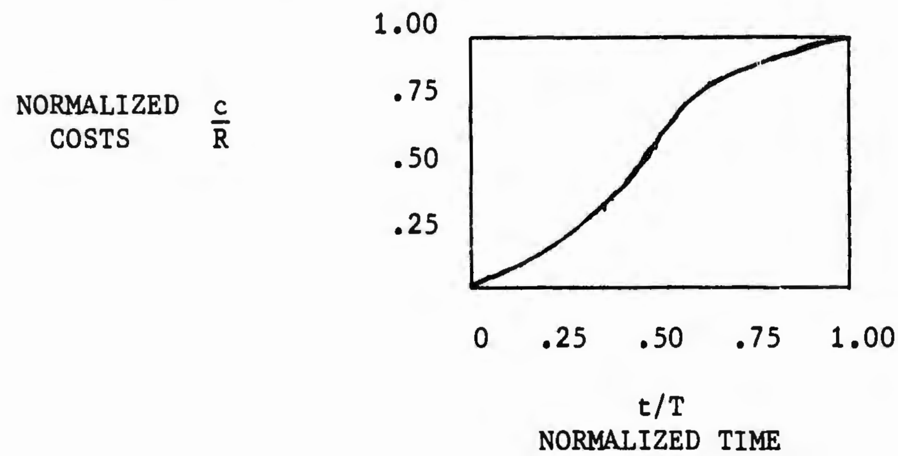
From this information expenditure factors can be derived at various points of the R&D Program as shown in Table V.

TABLE V

EXAMPLE OF EXPENDITURE FACTORS OVER TIME

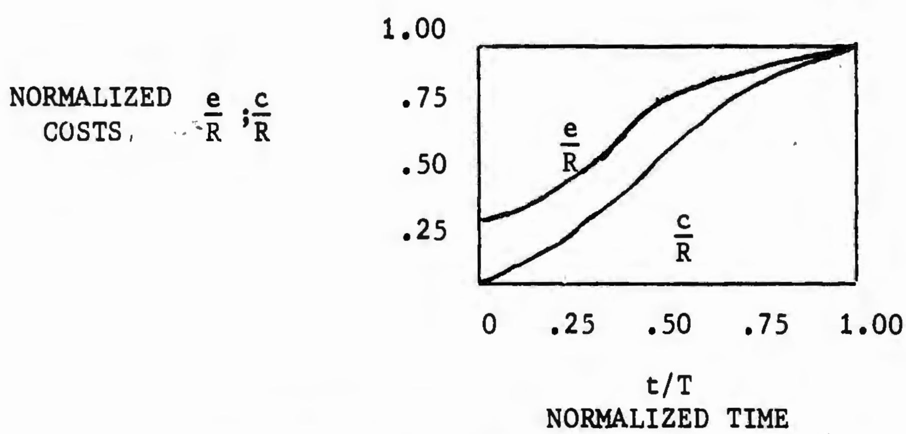
t/T	0	.33	.67	1.00
c/R	0	.30	.80	1.00

Table V shows that at the beginning of the R&D Program zero dollars have been expended but that by the time the program is 2/3 complete 80% of the RDT&E funds have been expended. Plotting c/R as a function of t/T, Figure 3 is obtained from Table V.



GRAPH OF TABLE V
FIGURE 10-3

If we combine Figures 2 and 3 we obtain Figure 4.



EXAMPLE OF ACCURACY AND EXPENDITURES FACTORS OVER TIME
FIGURE 10-4

Figure 4 indicates how well System A's actual RDT&E costs were estimated as well as how expenditures were distributed over time. The next section details how the ideas presented in this section are used in estimating RDT&E costs for systems still in development stages.

EXPLANATION

There are many reasons why a development program costs more than originally estimated. There may be simple underestimating, program stretchout, changes in technical characteristics, technical problems, and/or relocation of the project. The above reasons are common to most systems and are taken implicitly into account in the derivation of the curves. As mentioned previously, any abnormalities in a system under study should be taken into consideration when using this technique.

An accuracy curve was derived from studies done by the Cost Analysis Office, Headquarters, Army Materiel Command, for systems that have completed their development phase. The curve was calculated by "averaging" the individual accuracy curves for a number of similar systems. The expenditure curve was likewise calculated. (Note: The variance among the individual curves should also be studied for greater insight.) Table VI provides the accuracy and expenditure factors over time for eight Army missile systems. The accuracy and expenditure curves derived for systems having completed development are now used to estimate the time and costs for systems still in development. The main assumption is that the developing system will follow the same general experience pattern of estimates and costs as the sample of systems that have completed development.

Assume System A has been in its development phase for t years, and to date, c dollars have been spent. At time t the estimate for total RDT&E cost and time is e_o dollars and T_1 time respectively. At normalized time, $t/T_1 = X_1$, the accuracy curve indicates that at this point in time the accuracy factor is y_1, $o \leq y_1 \leq 1.00$ (in terms of %, $y_1 \times 100$). Therefore e_1, an estimate of eventual RDT&E cost, would be $e_1 = e_o/y_1$. However, e_1 is based on the estimate of time T_1 which is probably optimistic and will experience slippages. Computing c/e_1, the cumulative expenditures to date over the estimate of eventual RDT&E cost and using the expenditure distribution curve, find $X_2 = t/T_2$, $o \leq X_2 \leq 1.00$, that corresponds to c/e_1. Then $T_2 = t/X_2$ equals a new estimate of time to program completion. Using T_2 as the time estimate, t/T_2 gives a new accuracy factor, y_2, from the accuracy curve. Then $e_2 = e_1/y_2$ equals a third cost estimate that corresponds to T_2. Repeat this procedure until the time and cost estimates begin to converge. The judgment of the analyst familiar with the system is used to determine when to terminate the process.

e/R Data

t/T	A	B	C	D	E	F	G	H	AVERAGE
0	.30	.43	.19	.45	.49	.50	.28	.58	.40
.10	.35	.43	.39	.45	.49	.50	.29	.73	.46
.20	.45	.49	.65	.55	.49	.61	.33	.94	.56
.30	.54	.64	.81	.72	.49	1.04	.46	.98	.69
.40	.64	.75	.86	.85	.49	.89	.67	.99	.80
.50	.89	.80	1.01	1.06	.92	1.00	.90	1.00	.90
.60	1.00	1.00	1.00	.95	.98	1.00	.95	1.00	.97
.70	1.00	1.00	1.00	1.00	.99	1.00	.98	1.00	.99
.80	1.00	1.00	1.00	1.00	.99	1.00	.99	1.00	.99
.90	1.00	1.00	1.00	1.00	.99	1.00	.99	1.00	.99
1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

c/R Data

t/T	A	B	C	D	E	F	G	H	AVERAGE
0	.00	.00	.00	.00	.00	.00	.00	.00	0
.10	.02	.05	.03	.06	.01	.09	.01	.05	.04
.20	.12	.13	.23	.17	.08	.30	.02	.24	.16
.30	.28	.23	.44	.37	.15	.53	.06	.46	.32
.40	.47	.35	.64	.64	.29	.64	.20	.74	.51
.50	.60	.46	.75	.80	.48	.71	.53	.92	.67
.60	.70	.57	.80	.87	.79	.79	.83	.97	.79
.70	.86	.68	.86	.89	.94	.89	.96	.99	.89
.80	.97	.79	.92	.91	.98	.96	.98	1.00	.95
.90	1.00	.95	.97	.97	.99	.98	1.00	1.00	.98
1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

TABLE VI

ACCURACY AND EXPENDITURE CURVES OF ARMY MISSILE SYSTEMS A-H

In the next section, a numerical example will be given to further explain the process.

EXAMPLE

Figure 5 shows a typical accuracy curve, e/R, and cumulative expenditure distribution curve, c/R. These curves are derived from systems that have completed development and all variables are known. Note that the accuracy curve indicates that before development begins, i.e., at time zero, the cost estimate of a particular system has been on the average 40% underestimated; or, in other words, the final development cost has resulted in an increase of 2 1/2 times the original estimate. The following hypothetical example explains numerically how the STECPLOT is used as an aid in analyzing RDT&E costs.

System A's development phase has been ongoing for 5 years. The estimate of final RDT&E cost is currently e_o = \$133 million and the final time to completion estimate is T_1 = 10 years. Table VII shows the systems expenditures to date by year.

