RADC-TR-65-475

CRITERIA FOR VALUE ENGINEERING
PHASE I
FEASIBILITY STUDY

R. E. Purvis
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RCA Service Company

TECHNICAL REPORT NO. RADC-TR-65-475
February 1966

Code 1

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Reliability Branch
Rome Air Development Center
Research and Technology Division
Air Force Systems Command
Griffiss Air Force Base, New York

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AFLC, GAFB, N.Y., 29 Mar 66-80

FOREWORD

This report was prepared by Messrs. R.E. Purvis and R.L. McLaughlin, Radio Corporation of America, RCA Service Company Division, Alexandria, Virginia 22314, under Contract AF30(602)-3850, Project 5519, Task 551901. Mr. Julius Widrewitz (EMERE) was the RADC Project Engineer.

This technical report has been reviewed and is approved.

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This report summarizes the state-of-the-art of Value Engineering. A proposed structure for a general value analysis technique along with quantification of value is presented. Based on the proposed structure a general method for resource cost optimization is developed.

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1. INTRODUCTION

This report is the result of effort performed under Phase I of AF30(602)-3850. The purpose of this report is as follows:

a. To summarize the findings of a value analysis literature review.

b. To develop the logic of a value analysis methodology applicable to the conceptual and definition phases of system development.

c. To develop a schedule for the proposed Phase II program.

2. STATE-OF-THE-ART

2.1 Present Status

The evaluation of function is the present state-of-the-art of value engineering theory. And the basic tool may be summarized as a series of questions directed to function evaluation:

a. What is the product?

b. What is the function of the product?

c. How well does the product perform the function?

d. Are there acceptable alternatives for the design of the product for cost reduction and comparable quality?

This value engineering approach represents a qualitative rather than a quantitative process.

This tool applied to military value analysis takes the following additional forms:

a. Question constraints of contract. Does the contract cover or exceed the requirement of the function of the product? There are two types of requirements generally invoked in contracts: system operational requirements and military specification standards. System operational requirements constitute the big picture and are generally peculiar to the system. These requirements are mission/environment oriented. Military specification standards are detail part/performance requirements.

b. Question mission of the product.
Will the product perform the mission called for in the contract and specifications?

c. Question constraints of the "abilities," e.g., reliability.
Are the constraints of the other "abilities" compatible with the requirements of value for cost reduction?

d. Question alternatives to the design.
What alternative designs are possible to perform the required function of the product within the parameters of specifications, cost, and value?

e. Question the parameters of the function of the product.
Will the product perform the required function with the present design?

The existing value methodology is primarily used as an after the fact cost reduction mechanism. As a matter of fact, considerable value analysis effort is performed in the proposal, definition, and design phases of system development; but it is given scant recognition as such, due simply to the mensuration problems associated with cost savings.

There is in value literature a wealth of idea or generation of alternative devices both of a general nature and even categorized by problem type; e.g., to buy or make.

2.2 Present Problems

The existing problems of the value engineering discipline are as follows:

a. Need for quantitative criterion for value pointing up difference between value and cost.

b. Need to orient value analysis to total expected resource cost.

c. Need for a feasible systematic procedure for evaluation of feasible alternatives.

d. Need to reorient value analysis to the objective of elimination of excessive cost rather than reduction in cost, e.g., do it right the first time. How much can be saved by decreasing the value of the system (decreasing performance goals, e.g., reliability)?

e. Need to project alternatives into total cost picture early in the conceptual phases of system development; thus a means of making the systems circuit, and packaging engineer aware of total cost implications.

3. THE DECISION ENVIRONMENT

3.1 General

This section is directed to establishment of the fundamental concepts, working definitions for the value methodology, and the program time frame in which value analysis must be performed. For the purpose of this study, value engineering is considered to be that discipline directed to analysis of how system and equipment are related; whereas, system engineering is directed to analysis of the relation between mission and the system. Thus as the systems effectiveness analyst is related to the system engineer so is the value analyst related to the design engineer. Pictorially this relationship is shown in figure 3-1.

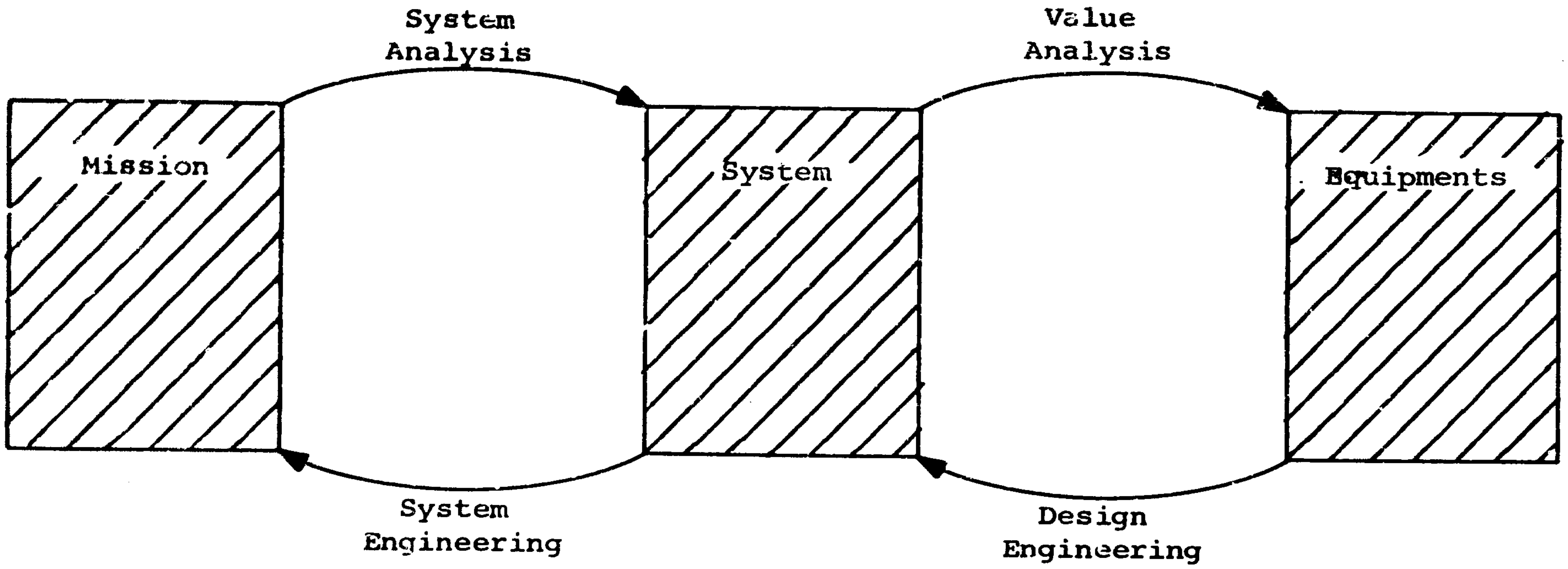


Figure 3-1. System Disciplines

The elements in common between system effectiveness and system value are the hardware/software to implement the system and the cost aspects of the hardware/software with related support aspects. Additionally, the interface of systems effectiveness and system value revolves about the method of implementing the function. In general, this will be hardware, but may be processes, schedules, etc., - anything involving program schedule, total expected cost, or performance.