TABLE VII

SYSTEM A EXPENDITURES TO DATE

t (years)	0	1	2	3	4	5
c = Cumulative RDT&E expenditures in millions (dollars)	\$0	\$5	\$15	\$35	\$60	\$85

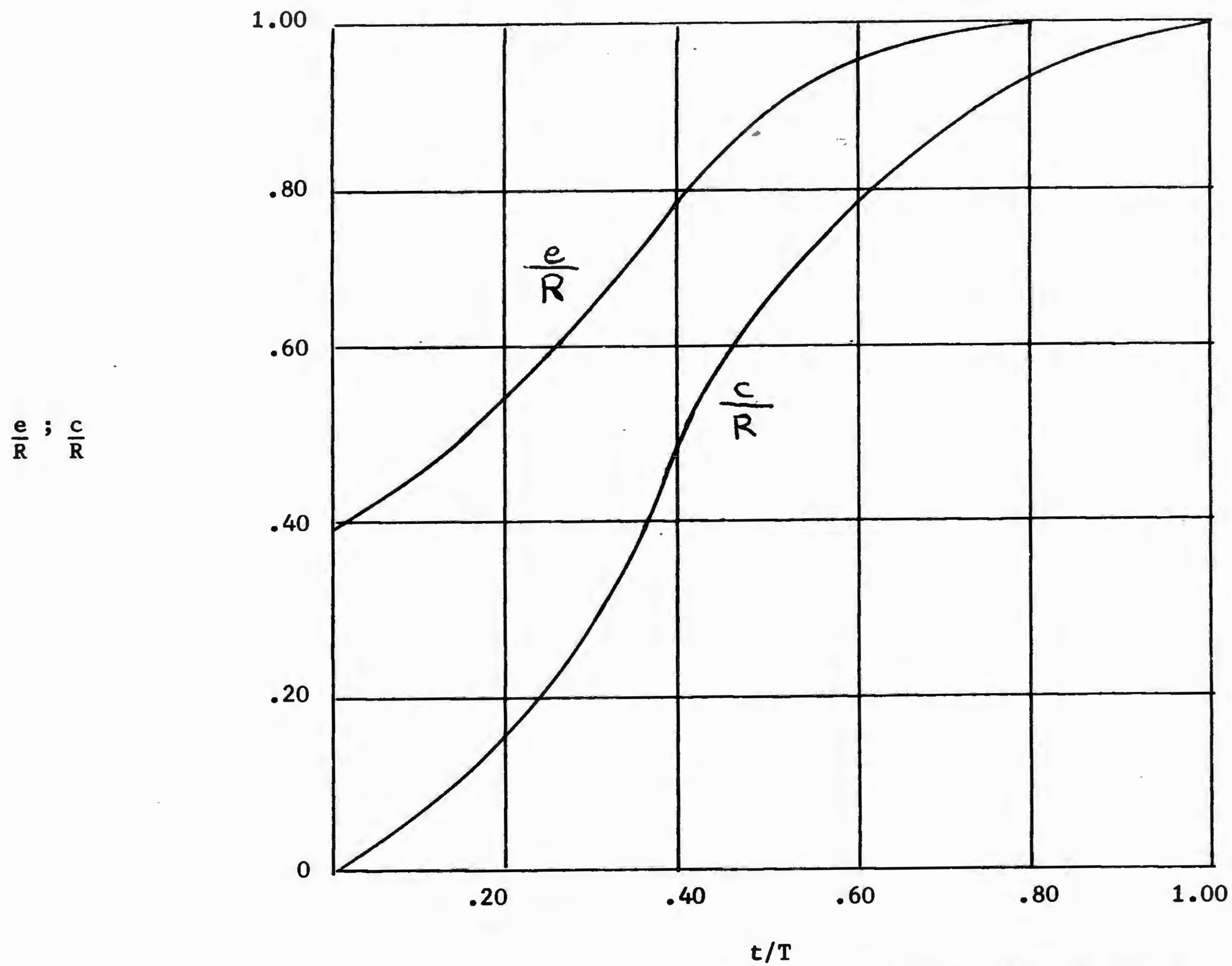
T_1 = 10 years e_o = \$133$\overline{M}$

The cumulative expenditures at time t = 5 is c = \$85 million. The steps in the procedure are given below, shown graphically in Figure 6 and summarized in Table VIII.

TABLE VIII

	T0	T1	T2	T3	T4
Estimated R&D Program Length (Years)	10*	10	11.6	12.5	12.8
Estimated Final Costs (million \$)	\$133*	\$146	\$158	\$166	\$168

* ORIGINAL ESTIMATE AND CURRENT ESTIMATE



ACTUAL DEVELOPMENT ACCURACY AND EXPENDITURE CURVES
Figure 10-5

STEP 1 $t/T_1 = 5/10 = .50 = X_1$; therefore, y_1 = Accuracy Factor = .91

$$e_1 = \frac{e_o}{y_1} = \frac{\$133}{.91} = \$146 \text{ million for 10 years}$$

Based on the accuracy curve, the estimate of 50% program completion has historically been 91% accurate. Thus the final cost is estimated to be $146 million for the estimated 10 year program.

STEP 2

a) $\frac{c}{e_1} = \frac{\$\ 85}{\$146} = .58$, which means that 58% of development funds have been expended.

b) Using the expenditure distribution curve, the percentage of time completed for expenditure of 58% of development funds has historically been 43%, which means the development program is not 50% completed.

X_2 = Time Factor = .43 = t/T_2, where T_2 is the new time estimate. Therefore, $T_2 = t/X_2 = 5/.43 = 11.6$ years, which implies a slip of 1.6 years in the R&D Program.

c) At $t/T_2 = .43$, Y_2 = Accuracy Factor = .84; therefore, $e_2 = e_o/y_2 = \$133/.84 = \$158$ million for 11.6 years; where e_2 is the estimate of final RDT&E costs based on the new time schedule.

STEP 3

a) $c/e_2 = \frac{\$\ 85}{\$158} = .54$ of RDT&E funds have been expended.

b) Then $t/T_3 = X_3 = .40$ (Means the R&D Program is 40% complete).

$T_3 = t/X_3 = 5/.40 = 12.5$ years, implies that the R&D program will not slip 1.6 years but 2.5 years.

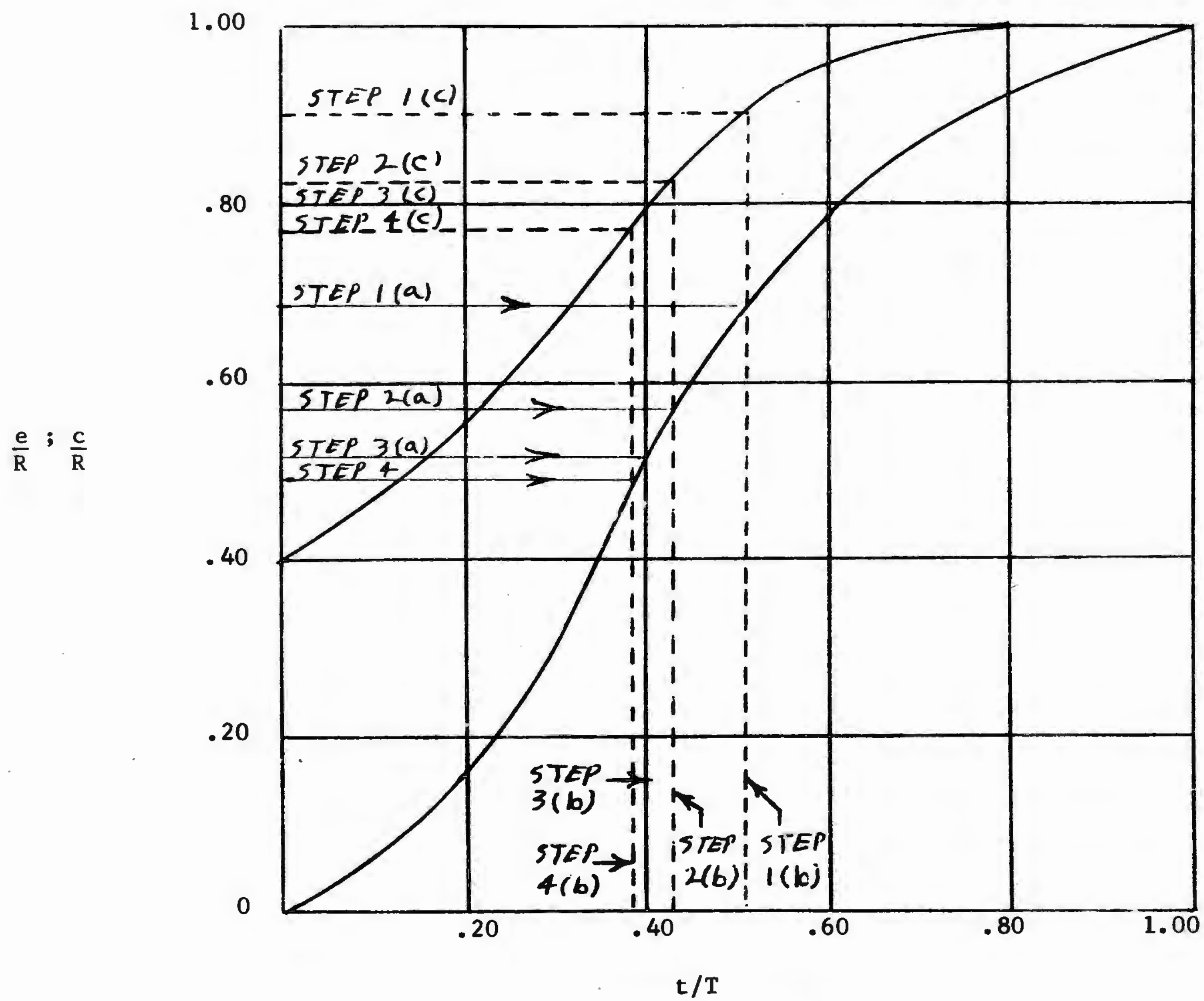
c) $t/T_3 = .40$, $y_3 = .80$. Therefore, $e_3 = e_o/y_3 = \$133/.80 = \$166$ million for 12.5 years.

STEP 4

a) $c/e_3 = \$85/\$166 = .51$ of R&D funds have been expended.

b) Then $t/T_4 = X_4 = .39$ (Means the R&D Program is 39% complete).