3.2 Value Engineering Fundamentals

3.2.1 General - A general value engineering methodology must meet certain specific requirements; these requirements are as follows:

a. The desired method should be useful for objectively quantifying value:

   1. As a tool for design decision through all project phases.

   2. In the development of proposals.

   3. In the evaluation of proposals.

   4. For monitoring the value level of systems/equipment undergoing development.

b. The method should have application to the bulk of military systems, equipments, missions, and situations.

c. The method must be technically valid and useful in practice as follows:

   1. It must provide realistic guidance for trade-offs between functional levels of performance and the costs of ownership and operation.

2. It should take into account the skill level of the average user (both contractor and customer) and the conditions under which it will be used.

3. The data required, and the actions to be taken to reach meaningful decisions, must be sequenced and timed to match normal program phasing.

4. The method should be capable of adjustment to maintain its validity in the face of advances in design, systems support policies, and mission requirements, as well as advances in analytical tools and the quality of available data.

5. The degree of refinement of a model or technique should be compatible with the basic accuracy and variability of the data needed for its use and the sensitivity of the output to variations in input.

6. The time and cost required to carry out the procedure at any phase of the development cycle should be compatible with design schedules and budgets. The cost of carrying out the procedure must not be disproportionate to the gains expected from its use.

In the past a number of factors have militated against meeting these requirements and care must be exercised in developing the approach without succumbing to the same pitfalls.

One pitfall is the failure to recognize that values have an existence at least semi-independent of cost. For instance, a battleship cut up for scrap has far less value than when it proudly joined the fleet. Yet many more dollars have gone into the operational and scrapping costs. A technological breakthrough can drastically reduce the cost of an equipment without affecting the value of the equipment at all.

A second pitfall is the not infrequent belief that all value parameters can be optimized at once. In most real cases (given a sound design to start with) it is not feasible to improve one function, indiscriminately, without adversely affecting others.

A third pitfall is a widely held tendency to look for absolute invariant value independent of the particular application and the particular user. A glass of water to a man on the desert has a value quite different from that it has for a man drowning in a lake. Obviously, elements of value are desire or need, and difficulty of acquisition.

The elements of value have, in present literature, been combined to arrive at a total figure of merit. This assumes discrete, mutually exclusive, parameters or courses of action; since this is not always the case, it is necessary to use more rigorous methods of combination, or to determine what errors are introduced by assuming that several parameters are independent, even if, in fact, they are not.

It is desirable not only to develop criteria for measuring value, but also to develop criteria for selection of areas of high yield. This will involve elements of timeliness and feasibility as well as such elements of yield as annual or contract cost of producing, the cost of operation and maintenance, complexity, ratio of special parts to standard parts, state-of-the-art, design maturity, and remaining useful life.

3.2.2 <u>Definitions</u> - Like any other prediction/measurement tool, value engineering can be predicated on an axiomatic set of assumptions, describing as realistically as possible the ground rules of the discipline. Value, for the present purpose, is appropriately viewed as the utility of a proposed system equipment to the user, measured in terms of achievement of some objective established by the user. Thus value (of a thing) is the utility (of a thing) professed in achievement of an objective. For military systems, this utility is quantifiable in terms of performance capability measures.

The term objective may be considered synonymous with the term function as used in value engineering literature.

Value engineering analysis is a quantitative and systematic method directed to the achievement of specified performance objectives equal to or greater than some pre-assigned value at minimum resource expenditive. (The terms value analysis and value engineering are treated synonymously in this report.) The term system is used in this report as an achievable objective specified in terms of performance parameters, which are transformable into hardware and/or processes, and/or schedules.

3.2.2.1 System Value Parameters - In general, there are two types of system value parameters. These are shown in table 3-1. The basic value parameters are as follows:

a. Design Value Parameters: These parameters establish the design requirements imposed on the system. The capability parameter is defined in terms of mission requirements. Each proposed design alternative may be predicted with respect to satisfying the parameter numeric. This would be generally accomplished using modeling techniques. Demonstration testing may be conducted to ensure satisfaction of the parameter numeric, with the exception of the survivability and safety parameter, in which it may be infeasible.

b. Operational Value Parameter: These parameters describe the use value of the system. The design and use value parameters constitute the total value to the United States Air Force. Specific numerical description is to be provided by the USAF of each design and use value parameter.

Value parameters, as defined above, satisfy quantitative requirements, prediction, and demonstration requirements;

TABLE 3-1
PARAMETER DEFINITION

System Value Parameters	System Utilization Rates	Acquisition Cost (Dependent Variable)	Support Cost (Dependent Variable)
Design			
Capability			
Availability			
Reliability		Design	Personnel Subsystems
Maintainability			Manning Requirements
Survivability		Fabrication	Skill Requirements
Safety			by location
		Installation	
	Scheduled Rates	Manuals	Spares
	Schedules		by type
	Unscheduled	Test Equipment	by location
	Spares Usage Rates		Utilities
	Training Rates	Tool	by location
	Operational Rates		Facilities
		Fixtures	by location
Operational			Depot costs
Deployment Capability			Transportation
Self-sufficiency			by location
Mobility			Installation
Storeability			by location
Life Expectancy			Documentation

and, as importantly, represents utility of the system to the Air Force in terms of achieving an objective(s).

3.2.2.2 System Utilization Rates - The value of the system is related to the cost of the system through utilization rates. (See table 3-1.) The prime utilization rate is the operational rate, viz., how much is something used. All other rates are either part of the operational rate (training rate) or derivatives of it (maintenance rates).

3.2.2.3 Dependent Variables - The system utilization rates, operating on design and operation value parameters, combine to determine both acquisition and support cost. Thus, for a well defined system design configuration - design and operational value parameters specified along with hardware implementation - the total expected cost of acquisition and support may be estimated, using the system utilization rates. The system utilization rates are intimately related to how the system value objective is achieved; that is, hardware alternatives. These alternatives are in turn related to basic cost inputs of acquisition and support.

3.2.3 Information Adequacy - At any point in the system development cycle, the information upon which decisions are based is in the form of estimates. Greater detail and accuracy may be obtained but only at the expense of time and cost and perhaps national safety. To assure optimality, information accuracy sufficient to assure that one alternative is superior to another is all that is required.

From the definition of value, and its relation to total expected cost, it is apparent that system value can only be predicted with the same degree of accuracy as can be the basic value parameters. Recognizing; that it is real differences in total expected cost which is the principle criterion, it is also true that information sufficient to assure that one alternative is superior to another is also sufficient to assure that the minimum cost goal can be achieved. This particular feature is singularly significant, in that as the hardware configuration becomes more defined variations in cost estimations for acquisition and support decrease. Further, for the purposes of comparing alternatives, the points of differences between alternatives may be singled out and, if necessary, greater detail information acquired.

In general, acquisition costs are best provided by the contractor since this is the source of alternatives and basic cost inputs. In order to project support cost as a function of design alternatives the USAF must be the source of operational parameters and specified cost constants. The system utilization rates will be a joint responsibility. The utilization rates are primary target for sensitivity analysis.

3.3 Phases of Design and Operation

The basic requirements of mathematical model or analysis technique is that it be capable of application in the time frame in which the problem exists and, additionally, that it be capable of utilizing information of limited accuracy. The refinement (closeness of fit) of the model should be predicated upon exactness of the information processed.

Throughout the conceptual phases of system development decisions are made sequentially with increasingly more accurate estimates of system performance and cost. In spite of the relatively inaccurate information available in the earlier stages, decisions still must be made concerning alternatives, and to ensure that the proper alternative is selected, the methodology of processing available information must permit finding quantitative differences between alternatives.

Figure 3-2A depicts the broad cause and effect relationships that in actual practice develops into a concatenation of events that terminates in a deployed and operational system. The important features are:

a. As time progresses, the alternatives available for subsequent phases become increasingly constrained.

b. Changes in concept at any phase can be reflected in terms of resource cost in subsequent phases.

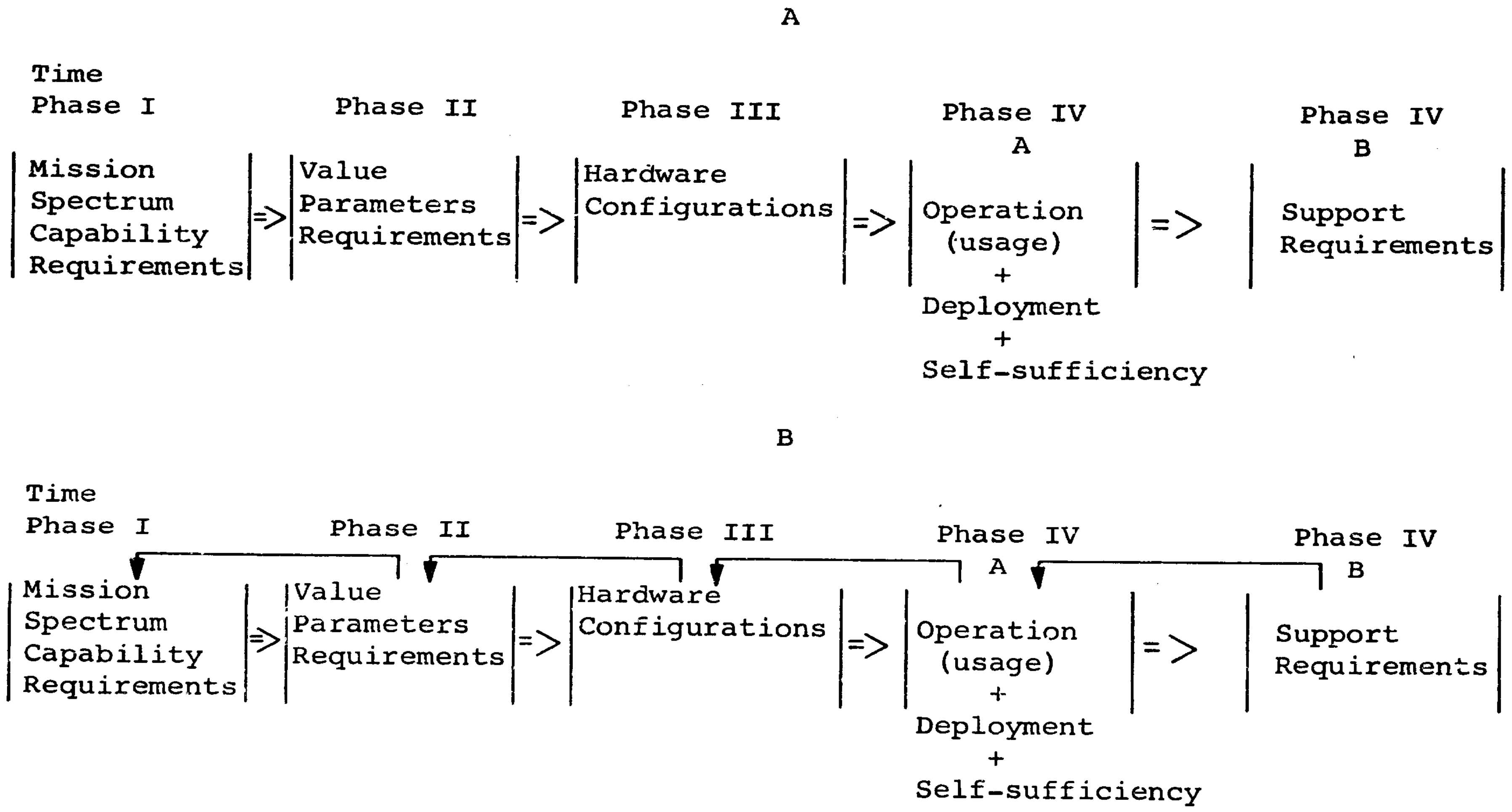


Figure 3-2. System Development

c. Input (requirements) at any phase may be categorically related to previous decisions or shown to be relatively independent.

Figure 3-2B depicts the same phases with feedback provision. This feedback is simulated in that alternatives at any phase are extrapolated into the terminal phases of the system life cycle. The value advantage afforded by simulated feedback are as follows:

a. Minimizes constraining requirements on subsequent phases without tested long range effects.

b. Permits relative evaluation of alternatives.

c. Permits sensitivity analysis to be performed. This type of analysis takes the following forms.

    1. Determination of importance or non-importance of a decision.

    2. Determination of effect if a change is necessitated in a subsequent phase of life cycle.

    3. Point up areas of high cost sensitivity.

Figure 3-3 provides a detailed picture of the system program phasing. Opportunity for change exists at every phase and at every level of system development. For "change" (PCP) read "value engineering" and the whole story is contained in one picture[15].