$T_4 = t/X_4 = 5/.39 = 12.8$ years, which implies that the R&D Program will not slip 2.5 years but 2.8 years.



STEPS IN STECPLOT
Figure 10-6

c) $t/T_4 = .39$, $y_4 = .79$; therefore, $e_4 = e_o/y_4$ = \$168 million for 12.8 years.

At this point, the process is arbitrarily stopped since it appears the differences are becoming quite small.

Table VIII indicates the range of costs and time estimates for the R&D phase of System A. Even without a time slip the program costs have been underestimated by \$13 million. However, a slip of 2.8 years is possible and RDT&E costs of \$35 million greater than presently estimated are possible.

Establishing a point estimate for System A involves somewhat the judgment of the analyst familiar with the system. However, an approach that may assist him in this estimate can be followed.

If it is assumed, at first, that the time estimate of 10 years and the accuracy factor of .91 are correct, then the cost estimate is \$146 million.

TABLE IX

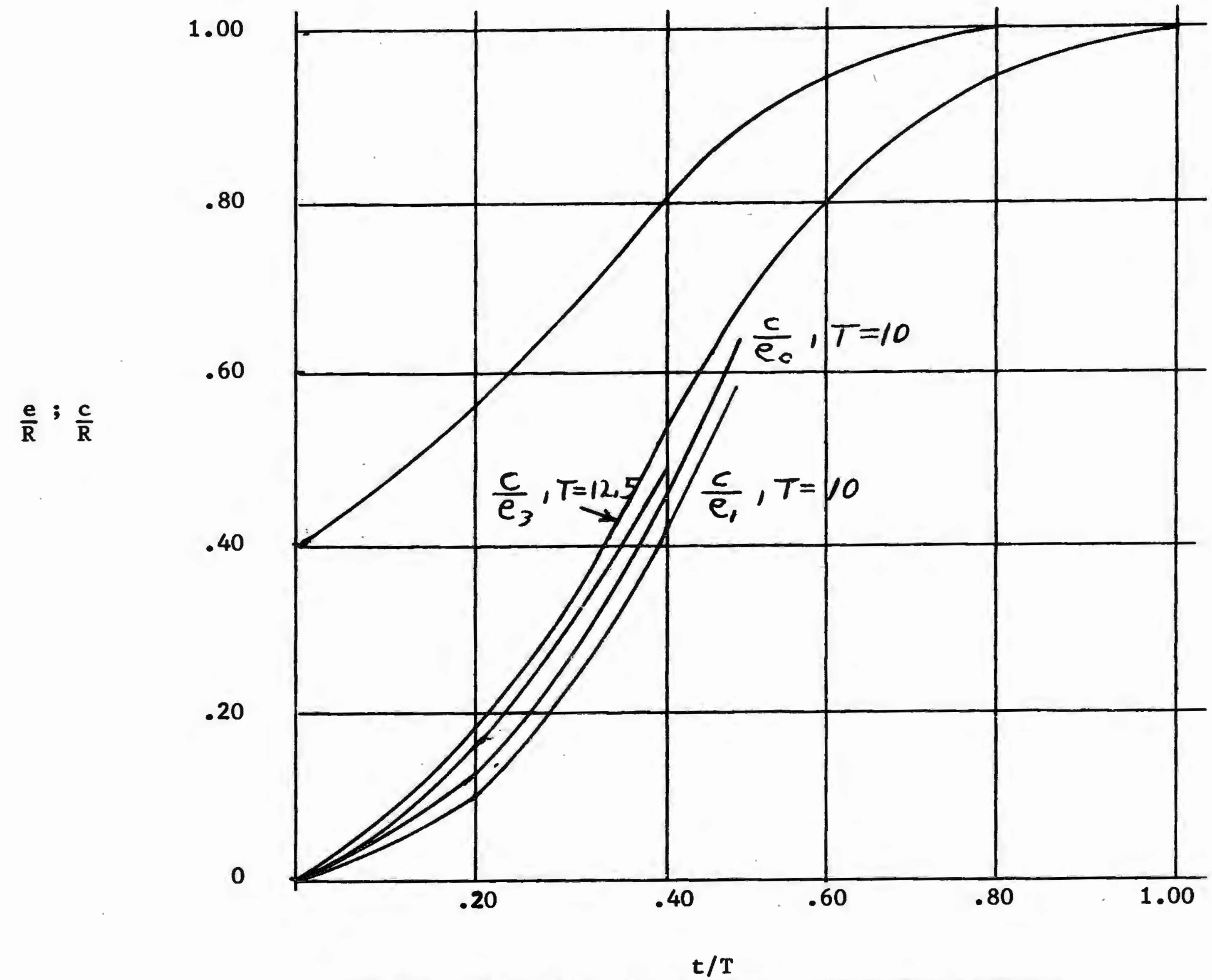
Time t Years	0	1	2	3	4	5
Cumulative Expenditures, c	\$0	\$5	\$15	\$35	\$60	\$85
t/10 years	0	.1	.2	.3	.4	.5
c/\$146 million	0	.03	.10	.24	.41	.58

The last two rows of Table IX are the calculations of the cumulative expenditures over time of System A based on a total RDT&E cost of \$146 million and a R&D Program length of 10 years. This curve (System A's current expenditure distribution curve) is plotted and compared to the average expenditure distribution curve (See Fig 7). In this case, the curve is below and to the right of the average distribution curve.

It will be observed that the position of System A's distribution curve is determined by the estimates of total time and total cost. The curve will move up and to the left, that is closer to the average distribution curve, if:

1) The total time estimated is increased relative to the total cost estimate

or if:



CURRENT EXPENDITURE DISTRIBUTION CURVES FOR SYSTEM A

Figure 10-7

2) The total cost estimate decreases relative to the total time estimate.

These facts can be seen in Figure 7. If it is assumed that the original cost estimate of System A, e_0, is low, as would be indicated by the accuracy curve, then it can be inferred that a higher estimate is a better approximation. Given this assumption, the cost estimate, e_3 = \$166 million and time estimate, T = 12.5 years, which shows a distribution curve quite close to the average, may be a good point estimate of the system's development program. (Possibly T_4, e_4 is even better.)

QUALIFICATIONS AND EXTENSIONS

The main assumption used in STECPLOT analysis is that the system under study will follow on the average the regularities of systems that have completed the R&D cycle. Considering our inability to forecast the occurrence of cost growth causes and their cost impacts, the assumption that a median level of past program disturbances will persist in the future is a reasonable assumption. This is a macroeconomic approach. In the actual use of the STECPLOT no attempt is made to isolate specific reasons why these regularities occur; they are taken into account at the "MACRO" level.

The analyst should be aware of the deficiencies in this assumption. The systems under study may have characteristics that have not been encountered in any previous systems, and these characteristics may have a great influence on the system cost. The correct use of the STECPLOT in this case would be to isolate those parts of the system that do have a historical basis; and those parts that don't might be analyzed separately. Another point of consideration is that the actual cost estimators (as distinguished from cost analysts) may become aware of the analyst's use of the STECPLOT. Consequently, his estimates may consciously or unconsciously take this fact into account, and his resulting estimates may be higher or lower than they would be in his naivete. The STECPLOT may then be self-defeating and that is not necessarily a deficiency. Since past history has indicated RDT&E costs to be usually underestimated, the estimator may work harder to upgrade his work.

At any rate, a known deficiency is to use the STECPLOT solely without other further analysis by someone not experienced with the system.

Much study is required to make the STECPLOT a more valuable tool in cost analysis. It is important, for example, to study the variance of the average curves. If the variance is relatively large, the curve use is negated proportionately. It may be possible using variances to determine statistical confidence levels of analysis. It also may be possible to solve the plot analytically since the curves approximate known functional shapes.

CONCLUSION

It should be repeated that the STECPLOT technique is an analyst's tool; an aid in studying costs at the macroeconomic level. The main assumption, stated many times in the text, must always be borne in mind. When these points are considered the STECPLOT has proven to be a valuable tool in obtaining more realistic cost estimates. In fact, a number of Army systems have shown a marked degree of consistency in following the trends discovered from previous systems.

APPENDIX A

Modeling and Simulation:

I. A model is a representative of the reality of an object, situation, condition, or operation under study. Its primary function is "explanatory" rather than descriptive. To present the situation, condition, or operation without error or uncertainty would be ideal. However, the problem encountered in trying to construct such a model is that it isn't known at the start what is relevant and what is superfluous. The first thing, then, in attempting to build a model is to discover the relevant factors. Following this, the model builder picks those facts which are or can be quantified, reduces this list of quantified factors to a more manageable number through aggregation, and finally, spells out the quantitative relationships between the relevant elements. Successful accomplishment of these four steps will give the analyst a most versatile tool for use in his mission as problem solver. Since models are representations of real things or processes, there are cautions to be observed. First, to become enamored with a model can lead easily to making all sorts of inferences about the problem but leave the question for which the model was constructed unanswered. Second, in order to impress superiors with their technical competence, analysts may try to interject structural complexity into their model which is unwarranted by the type of data available. The danger here is that an erroneous conclusion could be reached - either the wrong answer or saying that no answer can be reached. Next, trying to treat all aspects of a problem simultaneously can lead to criticisms that relevant facts were left out. If found to be true, and the analyst attempts to satisfy the objections, the model becomes bigger and more complicated. The analyst must maintain focus upon the real question being asked and he must avoid trying to do too much at one time. Finally, and very important, he should avoid the notion that there is such a thing as a universal model, that is, a single model which will provide answers to all questions relative to a given activity. Perhaps the basic reason for the inapplicability of the universal model concept is that such a framework tends to cloud or eliminate through assumptions, many extremely important problem uncertainties. These uncertainties must be explicitly considered and visually treated in all future cost analyses. These models may be classified into three basic types: iconic, analog, and symbolic.