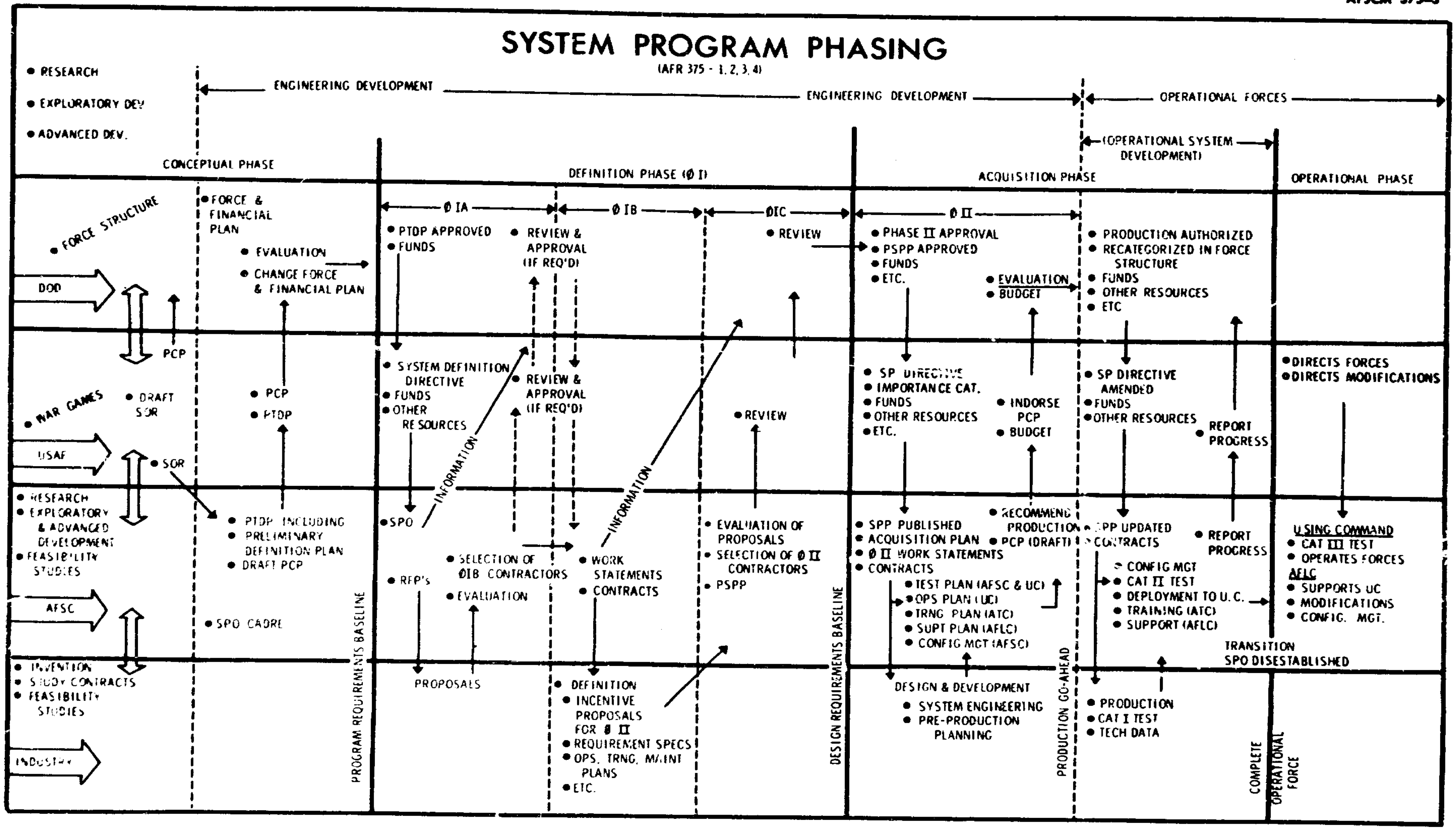

SYSTEM PROGRAM PHASING
(AFR 375 - 1, 2, 3, 4)
• RESEARCH
• EXPLORATORY DEV
• ADVANCED DEV.
ENGINEERING DEVELOPMENT
ENGINEERING DEVELOPMENT
OPERATIONAL FORCES
(OPERATIONAL SYSTEM DEVELOPMENT)
CONCEPTUAL PHASE
DEFINITION PHASE (Ø I)
ACQUISITION PHASE
OPERATIONAL PHASE
• FORCE STRUCTURE
DOD
PCP
• FORCE & FINANCIAL PLAN
• EVALUATION
• CHANGE FORCE & FINANCIAL PLAN
Ø IA
Ø IB
ØIC
Ø II
• PTDP APPROVED
• FUNDS
• REVIEW & APPROVAL (IF REQ'D)
• REVIEW
• PHASE II APPROVAL
• PSPP APPROVED
• FUNDS
• ETC.
• EVALUATION
• BUDGET
• PRODUCTION AUTHORIZED
• RECATEGORIZED IN FORCE STRUCTURE
• FUNDS
• OTHER RESOURCES
• ETC
• WAR GAMES
USAF
• DRAFT SOR
• SOR
• PCP
• PTDP
• SYSTEM DEFINITION DIRECTIVE
• FUNDS
• OTHER RESOURCES
• REVIEW & APPROVAL (IF REQ'D)
INFORMATION
INFORMATION
• REVIEW
• SP DIRECTIVE
• IMPORTANCE CAT.
• FUNDS
• OTHER RESOURCES
• ETC.
• INDORSE PCP
• BUDGET
• SP DIRECTIVE AMENDED
• FUNDS
• OTHER RESOURCES
• REPORT PROGRESS
• DIRECTS FORCES
• DIRECTS MODIFICATIONS
• RESEARCH
• EXPLORATORY & ADVANCED DEVELOPMENT
• FEASIBILITY STUDIES
AFSC
• PTDP INCLUDING
• PRELIMINARY DEFINITION PLAN
• DRAFT PCP
• SPO CADRE
• SPO
• RFP's
• SELECTION OF ØIB CONTRACTORS
• EVALUATION
• WORK STATEMENTS
• CONTRACTS
• EVALUATION OF PROPOSALS
• SELECTION OF Ø II CONTRACTORS
• PSPP
• SPP PUBLISHED
• ACQUISITION PLAN
• Ø II WORK STATEMENTS
• CONTRACTS
• TEST PLAN (AFSC & UC)
• OPS PLAN (UC)
• TRNG PLAN (ATC)
• SUPT PLAN (AFLC)
• CONFIG MGT (AFSC)
• RECOMMEND PRODUCTION
• PCP (DRAFT)
• SPP UPDATED
• CONTRACTS
• CONFIG MGT
• CAT II TEST
• DEPLOYMENT TO U. C.
• TRAINING (ATC)
• SUPPORT (AFLC)
• REPORT PROGRESS
USING COMMAND
• CAT III TEST
• OPERATES FORCES
AFLC
• SUPPORTS UC
• MODIFICATIONS
• CONFIG. MGT.
TRANSITION
SPO DISESTABLISHED
• INVENTION
• STUDY CONTRACTS
• FEASIBILITY STUDIES
INDUSTRY
PROPOSALS
• DEFINITION
• INCENTIVE PROPOSALS FOR Ø II
• REQUIREMENT SPECS
• OPS, TRNG, MAINT PLANS
• ETC.
DESIGN & DEVELOPMENT
• SYSTEM ENGINEERING
• PRE-PRODUCTION PLANNING
• PRODUCTION
• CAT I TEST
• TECH DATA
PROGRAM REQUIREMENTS BASELINE
DESIGN REQUIREMENTS BASELINE
PRODUCTION GO-AHEAD
COMPLETE OPERATIONAL FORCE

Figure 3-3

4. PROPOSED STRUCTURE

4.1 General

The methodology proposed in this report is expressly consistent with, and intentionally limited to, the existing DOD and USAF concept of Value Analysis; that is, achievement of specified functions at minimum total expected resource costs over the life cycle of the system. The program intent is the development of a technique which will permit achievement of a specified objective at minimum resource cost invested.

The important differences between the orientation of the proposed technique and conventional value analysis lie in the areas of application. The proposed technique is to be applied in the conceptual and definitions phase; whereas, conventional value analysis is directed to after-the-fact design analysis, generally directed to minimize acquisition costs, and usually exercised under contractual incentive types contracts. This latter approach is quite legitimate due to the inability to evaluate consistently the savings through value engineering efforts at earlier conceptual time; that is, how are cost savings demonstrated in the conceptual and definition phases.

The position taken on this matter in this program is, that the aim is not directed to reducing cost; but, stated negatively, to eliminate alternatives requiring unnecessary costs before these costs are incurred. Measured in this way, a product which undergoes significant cost reduction in the acquisition stage is poorly designed; depending upon:

a. Did a preferable alternative exist at the time the decision was made?

b. Does additional information exist now which did not exist previously?

c. Was the decision made using the best information available?

d. Were the alternatives projected into total life cycle?

e. Were chance events weighed and/or explored?

The methodology developed in the following sections is directed to provide the least cost alternative through a quantitative systematic analysis.

4.2 Definition of Objective

Let E designate a set of parameters describing the system effectiveness of the system under evaluation.

$$E=E(e_1,e_2,e_3...e_n) \qquad (4\text{-}1)$$

Let E_O designate the set of parameters (e_{iO}) having the minimum acceptable performance numeric associated with each parameter (greater than which there is no return in effectiveness for the system). This set of parameter numerics constitute the value (V) of the system.

The value engineering criterion or objective now becomes

$$\text{Objective: Minimize } T=A+S \quad \text{Subject to } E \geq E_O,\ D \leq D_O \qquad (4\text{-}2)$$

where A = cost of acquisition
S = cost of support
D = delivery schedule
D_O= minimum acceptable delivery schedule.

This model may be expressed also in the form

$$\begin{aligned} \text{Min}F(T)=&S+\lambda_3(A-A_o+r_3^2)+\lambda_1(E-E_o-r_1^2) \\ &+\lambda_2(D-D_o+r_2^2) \end{aligned} \qquad (4\text{-}3)$$

where:

$$E-E_0-r_1^2=0 \qquad E \geq E_0$$

$$D-D_0+r_2^2=0 \qquad D \leq D_0$$

$$A-A_0+r_3^2=0 \qquad A \leq A_0$$

where:

λ_i is a Lagrange multiplier,[18] introduced to ensure the proper demensionality along with numerical value, and r_i is a slack variable necessary to ensure that the inequalities are satisfied.

The importance of equation 4-3 from the value analysis viewpoint, lies in recognizing that variations beyond the minimum required (e_{i0}) may result in a very real cost reduction. Figure 4-1 illustrates this relationship, where e_{i0} is the specified numeric from the systems study beyond which further improvement does not contribute significantly to system effectiveness, and e_{im} is the absolute minimum cost point. Most examples of cost reduction result in increased performance, i.e., beyond requirements.[17] For example, a fringe benefit of cost reduction resulted in an increase in reliability of 30% of Class I changes and 48% of Class II changes. This implies misdirection from the existing definition of value as well as value analysis. The difficulty arises from the tacit assumption that achievement of a quantitatively specified objective at minimum cost results in the absolute minimum cost.

4.2.1 General Value Function - The definition of value given above obviates the problems of dimensionality that has plagued investigators seeking a value model which permits establishing ratios to determine greater than or less than conditions. The following development shows the characteristics such a function must possess to satisfy a ratio test, viz.

If

$$\frac{V_1/T_1}{V_2/T_2}<1 \qquad (4\text{-}4)$$

then V_2/T_2 is preferably to V_1/T_1, etc.