<u>ICONIC MODELS</u>. Iconic models look like the object which they purport to represent. They result from the scaling down in size an object such as an airplane or world globe.

ANALOG MODELS. These models are produced by a convenient transformation of certain properties of the objects represented. An electrical circuit diagram of a computer is an analog of the physical system of equipment.

SYMBOLIC MODELS. Symbolic models represent the characteristics and relationships of the original problem or situation through the use of symbols. This form of model does not bear any physical resemblance to the original thing or situation. Mathematical models are examples of symbolic models.

Mathematical models are the type of models which are of most interest to the cost analysis community, may be further described by the terms deterministic (exact) and probabilistic (stochastic). The former is characterized by the condition that chance plays no role in arriving at the solution. The latter type is one where chance plays a major role. These types of models involve solutions derived through analytic, numeric, or Monte Carlo processes. Turning specifically to cost models as the subset of mathematical models with which we are herein concerned several cost model characteristics1/ should be noted:

1. The total resource implication of the systems or organizations to be costed are divided into three major cost categories that portray their time-phased "cradle-to-grave" life cycle.

   a. Research and development costs.
   b. Initial investment costs.
   c. Annual operating costs.

2. Each of these major cost categories is composed of other subsets of categories constructed to preclude the omission of significant cost elements.

3. The relation of each element and category is spelled out quantitatively.

4. The cost model is designed in such a way as to assist in the analysis of the cost elements that have the greatest impact on the total cost of a system or organization.

5. The cost model in its final form usually is composed of a set of equations that give in quantitative terms the type of cost information desired.

1/ Research Analysis Corporation Technical Paper (TP-183), An Individual System/Organization Cost Model, Jan 66.

From a consideration of these characteristics, a cost model may be defined as any generalized framework, normally involving quantitative techniques, used to estimate the relative costs of competing systems or organizations. The design of these models depends upon the data inputs available on cost and quantities of physical resources and the output in terms of cost categories desired for a specific study.

Of course there is a wide diversification of cost studies and estimates. Correspondingly, there is a wide diversification of cost models. The simplest form of a cost model is a CER or cost equation such as may be used to come up with a rough estimate of, let's say, the production cost of a rifle.

$$\text{Cost} = f(\text{wt}, \text{cal})$$

A most comprehensive and detailed type of model would be required to conduct a total force structure cost study involving several mixes of various types of military forces.

Most cost studies and analyses, however, fall in between these two extremes of complexity. As a result of this large diversification of types of cost estimates and studies, there is a wide range of basic costing approach/philosophy, model types, and types of computational equipment which cost analysts employ.

The basic costing approach used, such as the level of cost detail to be employed and the establishment of accuracy requirements, is dependent upon the nature of the problem, the availability of time and competent personnel, as well as upon the availability and accuracy of relevant basic information and data. For instance, it is by careful consideration of these factors that one would decide whether to use a detailed engineering cost approach of a cost estimating philosophy employing primarily the statistical or parametric approach.

In making this decision, it is well to bear in mind Enthoven's admonition to systems analysts that it is better to be roughly right than to be precisely wrong. Saying it another way, the degree of accuracy sought and the level of detail employed should be consistent with the type and purpose of the problem as well as the degree of accuracy and the level of detail of available data and other cost information. Of course, the availability of time is also a most important factor in deciding upon a basic costing approach.

This matter of basic costing approach is a very very important one, since it is so fundamental that it generally determines the entire mode and tone of operation of a cost analysis organization. Stated most simply, this philosophy may be stated as follows:

Except for those rare instances in which a high degree of accuracy is mandatory and the required time, information, and competent engineering talent are available, the statistical or parametric approach is generally considered preferable to the detailed engineering costing approach.

PRINCIPLE TYPES OF COST MODELS

Mathematical cost models are either deterministic or stochastic. A deterministic model treats parameters or inputs as discrete point estimates while a stochastic model treats input parameters as random variables so that resulting costs are developed in the form of a distribution of costs. The models discussed in detail later on are deterministic, though these conceivably could be converted to the stochastic type with the use of a random number generator and inputs in the form of probability distributions. Use of the stochastic model is one way to handle the problem of cost uncertainty.

Three types of computational equipment are necessary in the efficient operation of a Cost Analysis Office. These are: (1) desk calculators and adding machines; (2) desk type computers; and (3) high speed computers. All of the models which will be discussed in this appendix were designed for use with a high speed computer. In most cases, they were designed to develop detailed, yearly life cycle costs for several mixes of several different weapons per mix.

Although there is a wide variety of cost studies and analyses pertaining to Department of Defense problems, there is general agreement that most of these fall into one of three basic types. These are

1. Force Structure Cost Analysis
2. Individual Organization Cost Analysis
3. Weapon System Cost Analysis

Although all three types of cost analyses attempt to determine the resource implications of alternative courses of action, they do so under different conditions. The third type, or "Weapon System Cost Analysis", is generally concerned only with the cost of specific weapon systems and those associated costs which are directly related to these systems. Army tank cost problems, for instance, might be concerned with the acquisition costs of the tank, trainers, and associated equipment, as well as operational, maintenance, and training costs. A weapon system cost study, for a given type of tank, would include costs for crew and maintenance personnel, costs for their training; as well as costs for repair parts, POL (i.e., Petroleum, Oils and Lubricants), and overhaul and rebuild. Unlike the first two types of cost analysis problems, Weapon System Costing does not include the costs of other personnel, equipments, and facilities which may be part of the same army organization to which the tanks are assigned.

In regard to the principal difference between Force Structure and Individual Organization Cost Analysis, Dr. Robert Crosse explains this very concisely and to the point by saying ---- "Individual Organization Cost Analysis determines the costs of a given alternative as if it were isolated from the rest of the force. On the other hand, Force Structure Cost Analysis costs the alternative in the context of the total force so that interrelationships that occur among the organizational elements of the force may be realistically appraised. --- Consequently, the basic underlying difference between the two types of organization type costing is in the treatment of inventory levels and the availability of assets as changes in the force occur. Force structure cost analysis attempts to quantify these asset movements, such as the availability of personnel and equipment to an incoming organization as another organization phases out of the force."

Such organizational type cost analysis problems may pertain to the development of life cycle costs for a completed defense organization, ranging from a single army division or even a divisional sub-unit, all the way to the entire U. S. Army, Navy or Air Force --- or, it could even pertain to costs for the entire U. S. Defense establishment.

As an example, consider the costing of a specific type of U. S. Army Division. One would have to list all the ordnance and quartermaster materiel ordinarily assigned to such a division. Also, one would have to list all personnel and any facilities and/or buildings, if applicable. The acquisition cost of all materiel, not inherited from some other organization, would have to be computed. Usually, this can be done by applying figures from standard army price lists. Yearly average operational and maintenace cost factors can then be applied for each type of equipment and materiel for each year considered. Also to be included would be the average yearly costs of all consumables such as fuel. Personnel costs would include yearly pay and allowances, subsistence, travel costs, and any applicable training costs.

It is easy to see that a model developed for this type of study would indeed be very large and would require a large number of inputs and computations. It is obvious that such a model would have to be automated.

DESIGN AND USE OF WEAPON SYSTEM COST MODELS

As a result of the large diversity of types of cost problems, as well as the variety in types of weapon systems and other Army hardware which an Army cost analysis office may have to deal with, one inevitably is faced with a very basic problem in trying to decide upon the design of life cycle cost models to apply to these various problems and weapon systems.

It appears that there are at least four basic approaches to this cost model design problem. These are:

1. The design of a completely flexible model.

2. The design of a series of rigid models (each designed for a specific type of weapon and/or type of cost study).

3. The design of semirigid models (with enough flexibility to be applicable to several types of weapons and studies).

4. A concept of modular constructed models (i.e., the development of a library of submodels, or subroutines, which would serve as the building blocks for specific life cycle cost models).

The first type of model (i.e., the completely flexible model) is really not so much a model as it is basic framework upon which specific models may be built. It consists, essentially, of a computer program, with standardized subroutines and standardized input and output formats which facilitate the development of an automated life cycle cost model to meet specific cost problems. However, use of this type of model requires the development and programming of a series of cost equations, input data requirements, and requirements for the output of cost summarizations. The basic computer program merely standardizes and thereby facilitates the conduct of these tasks. An example of this type of model is the series of Individual System/Organization Cost Model (ISOC) developed by the Research Analysis Corporation for the Department of the Army. This type model has certain advantages but requires the development of a new model for each problem presented.

The second type of model (i.e., the design of a tailor-make model for each cost problem) is self-explanatory and represents a very inefficient approach.

The third type of model, the semirigid model, with sufficient flexibility to be applicable to several different types of weapons and cost problems, is a feasible approach and is quite efficient. However, experience shows that this approach has certain disadvantages which may be overcome only by making the model more complex in design and, thereby, making it more cumbersome and difficult for analysts to use and learn to use.