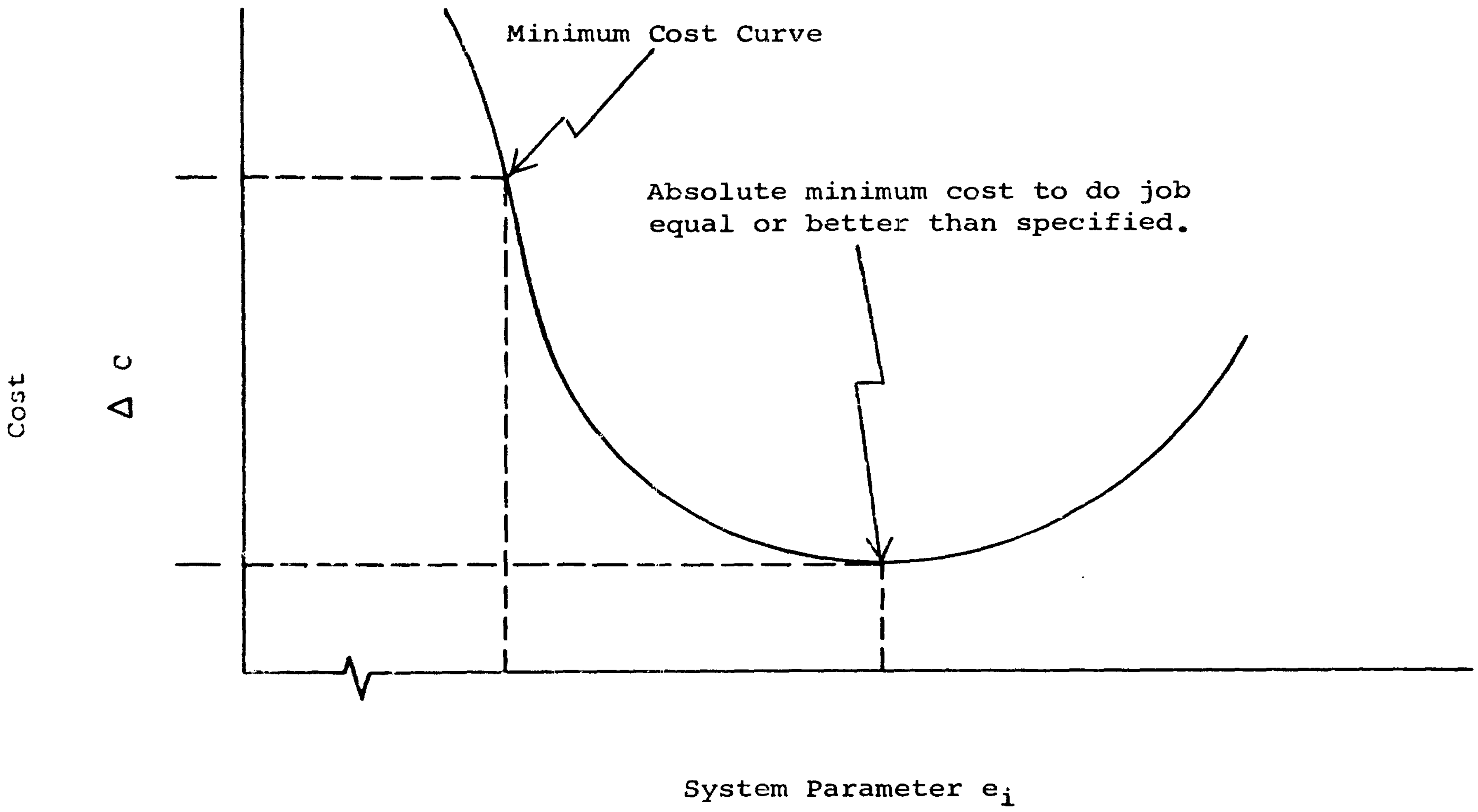


Figure 4-1. Cost Changes

4.2.1.1 Requirements of a General Value Function - Let $\alpha_1, \alpha_2 \ldots, \alpha_n$ be values of parameters describing a design alternative and let V, a function of the parameters, be the value of the design alternative. The function V $(\alpha_1, \alpha_2 \ldots \alpha_n)$ is to be determined which expresses the relative value (or absolute) of the design alternative. An alternate design is described by values of parameters.

It be required that the ratio

$$V(\alpha_1, \alpha_2, \ldots, \alpha_n) / V(\beta_1, \beta_2, \ldots, \beta_n)$$

be independent of the units of measurements. Then V must be of the form

$V = \prod_{i=1}^{n} \alpha_i^{s_i}$ where s_i is a constant and independent of α_i. The s_i is a measure of the significance of α_i. The exponent may be either positive or negative. The values of the exponents may be determined from

$$|s_i| = k_{ij} |s_j|$$

if such a relationship can be established. This yields n-1 equations for determining the n exponents. Given any s_i, and knowing the value of k_{ij}, all others may be determined.

The model above is predicated on the constancy of the relationship between s_i and s_j, e.g., speed is always twice (k=2) as important as cost. Thus this model forces a linear relationship among exponents. Secondly, the model dictates that an increment in the value of a parameter α_i be independent of the weight s_i associated with that parameter.

4.2.1.2 The Probability Distribution Function - One function which satisfies the difficulties of dimensionality is the probability function. The basic requirements are satisfied if

a. The probability density function is

$$p(t) \geq 0 \qquad (4-5)$$

b. and the probability distribution function is

$$\int_{-\infty}^{\infty} p(t)dt=1 \tag{4-6}$$

Note also, that the probability distribution function

$$P(t\geq t_0) = \int_{t_0}^{t=\infty} p(t)dt$$

is, of course, dimensionless.

Thus, the probability function approach does satisfy the dimensionality difficulties. The value engineering structure proposed in the methodology developed in this section is completely compatible with the notion of value as a probability function. The differences arise in that it is assumed that parameter-values have been established from system effectiveness trade-off analysis. This permits treatment of the function in disjointed form presented in section 4.3.

4.3 Cost Analysis

The method of analysis is based on the sequential decision processes, characterized by a logical sequence of events. The events are of three types as follows:

a. Feasible alternatives

b. Chance events

c. Program schedule

The approach is commonly treated in literature as a decision tree.[2]

This sequential decision approach is analogous to dynamic programming, in that alternatives which possess both contingency events and subalternatives are evaluated using a backward evaluation process. This feature permits significant computational reduction which otherwise could render the technique infeasible.

Each sequence in the decision tree may be considered a strategy. And associated with each strategy is a resource cost. The optimum resource cost is found by successively evaluating each alternative in the backward sense. At each common branch point, rolling backward, the more costly alternative is eliminated.

4.3.1 The Decision Tree - The technique to be employed is most easily grasped using the decision tree diagram. This is shown in figure 4-2. The circled (O) entries represent feasible alternatives and the boxed (□) entries represent chance events. Associated with each chance event is an estimated probability of occurrence. Regardless of the specific sequence chosen, each sequence results in a terminal event T_i which, in this case, represents a complete definition of a proposed hardware configuration of the system, complete with the cost (C) of the alternative. The sequential decision tree may be considered the sequence of increasing definition of the hardware design, the branches represent alternate design approaches at successively greater levels of hardware definition.

4.3.2 Evaluation of Design Alternates - The first step in the evaluation process is the establishment of feasibility. Specifically, two types of constraints must be met. These are, from the basic definition of value of section 4.2.

a. $T_i \leq T_o$

T_i= time required to implement the strategy

b. $E \geq E_o$

Here T_i may be established using a PERT project technique and E is established using either the standard prediction techniques (reliability, maintainability, etc.) or a prediction model specifically developed for the specific system parameter.

The second step in the process (having eliminated those alternatives which do not satisfy either or both constraints above) is the estimation of the total resource