In trying to employ each of these philosophies of life cycle cost model design in cost studies over the years, the analyst arrives at the conclusion that none of the first three types of models is really suitable for general and standard application to work in most cost analysis offices. It appears that the best solution is the fourth approach.

This fourth basic design approach is termed "Modular Constructed Models". According to this concept, a library of cost model subroutines (or sub-models) would be developed as the need for each one became necessary. These would be subroutines for each phase of the life cycle, for each basic type of weapon system, for various output formats, various methods of treating the cost uncertainty problem, and for many other purposes. The idea is that eventually, with a varied and well-established library of such subroutines, an analyst will be able to readily construct an automated life cycle cost model practically tailor-made to apply to any cost problem be a judicious selection of these subroutines. These subroutines may be stored on disc files and easily retrieved in the required order by a few punched computer cards.

Actually this concept has been demonstrated in the latest ICE study on the Bushmaster Machine Gun. ICE is the acronym for a series of comprehensive life cycle cost studies on important Army Materiel Command weapon systems and stands for "Improved Cost Estimates".

Why is the Army concerned with life cycle cost models and why is it so important that such models be automated? In the very early 1960's, Robert McNamara's cost-effectiveness and planning, programming, and budgeting approach resulted in continual demands upon the US Army Materiel Command and its Major Subordinate Commands for very comprehensive cost studies involving life cycle costs for several alternative weapon designs or courses of action. These comprehensive cost studies, the demand for which is continually increasing, usually involve the development of detailed, yearly life cycle costs for several weapon systems, one weapon system with several different quantities (and/or time frames) or a combination of several weapons systems and many different quantities and time frames per weapon system.

In the early 1960's, such cost studies were computed with desk calculators. A special staff of many experts, calculator operators, and typists would be assembled in a large room. Large cost charts would be prepared. Sometimes, it would take months to complete a study involving several alternative courses of action, and the resulting costs for each alternative would be based upon a fixed set of assumptions, weapon quantities, and cost factors. In the process of conducting such a study, so much time had to be devoted to calculations, typing, and preparation of the final report that those in charge felt compelled to start the calculation process too early in the game, before the problem had been sufficiently formulated and before a proper search for data could be conducted. Of course, many mathematical errors were generally made, either by those conducting the computations or by typists transcribing the results of calculations.

As if these problems were not enough, the worst problem of all usually became apparent after the study was completed and the special task force disbanded.

Since each alternative course of action was based upon one set of assumptions and one set of numbers as input data, it was quite embarrassing when a general or some other decision-maker would disagree with the choice of assumptions or numerical input data employed. Sometimes, a slight change in one of the input factors or assumptions could upset completely the relative final costs of the alternative courses of action. We shall see later that a single factor can control the final results and conclusions of an entire study.

Needless to say, this type of an approach for the conduct of such comprehensive cost studies was not only inefficient and wasteful of resources, but also was quite inadequate in that it never got the job done properly.

By 1964, it was quite obvious to DA analysts involved in cost/effectiveness studies that the answer to the problem was the development of automated, mathematical cost models.

II. Simulation is defined as the use of a model which takes account of those essentials of reality which are significant to the decision-making objective. A decision can be made by running the simulation a number of times for different alternatives, if necessary, and comparing results. The model does not have to look like the real environment it is simulating, but it must give the same results which the real environment would yield. Thus, simulation is the technique of performing sampling experiments on the model of the real system to reach a decision. The experiments are performed on the model rather than on the real system itself only because the latter would be too expensive, inconvenient, and time-consuming. It should be obvious then that for a simulation experiment to be successful, it is essential that the simulation model abstract the major characteristics of the real world problem.

There are many types of models used in simulation experiments. Some of the more common examples are physical duplications, such as an aircraft trainer; contour maps to study geographical areas; a layout diagram of a factory; charts and graphs; mathematical models; etc. The type of model of most concern for this discussion is the mathematical model. In a mathematical model, symbolism in terms of variables and relationships is used to represent and describe how the factors under study behave in reality. Since mathematical models are quite often very complicated, the digital computer is often used to carry out calculations. As a matter of fact, most meaningful mathematical models must use the computer and as such it is indispensable. Some of the examples discussed here will not require the computer but its use can still be made clear.

Example 1: A game is played in which a fair coin is flipped until the difference between the number of heads and number of tails is 3. This ends 1 experiment and the coin is tossed again for second and subsequent experiments. It is required to pay $1.00 for each toss during an experiment and at the end of the experiment, the player receives $8.00. Should one play this game?

The answer could be calculated analytically to determine the average (expected) number of tosses before the experiment ends. However, it is not a simple solution. One could toss a coin for a half an hour and observe the outcomes; or one could simulate the game on the computer and observe the results by that method.

At this point, it is worth noting the differences between the analytic solution and the simulated solution. The analytic solution will be exact whereas the simulated solution will always depend on the number of times the experiment is performed and how good the model is. Even then, it is highly unlikely that the exact solution will be obtained. On the other hand, many times an analytic solution is almost impossible or very costly to obtain as compared to the closeness and convenience of simulating the answer. These considerations must be made in order to determine which method to use.

To illustrate the simulated solution to this example, consider the fact that most computers have what are known as pseudo-random number generators. (Random numbers are extremely important in simulation and will be discussed in much more detail further on.) The most common algorithm is one which generates the numbers from 0 - 9 and each has a probability of 1/10 of occurring. Therefore, since a head and a tail have probabilities of 1/2, arbitrarily designate the occurrence of the numbers 0, 1, 2, 3, and 4 as meaning a head occurs; and 5, 6, 7, 8, 9 as a tail occurring. Thus, generating a sequence of numbers until the number of numbers 5 or above is three more than the numbers 4 or below or vice versa constitutes the end to one experiment.

Example 1 - continued:

8, 1, 3, 7, 2, 7, 1, 6, 5, 5, 7	7T, 4H
T, H, H, T, H, T, H, T, T, T, T	11 flips of the coin were required

Suppose we made 14 experiments and the number of flips until each experiment ended was 11, 5, 5, 9, 7, 7, 5, 3, 17, 5, 5, 3, 9, and 7. The average number of tosses from this sample calculates to be 7. Based on this simulation, one's decision would be to participate in the game because he would in the long run expect to win $1.00 per game. It is interesting to note that the analytic solution, which is of course exact, calculates to an expected number of tosses of 9. Therefore, a player would expect on the average to lose $1.00 per game. This indicates that a sample size of 14 for this simulation may have been too small. Beyond the scope of this instruction is the design of simulation experiments.

Simulating Risk (Monte Carlo Techniques)

Almost all economic decisions involve information that is not certain; that is, risk and uncertainty are present. Monte Carlo techniques, which is the exotic name for methods using random numbers, are the methods used to simulate risk in situations where the probability distributions are known.

Random number generators in computers have been previously mentioned, and the computer is usually the medium for economic problems. As also mentioned, pseudo-random number generators in the computer usually consist of generating the numbers from 0 to 9 (uniform distribution) all with equal probability of 1/10. Therefore, Monte Carlo techniques include methods of translating the uniform probability distribution into other probability distributions such as the normal or exponential.

Example 2:

A maintenance shop has to be set up in order to service items at a particular base. Previous data indicate that the number of items that are required for repair per day and the time to repair them follow the following probability distributions respectively.

a.

# items/day	9	10	11	12
Probability	.4	.2	.3	.1

b. Time for repair - Exponential Distribution: $P(X>K) = 1 - e^{-K}$ where X = time to repair (hours), K = given # of hours which means the probability that the repair job X takes less than K hours is the expression shown $(1 - e^{-K})$.

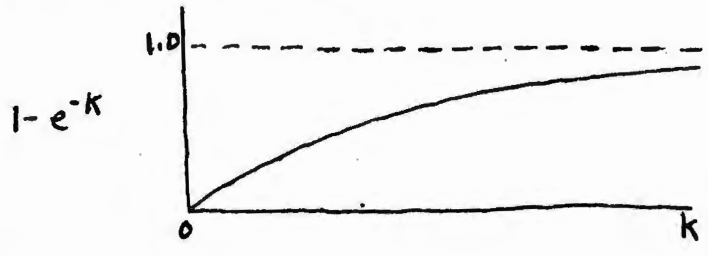
The question is "How many men must be assigned to the shop so that there is a 90% chance that all the work received will be completed in an eight hour day?"

Setting up this simulation experiment is not very difficult; but Monte Carlo techniques are used. To generate random numbers to simulate the number of items for repair each day, use the same method as shown in Example 1. Therefore

Generating random numbers	0,1,2,3	4,5	6,7,8	9
Means X items for repair per day	19	20	21	22

To simulate the time needed for repair of each item is more complicated and requires some theory. Notice that X, the time to repair, can be (theoretically) as small as zero and as large as infinity. Therefore $1 - e^{-K}$ equals 0 when K is zero and equals one when K is infinity. This makes sense because the probability of something occurring can never be less than zero or greater than one.

The graph of $1 - e^{-K}$ is shown



and note that $1 - e^{-K}$ is always between zero and one. The computer random number generator can give numbers from zero to one also by expeditious placing of the decimal point. Thus, one can generate two random numbers 1 and 6 and this can represent the number .16. Since $1 - e^{-K}$ and the random number generators are between zero and one, set the number generated on the computer equal to $1 - e^{-K}$. For example, if .50 was generated,

set $.50 = 1 - e^{-K}$, or $e^{-k} = .50$

Therefore, $k = .70$ since $e^{-.70} = .50$ which means the first item requires 7/10 of an hour (42 minutes) service time. Thus, by generating a number from a uniform distribution and applying it to the equation of the exponential distribution, the number derived is simulated to come from the exponential distribution. The above is an illustration of Monte Carlo techniques to simulate the occurrence of phenomena that follow given probabilities.

Example 2 (continued):

It should now be apparent how to arrive at the answer using simulation techniques. Suppose it was decided that 10 days would be a large enough sample for this problem and the following information was generated.

Day No.	1	2	3	4	5	6	7	8	9	10
Random Number Gener.	5	0	0	4	9	3	2	8	3	6
No. of items repaired	20	19	19	20	22	19	19	21	19	21

The generation of time to repair for each item on each day by using the method previously described; and then adding the times for each day's number of items yields

Day No.	1	2	3	4	5	6	7	8	9	10
Total Repair Time (Hrs)	36	24	31	43	37	20	29	29	30	34

Assuming that each man works a 10 hour day, the following table is derived:

	20-29	30-39	40-49
Number of Days	4 days	5 days	1 day
% of Total	40%	50%	10%
No. of men required/day	3	4	5

Based on this sample, it is seen that 5 men were needed only once in the ten days simulated. Therefore, it could be concluded that 4 men would satisfy the requirement of work completion 90% of the time.

Appendix B

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Appendix C

GLOSSARY

ACCRUED EXPENDITURES: The monetary amounts of goods received, services rendered, expenses incurred, assets acquired (except as noted below), construction performed, and grants earned during a given period, regardless of when payment is made, or of whether invoices have been received. The portion of any such expenditures which is unpaid at a given point in time is a liability. The portion of payments made for which the expenditures have not accrued (such as advances and pre-payments) is an asset. As noted by the Budget Commission, accrued expenditures should not be confused with program costs. Accrued expenditures measure resources acquired, while program costs measure resources used.

ALGORITHM: An orderly, step-by-step procedure for performing a mathematical operation in a finite number of steps. The 1040 form is an algorithm for computing personal income tax.

ALLOTMENT: An authorization granted by an operating agency to another office to incur obligations within a specified amount pursuant to an appropriation or other statutory provision and subject to specific procedural, bookkeeping, and reporting requirements.

ALTERNATIVES: The means by which objectives can be attained. They need not be obvious substitutes for one another or perform the same specific function. Thus, to protect civilians against air attack, shelters, "shooting" defenses, and retaliatory striking power are all alternatives.

ANALOG METHOD OF COST ESTIMATING: A graphical method of cost estimating which is based on historical costs that are too limited to allow statistical estimating and which is more economical to prepare than an engineering estimate. Graphical analysis is often helpful to more clearly understand the degree of relationship of the data points. The analog estimate is normally adjusted by deducting historical costs of components. See also: Statistical method of cost estimating; Cost estimating relationship; Engineering method of cost estimating; Regression analysis.

ANALYSIS OF VARIANCE (ANOVA): The basic idea of ANOVA is to express a measure of the total variability of a set of data as a sum of terms, each of which can be attributed to a specific source or cause of variation.

APPORTIONMENT: A distribution made by the Bureau of the Budget of amounts available for obligation or expenditure in an appropriation or fund account into amounts available for specified time periods, activities, functions, projects, objects, or combinations thereof. The amounts so apportioned limit the obligations to be incurred or, when so specified, expenditures to be accrued.

APPRAISAL: Impartial analysis of information conducted at each responsible management and control level to measure the effectiveness and efficiency of the total process and determine preventive/ corrective action.

APPROPRIATION: Ordinary current appropriations (either no-year or one or more years) are budget authorizations granted currently by Congress, both to incur obligations and to make expenditures in a definite specified amount. Has excluded contract authorizations and authorizations to spend debt receipts. Under the Budget Commission's recommendations, these latter types of authorizations are also called appropriations, but appropriations to liquidate contract authorizations would not be counted as new appropriations.

AUTHORIZATION: An Act of Congress which authorizes Federal programs, obligations, or expenditures. The term sometimes refers to basic substantive legislation setting up a program or an agency, and authorizing appropriations to be made for them, but not actually providing authority to spend. See also: Appropriation.

AVAILABILITY: The probability that the system is operating satisfactorily at any point in time when used under stated conditions, where the total time considered includes operating time, active repair time, administrative time, and logistic time.

AVERAGE OUTGOING QUALITY LIMIT: The average maximum fraction defective leaving an acceptance sampling plan.

BALANCE OF INTERNATIONAL PAYMENTS: A systematic record of the economic transactions of a country during a given period which involve a transfer of currency between the country's residents and the residents of the rest of the world.

BIAS: An unbalanced range of error such that the average error is not zero.

BREAK-EVEN POINT: In engineering-economic studies, the point at which two alternatives become equally economical by altering the value of one of the variables in a situation.

BUDGET: A proposed plan by an organization for a given period of time reflecting anticipated resources and their estimated expenditure in the pursuit of objectives.

BUDGETING: Budgeting is the process of translating, planning, and programming decisions into specific projected financial plans for relatively short periods of time. Budgets are short-range segments of action programs adopted which set out planned accomplishments and estimate the resources to be applied for the budget periods in order to attain those accomplishments.

CERTAINTY: The state of absolute confidence in which outcomes are sure and predestined.

COEFFICIENT OF CORRELATION (r): A measure of how well a linear regression line (q.v.) fits the data. This measure, when squared, equals the coefficient of determination (r^2) which is a measure of the proportion of the total variation (squared deviations from the average) in the dependent variable explained by variation in an independent variable. A high coefficient of correlation of 0.9 indicates that the least-squares regression of the dependent variable on the independent variable accounts for 81 percent (the coefficient of determination) of the variance in the dependent variable. The limit of the coefficient of determination and of the coefficient of determination and of the coefficient of correlation is 1.0.

CONFIDENCE: The degree of trust or assurance placed in a given result.

CONFIDENCE INTERVALS: A measure of effectiveness in testing, expressed in quantitative terms; e.g., the value of a specific factor (variable) lies within a specified interval 95% of the time.

CONFIDENCE LEVEL: The probability that the true value of a parameter lies within a stated interval.

CONSOLIDATED CASH BUDGET: A Federal budget which shows receipts from and payments to the general public, i.e., all non-Federal Government units, including trust funds and some Federal government sponsored enterprises. A deficit shows that the public is accumulating cash or government securities. This budget stresses the financial impact of the overall Government program. See also: Budget, Administrative budget; National Income Accounts budget.

CONSTANT DOLLARS: A statistical series is said to be expressed in "constant dollars" when the effect of changes in the purchasing power of the dollar has been removed. Usually the data are expressed in terms of some selected year or set of years.

CONSUMER PRICE INDEX: A measure of the period-to-period fluctuations in the prices of a quantitatively constant market basket of goods and services selected as representative of a specific level of living. Hence, it can be thought of as the cost of maintaining a fixed scale of living.

CONSTRAINT: A resource limitation, which may be specific (e.g., the supply of skilled manpower or a particular metal), or general (e.g., total available funds).

CONTINGENCY ANALYSIS: Repetition of an analysis with different qualitative assumptions such as theater, or type of conflict, to determine their effects on the results of the initial analysis.

CORRELATION: In a general sense in statistics, correlation denotes the co-relation or covariation between two variables.

COST ANALYSIS: The systematic examination of cost (total resource implications) of interrelated activities and equipment to determine the relative costs of alternative systems, organizations, and force structures. Cost analysis is not designed to provide the precise measurements required for budgetary purposes.

COST CATEGORIES: Three major program cost categories are: (1) Research and Development. Those program costs primarily associated with research and development efforts, including the development of a new or improved capability to the point of operation. These costs include equipment costs funded under the RDT&E appropriations and related Military Construction appropriation costs. They exclude costs that appear in the Military Personnel, Operation and Maintenance, and Procurement appropriations. (2) Investment. Those program costs required beyond the development phase to introduce into operational use a new capability, to procure initial, additional, or replacement equipment for operational forces or to provide for major modifications of an existing capability. They include Procurement appropriation costs and all Military Construction appropriation costs except those associated with R&D. They exclude RDT&E, Military Personnel, and O&M appropriation costs. (3) Operating. Those program costs necessary to operate and maintain the capability. These costs include Military Personnel and O&M appropriation costs, including funds for obtaining replenishment spares from stock funds. They exclude RDT&E and Military Construction appropriation costs.

COST CURVE: A graphical representation of the relationship of cost to another variable, such as output. It is conventional to construct these curves with costs along the vertical axis and the related variable along the horizontal axis.

COST EFFECTIVENESS ANALYSIS: The quantitative examination of alternative prospective systems for the purpose of identifying a preferred system and its associated equipment, organizations, etc. The examination aims at finding answers to a question and not at justifying a conclusion. The analytical process includes trade-offs among alternatives, design of additional alternatives, and the measurement of the effectiveness and cost of the alternatives.

COST ELEMENTS: The subdivision of cost categories related to work areas or processes performed in developing, producing, and operating a weapon/support system.