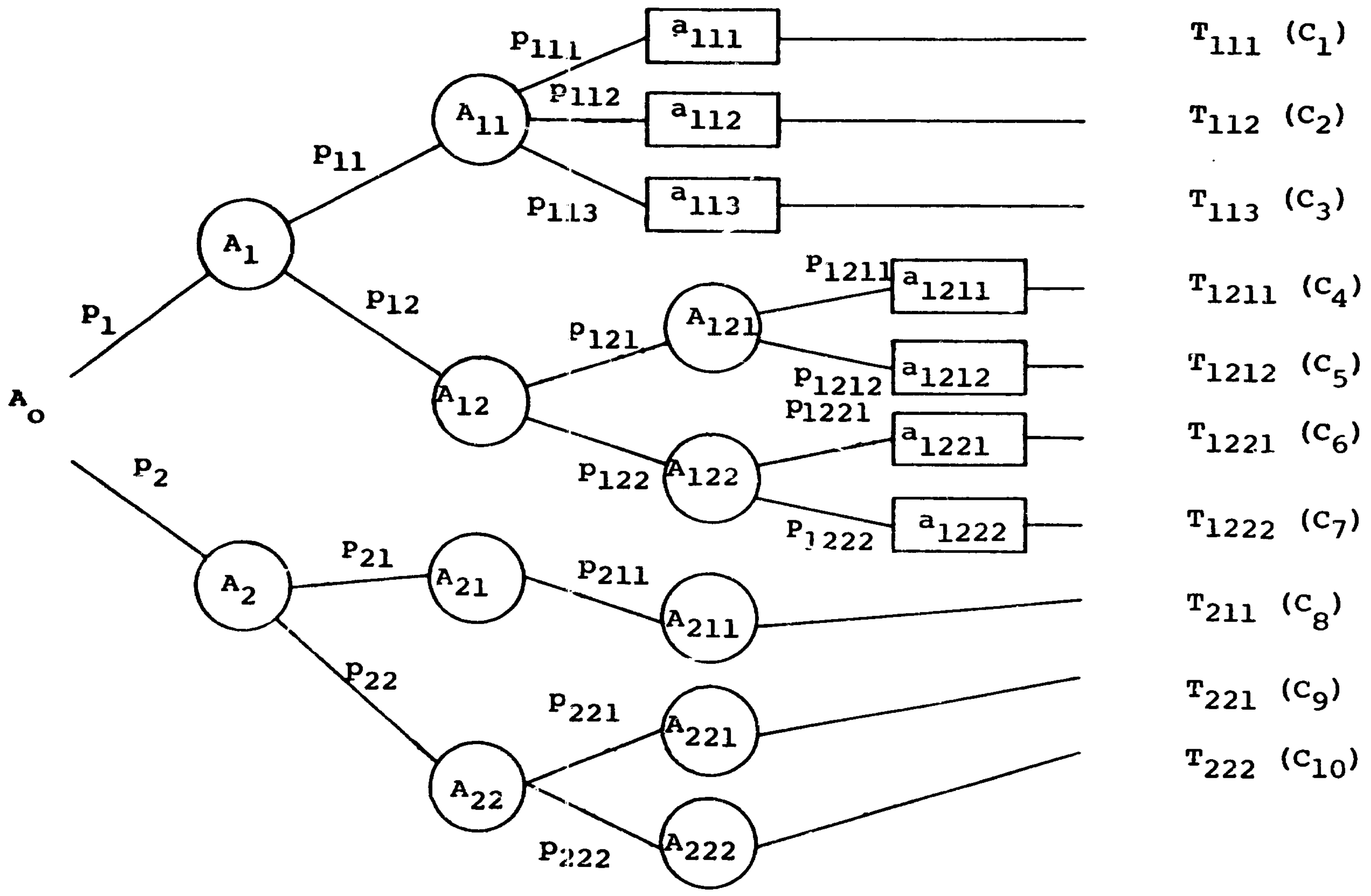


Figure 4-2. The Decision Tree

cost. This may be accomplished using peculiar contractor cost accounting or PERT/COST techniques. Starting from the terminal points having common branch points, the more costly alternatives are eliminated. This procedure is reiterated until only one alternative remains. The degree of accuracy involved in the costing analysis should be guided by the relative magnitude required to demonstrate that one alternative is superior to the other.

4.3.3 Value Analysis in the Continuous Time Domain - Many design alternatives will be relatively simple decisions whereas others may be more complex. The simpler evaluations will generally involve only acquisition cost, there being no essential difference in value parameters, or alternately, only differences in support cost. Another aspect which characterizes these simpler evaluations will be the independence of subsequent decisions involving the system. However, in general, particularly of the more important decisions, the sequential aspect of the decisions will predominate. The question quite naturally arises of the feasibility of being able to completely define a particular configuration during a preceding system conceptual phase. The practical aspects of this question are available time, cost, and information adequacy. Recognizing that as the hardware becomes more defined, decisions involving changes or modifications become relatively less important than the decisions made at a previous stage. Further, only sufficient information to ensure that the best of the feasible alternatives is selected is required, thus information is required only sufficient to ensure dominance of one alternative to another.

4.3.4 Method of Application - It is important to recognize that it is unlikely that equations will ever be developed which extrapolate design value parameters in conjunction with operational value parameters into exact support costs. However, from the viewpoint of value analysis, it is not necessary to possess such comprehensive equations. What is necessary is the ability to evaluate alternatives via cost/performance differences.

The cost methodology aspect of value analysis is of primary significance, since any unrequired sophistication and/or information and documentation may offset advantages offered by the technique.

The proposed approach is advantageous in that it permits individual contractors to use their own cost accounting systems. The only requirement is the ability to differentiate between alternatives as measured by acquisition and support cost.

4.4 Detailed Cost Procedure

The total cost (T) of a system, equipment, etc., can be represented by

$$T=A+S \qquad (4\text{-}7)$$

where

A=the cost of acquisition
S=the cost of operation and support

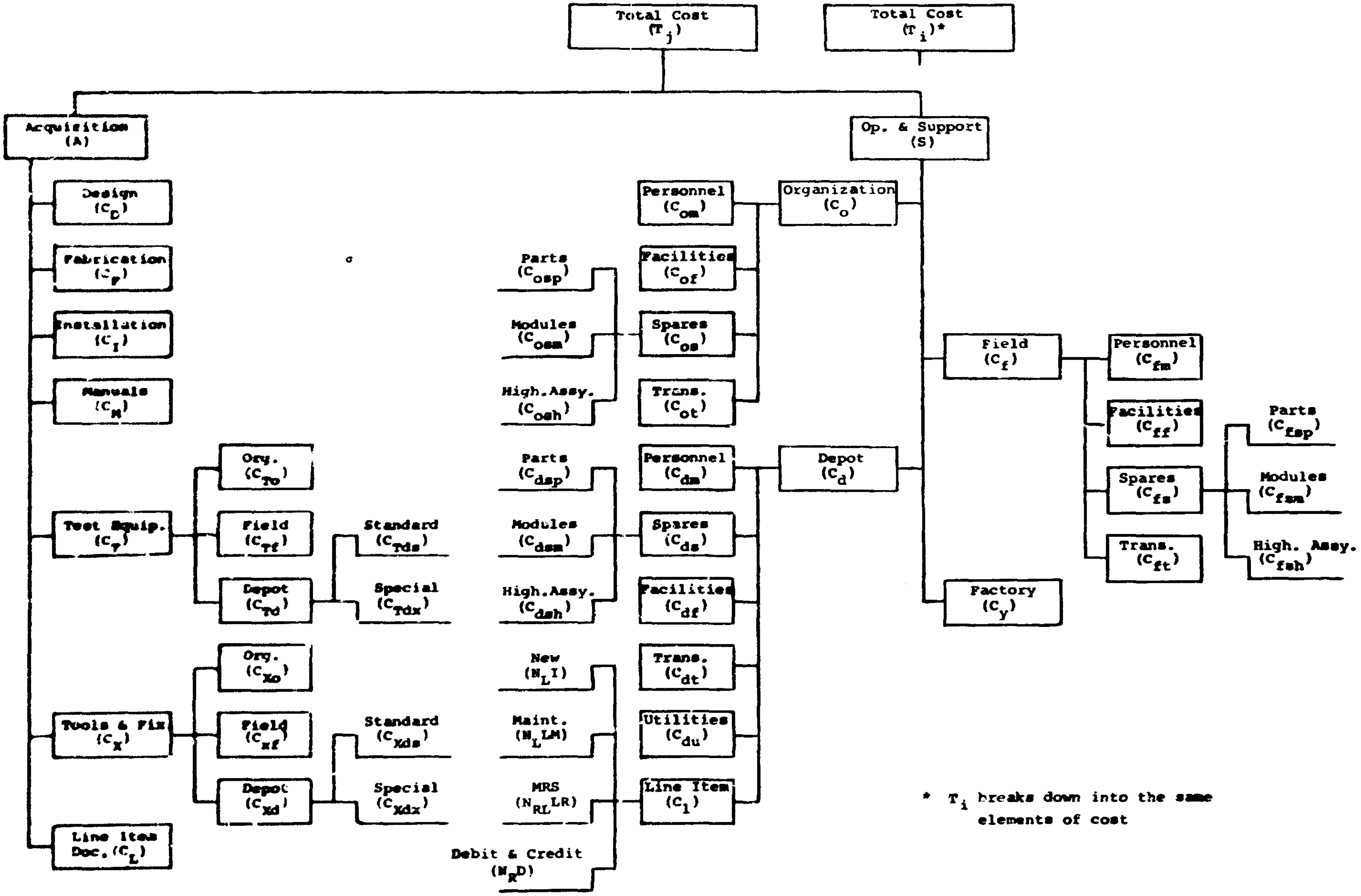
The cost S is based on the expected lifetime cost. Figure 4-3 shows the basic cost model which has to be evaluated. Each element would ordinarily be evaluated to obtain the total cost. For purposes of reaching a decision on whether to accept a particular alternative, differences in total cost are employed. Thus, it is unnecessary to evaluate equivalent elements of the two alternatives when considering which one of two to choose. It is necessary only to evaluate the elements that are pertinent to a particular decision.