COST ESTIMATE: The estimated cost of a component or aggregation of components. The analysis and determination of cost of interrelated activities and equipment is cost analysis.

COST ESTIMATING RELATION (CER): A numerical expression of the link between a physical characteristic, resource, or activity and a particular cost associated with it; e.g., cost of aircraft maintenance per flying hour.

COST INFORMATION REPORTING (CIR): A uniform system for collecting and processing cost and related data on major items of military equipment. Its purpose is to assist both industry and government in planning and managing weapon systems development and production activities.

COST MODEL: An ordered arrangement of data and equations that permits translation of physical resources into costs.

COST SENSITIVITY: The degree to which costs (e.g., total systems costs) change in response to varying assumptions regarding future weapon system characteristics, operational concepts, logistic concepts, and force mix.

DECISION VARIABLE: A variable over which one can exert some control, whose value one can choose as a result of a decision. The decision variable might be the amount of food one must eat to satisfy hunger. If the relationship between the values of the decision variable and the level of goal attainment can be defined, one can then find the value of the decision variable that maximizes the attainment of the goal.

DEGREES OF FREEDOM: Refers to the size of the sample(n) less the number of parameter estimates "used up" in the process of arriving at a given unbiased estimate. For example, to estimate the arithmetic mean needed to calculate the variance of a population it is necessary to use the arithmetic mean of the sample, thus using up one degree of freedom. The estimate of the population variance would thus have n-1 degrees of freedom. In the case of regression analysis, one degree of freedom is lost for each of m variables; thus the regression variance has n-m-2 degrees of freedom.

DIMINISHING MARGINAL UTILITY: The principle that, as the rate of consumption of a good is increased, a point is reached where additional units provide less and less utility.

DIMINISHING RETURNS: An increase in some inputs relative to other fixed inputs will cause total output to increase; but after a point the extra output resulting from the same additions of extra inputs is likely to become less and less. This falling off of extra returns is a consequence of the fact that the new "doses" of the varying resources have less and less of the fixed resources to work with.

DISBURSEMENTS: The amount of expenditure checks issued and cash payments made, net of refunds received.

ECONOMETRICS: The branch of economics that uses mathematics and statistics to build and analyze economic models, to explain economic phenomena, and to estimate values for economic variables. The statistical methods used are especially designed to deal with time-series data.

ECONOMIC ANALYSIS: A systematic approach to a given problem, designed to assist the manager in solving a problem of choice. The full problem is investigated; objectives and alternatives are searched out and compared in the light of their benefits and costs through the use of an appropriate analytical framework.

ECONOMIC LOT SIZE: The cost-minimizing size or order to buy or batch to make.

ECONOMIES OF SCALE: Efficiencies, usually expressed as reduction in cost per unit of output, that result from increasing the size of the productive unit.

ECONOMY: Using the least amount of resources to attain a given output or fixed objective.

EFFECTIVENESS: The degree or amount of capability to accomplish some objective(s). Various criteria (e.g., targets destroyed, tonnage moved, etc.) might be used to provide a measure of this amount of capability.

ENGINEERING METHOD OF COST ESTIMATING: A traditional means of cost estimating which depends on a well-defined description of a proposed system, availability of detailed bills of material, detailed operations, and specialized judgment. The method produces good results for systems involving standard components and no high risk developments.

ESSENTIAL ELEMENT OF ANALYSIS: A question specifically designed to obtain data that will provide an answer in a particular problem area, or information required to conduct an evaluation in a particular functional area.

EXPECTED VALUE: The probability of an event occurring multiplied by the payoff associated with its occurrence.

EXTRAPOLATE: Estimate by trend projection the unknown values that lie beyond the range of known values in a series.

FAILURE RATE: The number of items replaced per unit time due to failure of that item.

FEASIBILITY STUDY: (1) A study of the applicability or desirability of any management or procedural system from the standpoint of advantages versus disadvantages in any given case; (2) also a study to determine the time at which it would be practicable or desirable to install such a system when determined to be advantageous; (3) a study to determine whether a plan is capable of being accomplished successfully.

FISCAL POLICY: Federal Government economic stabilization policies designed to foster economic goals such as high employment, stable growth and prices, and balance of payments equilibrium, through changes in taxes and levels of Government spending as distinct from monetary policy (q.v.).

FIXED COSTS: Those elements of cost that do not vary with volume of production.

FLOW CHART: A graphic representation of the major steps of work in a process. The illustrative symbols may represent documents, machines, or actions taken during the process. The area of concentration is on where or who does what rather than on how it is to be done.

FORCE STRUCTURE ANALYSIS: The analysis of proposed forces to obtain a picture of resource implications for planning.

FORCE STRUCTURE COSTING: The determination of the resource implications (manpower, materiel, support, training, etc.) in dollar terms of a given force structure or change to it.

HISTORICAL COST: The cost of any objective based upon actual dollar or equivalent outlay ascertained after the fact. May use any of many methods of cost determination.

INCREMENTAL COST: The added costs of a change in the level or nature of activity. They can refer to any kind of change: adding a new product, changing distribution channels, adding new machinery. Although they are sometimes interpreted to be the same as marginal cost, the latter has a much more limited meaning, referring to cost of an added unit of output.

INFLATION: A rise in the general level of prices. (Pure inflation is defined as a rise in the general level of prices unaccompanied by a rise in output.

INFORMATION SYSTEM: A combination of personnel, efforts, forms, formats, instructions, procedures, data, communication facilities and equipment that provides an organized and interconnected means--automated, manual, or a combination of these--for recording, collecting, processing, transmitting, and displaying information in support of specific functions.

INPUT-OUTPUT ANALYSIS: A quantitative study of the interdependence of a group of activities based on the relationship between inputs and outputs of the activities. The basic tool of analysis is a square input-output table, interaction model, for a given period that shows simultaneously for each activity the value of inputs and outputs, as well as the value of transactions within each activity itself. It has been applied to the economy and the "industries" into which the economy can be divided.

INVESTMENT COST: The cost beyond the Research and Development phase to introduce a new capability into operational use.

LAPLACE CRITERION: This criterion bases decisions under uncertainty upon the assumption that, because the probabilities of future states of nature are unknown, they should be considered to be equal. If a decision is based on the Laplace criterion, equal probabilities are assigned to each possible state of nature, and the alternative which maximizes expected value if selected. The Laplace criterion is sometimes called the "Principle of Insufficient Reason."

LEARNING CURVE: The cost-quantity relationships for estimating costs of equipment. Generally used to predict or describe the decrease in the cost of a unit as the number of units produced increases.

LEAST-SQUARES METHOD: A method of fitting a calculated trend to statistical data, so called because the sum of the squared deviations of the calculated from the observed variables is a minimum. "Least squares" also refers to the criterion that, when followed, yields this result.

MARGINAL COST; REVENUE: Costs incurred or expected to be incurred in the production of an additional unit of output. Marginal revenue is revenue received or expected to be received from the sale of an additional unit of output. To maximize its profits, a firm has to extend production to the point where marginal revenue equals marginal cost.

LOGARITHMIC SCALE: When the vertical axis of a chart is laid off in terms of the logarithms of natural numbers the arrangement is known as a semilog chart and the vertical scale is called a log scale. A curve plotted on such a chart represents not the numbers in the series but the logarithms of these numbers. Changes in the slope of such a curve show changes in the percentage increase or decrease of the original series. As long as there is no change in direction, equal distances on the vertical scale correspond to the same percentage change in the original series.

MATRIX: A rectangular array of terms called elements. It is used to facilitate the study of problems in which the relation between these elements is fundamental. A matrix is usually capable of being subject to a mathematical operation by means of an operator or another matrix according to prescribed rules.

MAXIMAX CRITERION: This criterion bases decisions under uncertainty upon the optimistic hypothesis that the decision maker should select that strategy which produces the maximum of the maxima. See also: Hurwicz criterion; Maximin criterion.

MAXIMIN CRITERION: (WALD CRITERION) This criterion bases decisions under uncertainty upon the conservative hypothesis that the alternative which produces the maximum of the minimum returns should be selected. This criterion can also be employed (as can the Laplace, et. al., criteria) in minimizing as well as maximizing problems. In minimizing problems, one seeks the alternative which gives the minimum of all maxima. The criterion in these circumstances is called minimax rather than maximin. See also: Hurwicz criterion; Maximax criterion.

MEAN: The most common measure of central tendency equal to the sum of the observed quantities divided by the number of observed quantities.

MODEL: A simplified representation of an operation, containing only those aspects of primary importance to the problem under study. The means of representation may vary from a set of mathematical equations or a computer program to a purely verbal description of the situation. In cost/effectiveness analysis (or any analysis of choice), the role of the model is to predict the costs that each alternative would incur and the extent to which each would attain the objective.

MONTE CARLO METHOD: Any procedure that involves statistical sampling techniques from a distribution of possible outcomes for obtaining a probabilistic approximation to the solution of a mathematical or physical problem. Monte Carlo Methods are often used when a great number of variables are present, with interrelationships so extremely complex as to forestall straightforward analytical handling. This method generally involves the use of simulated data acquired by putting random numbers through transformations such that the data imitates significant aspects of a situation.

NEW OBLIGATIONAL AUTHORITY (NOA): The total of all budget authorizations, provided by current or prior actions of the Congress, of whatever type, of a given year which provide new authority to incur obligations. NOA has consisted of appropriation, contract authority, or authority to spend debt receipts. Under the Budget Commission's recommendations, the word "appropriations" will be applied to this concept of NOA.

OBLIGATIONS: Obligations in Federal accounting represent commitments to acquire materials or services or to make payments under certain conditions (such as loans, grants, subsidies, and contributions). The Congress has specifically prescribed the kinds of transactions that may be recorded and reported as obligations of the Government of the United States. Total obligations incurred would thus be the amounts of orders, places, contracts awarded, services received, and similar transactions requiring disbursement of money. In contrast, under the accrual basis of accounting, expenditures represent the receipt of funds, property, or services within a given period of time. See: Accrual accounting.

OPERATING COST: The recurring cost required to operate and maintain an operational capability.

OPERATING PROGRAM: Conceptually, a mix of activities and resources under common management which represents the most detailed organizational or budgetary level whose identification is required in the information system. The operating program may be identical with a program element (q.v.) if its purpose can be identified by only one program category (q.v.). Alternatively, the operating program may serve more than one such purpose, in which case each part of the operating program identified by a discrete program category is a program element.

OPERATIONS RESEARCH: The use of analytic methods adopted from mathematics for solving operational problems. The objective is to provide management with a more logical basis for making sound predictions and decisions. Among the common scientific techniques used in operations research are mathematical programming, statistical theory, information theory, game theory, monte carlo methods, and queueing theory.

OPTIMIZATION: The attainment of the best possible result, i.e., the maximization (minimization) of some desirable (undesirable) criterion measure, subject to the constraints imposed on the choice of solutions.

PARAMETER: A constant or a variable in mathematics which remains constant during some calculation. It is generally a definable characteristic of an item, device, or system.

PLANNING: The selection of courses of action through a systematic consideration of alternatives in order to attain organizational objectives.

PLANNING-PROGRAMMING-BUDGETING: The Planning-Programming-Budgeting System (PPBS) represents an effort by the Executive Branch of the Federal Government to prepare budgets in such a systematic way as to make them most useful in establishing priorities, in forward planning, in choosing between programs, and in measuring costs against meaningful performance yardsticks.

POINT ESTIMATE: An estimate which states that the characteristic of interest has a single, specific value. It is the single best estimate of a population value made from a sample. This may be contrasted with an interval estimate which states that the population value of interest falls somewhere within a range or interval.

POPULATION: If a set of data consists of all conceivably possible (or hypothetically possible) observations of a certain phenomenon, we refer to it as a population; if it contains only part of these observations, we refer to it as a sample.

PRESENT VALUE: The estimated present worth of a system of future benefits or costs arrived at by discounting the future values, using an appropriate interest rate.

PROBABILITY: A number between 0 and 1 that, when assigend to an event or occurrence, expresses the likelihood that the event will occur.

PROGRAM: (1) A plan or scheme of action designed for the accomplishment of a definite objective that is specific as to the time-phasing of work to be done and the means proposed for its accomplishment, particularly in quantitative terms, with respect to manpower, material, and facilities requirements; thus, a program provides a basis for budgeting; (2) a segment or element of a complete plan; (3) a budget account classification.

PROGRAM ELEMENT: A subdivision of a program category (q.v.) which comprises the specific products that contribute to an agency's objective(s). If an agency's operating program (q.v.) is distributed over several program categories (q.v.) each part of the operating program identified by a discrete program category is a program element.

RANDOM NUMBERS: A sequence of digits in which each digit has an equal probability of occurring in each position, wholly independent of which digits appear elsewhere in the sequence.

RANDOM SAMPLE: A sample selected, from a population to be tested, in such a manner that every element in the population has an equal chance of being chosen for the sample.

REGRESSION ANALYSIS: The association of one or more independent variables with a dependent variable. Under static conditions the analysis is called correlation. When used for predictive purposes, it is referred to as regression. The relationships are associative only; causative inferences are added subjectively by the analysts.

Where only one independent variable is used the technique is known as simple regression and takes the form of a regression line (q.v.) of the equation:

$$y = a + bx$$

When more variables are added, a dimension is added with variables, making graphical representation impossible beyond two independent variables. However, the general analysis is the same for multiple regression, taking the general equation form:

$$y = a + bx_1 + cx_2 + dx_3 + \ldots + zx_n$$

For effective regression analysis to be undertaken, the data base must meet certain requirements.

REGRESSION LINE: A least squares equation meeting these assumptions: a stochastic (q.v.) relationship in which the random error term is from a normally distributed population with zero mean and constant variance. See also: Regression analysis.

RESEARCH AND DEVELOPMENT (R&D): Basic and applied research in the sciences and engineering, and the design and development of prototypes and processes. Excludes routine product testing, market research, sales promotion, sales service, and other non-technological activities or technical services.

Basic research includes original investigations for the advancement of scientific knowledge that do not have specific practical objectives.

Applied research is the practical application of knowledge, material and/or techniques toward a solution to an existent or anticipated military or technological requirement.

Development includes technical activities of a nonroutine nature concerned with translating research findings or other scientific knowledge into products or processes. Development does not include routine technical services or other activities excluded from the above definition of research and development.

RESEARCH AND DEVELOPMENT (R&D) COSTS: The cost of developing a new capability to the point where it is ready for procurement for operational units.

RISK: As used in cost-effectiveness analysis and operations research, a situation is characterized as risk if it is possible to describe all possible outcomes and to assign meaningful objective numerical probability weights to each one. For example, an action might lead to this risky outcome: a reward of $10 if a "fair" coin comes up heads, and a loss of $5 if it comes up tails. Another example, 50% of all missiles fired can be expected to land within one CEP of the target.

SENSITIVITY ANALYSIS: Repetition of an analysis with different quantitative values for cost or operational assumptions or estimates such as hit-kill probabilities, activity rates, or R&D costs, in order to determine their effects for the purposes of comparison with the results of the basic analysis. If a small change in an assumption results in a proportionately or greater change in the results, then the results are said to be sensitive to that assumption or parameter.

SETS: A collection of items (elements) chosen as pertinent.

SIMULATION: The representation of physical systems and phenomena by computers, models, or other equipment. The model or computer representation is manipulated to imitate significant aspects of a situation.

STANDARD DEVIATION: A measure of the dispersion of observed data. Mathematically, it is the positive square root of the variance.

STANDARD ERROR: The standard deviation of a group of measures of the same characteristics (often termed a "statistic" or a "parameter") each obtained from a distinct sample drawn from a larger "universe" or "population".

STATISTICAL BIAS: If some samples or observation data are more likely to be chosen than other, or if subjective methods are used in selecting sample data, the results are considered biased.

STATISTICAL DECISION THEORY: Theory dealing with logical analysis of choice among courses of action when (1) the consequence of any course of action will depend upon the "state of the world," (2) the true state is as yet unknown, but (3) it is possible at a cost to obtain additional information about the state.

STATISTICAL INFERENCE: Using information contained in a sample to make predictions about a larger set, the population.

STATISTICAL METHOD OF COST ESTIMATING: A method of cost estimating utilizing statistically determined cost estimating relationships which express cost as a function of the characteristics specified for the case in question. A valuable aspect of statistical estimating is that an objective statement regarding cost uncertainty can be provided.

SUNK COSTS: Costs which are irrevocably committed to a project; such costs normally have no bearing on current management decisions.

SYSTEMS ANALYSIS (SA): A formal inquiry intended to advise a decision maker on the policy choices involved in a major decision. In DOD a systems analysis may be concerned with such matters as weapon development, force posture design, or the determination of strategic objectives. To quality as a system analysis a study must look at an entire problem as a whole. Characteristically, it will involve a systematic investigation of the decision maker's objectives and of the relevant criteria; a comparison--quantitative when possible--of the costs, effectiveness, and risks associated with the alternative policies or strategies for achieving each objective; and an attempt to formulate additional alternatives if those examined are deficient.

TIME-PHASED COSTS: A presentation of the cost results broken down by the time period in which the costs occur rather than a single total cost figure.

TOTAL OBLIGATION AUTHORITY (TOA): The cost allocated to a given system or organization. This cost when related to a specific time period, for example, a year represents obligations that can be incurred during that year and not necessarily expenditures. The total obligation authority for a specific year to furnish a house is the cost of what can be ordered during that year even if deliveries and payments are made in later years.

TOTAL SYSTEM COST: The total R&D, Investment, and Operating Costs (for a specified number of years of operation) required to develop, procure, and operate the particular weapon system.

UNCERTAINTY: A situation is uncertain if there is no objective basis for assigning numerical probability weights to the different possible outcomes or there is no way to describe the possible outcomes. For example, the probability of a foreign nation continuing to furnish the U.S. with base rights is an uncertainty.

VALIDATED COST DATA: Resource data which have been objectively analyzed and documented by the preparing agency, and independently evaluated and coordinated with those Department of the Army agencies with a functional responsibility for the data.

VARIABLE COSTS: Those costs that vary with the volume of output as contrasted with fixed costs, which do not vary with output.

VARIABLES: General numbers, such as x or y which may take on many values or which may have conditional fixed values as in $x^2 + 2x = 19$.

WORK BREAKDOWN STRUCTURE: A standardized division of a weapon/support system into components and subcomponents. This is represented by a structure displaying the system in levels of subcomponents which can be consolidated into higher levels of component aggregation.