Let

T_1=total cost of the first alternative
T_2=total cost of the second alternative

the difference in total cost ($\Delta T_{2,1}$) is represented by

$$\Delta T_{2,1}=T_2-T_1 \qquad (4\text{-}8)$$



* T_i breaks down into the same elements of cost

Figure 4.3. Cost Model

where elements of cost common to the first and second alternatives need not be considered if they are equal. If the quantity $\Delta T_{2,1}$ is negative, it means that the second alternative is less costly. If positive, it means that the first alternative is the correct choice, viz., less costly.

Once two alternatives have been compared, the one yielding the lesser cost advantage is dropped from further consideration. Successive alternatives are devised and matched against the current alternative that has greater cost advantage.

4.4.1 Cost of Acquisition - The elements to be considered include all charges which may arise from the design, development, fabrication, and installation of the equipment.

Particular attention should be paid to items which mark the differences between otherwise similar alternatives. Among these may be:

a. Built-in fault isolation features

b. Special test equipment

c. Special tools

d. Facility of manufacture

Differences in research, development, design, or hardware costs should be considered where they constitute a significant difference among the alternatives. Differences in requirements for government furnished equipment (GFE) should also be established. In any case, refined estimates of costs are justified only when the alternative, or group of alternatives, has cost or other advantages which make it a good candidate for selection.

Cost of acquisition (A) can be represented by:

$$A=C_D+C_F+C_I+C_M+C_T+C_X+C_L \qquad (4\text{-}9)$$

where

C_D=cost of design
C_F=cost of fabrication
C_I=cost of installation
C_M=cost of manuals
C_T=cost of test equipment
C_X=cost of tools and fixtures
C_L=cost of line item documentation

These costs have been tentatively identified in section three and will be considered, and further refined, in phase II of the program.

4.4.2 Cost of Operation and Support - The cost of operation and support (S) is represented by

$$S=C_o+C_f+C_d+C_y \tag{4-10}$$

where

C_o=cost at organization
C_f=cost at field
C_d=cost at depot
C_y=cost at factory

4.4.2.1 Cost at Organization - The cost at organization (C_o) is represented by

$$C_o=C_{cm}+C_{of}+C_{os}+C_{ot} \tag{4-11}$$

where

C_{om}=cost of personnel
C_{of}=cost of facilities
C_{os}=cost of spares
C_{ot}=cost of transportation

4.4.2.2 Cost at Field - The cost at field (C_f) is represented by

$$C_f=C_{fm}+C_{ff}+C_{fs}+C_{ft} \tag{4-12}$$

where

C_{fm} = cost of personnel at field
C_{ff} = cost of facilities at field
C_{fs} = cost of spares at field
C_{ft} = cost of transportation at field

4.4.2.3 Cost at Depot - The cost at depot (C_d) is represented by

$$C_d = C_{dm}+C_{df}+C_{ds}+C_{dt}+C_{du}+C_1 \qquad (4\text{-}13)$$

where

C_{dm} = cost of personnel at depot
C_{df} = cost of facilities at depot
C_{ds} = cost of spares at depot
C_{dt} = cost of transportation at depot
C_{du} = cost of utilities at depot
C_1 = cost of line item at depot

4.4.2.4 Support Cost at Factory - The total cost of factory (C_y) will vary so much with the type of labor to be employed that no attempt will be made to estimate the cost.

Repair at factory is rare; however, special conditions may make it appropriate in some cases. Repairs may be made at the factory rather than at the depot for several reasons. Most instances are accounted for by one of the following:

a. Rare skills and/or expensive special test equipment are required to perform maintenance, e.g., gyroscopes and some other sealed assemblies.

b. Demands for maintenance exceed capacity at depot (as limited, for example, by employment budget) and factory charges are not far in excess of depot costs.

In both of these instances, costs associated with performing the work at the factory generally should be about the same or less than would be incurred if the work were done at the depot. Otherwise, the work should be scheduled for performance at the depot.

In general, factory maintenance is not planned as an integral part of maintenance policy. Requirements for self-sufficiency of the military generally preclude planning on factory or other contractor maintenance of critical equipment. Where it might be planned (as in a above) experience and/or estimates from the probable contractor should provide adequate cost figures for use in comparisons. Detail costing becomes less important in fixed price contracts, favored type today, as contrasted to cost plus fixed fee and similar types common in the past. Consequently, no detail breakdown will be made for estimating costs of factory maintenance in the few situations where it is applicable.

4.4.3 General Evaluation Procedure - Figure 4-4 illustrates a tabular procedure for evaluating each element of the cost model. Provision is made, in figure 4-4, for the evaluation of two alternatives. Only the elements that change, from one alternative to the other, will be required. Once two alternatives have been evaluated, the one yielding a cost advantage is retained, and the other alternative is no longer considered.

TABLE ( )
COST DECISION ELEMENTS

		Step ( )										
Cost Element (C)	Subscript			A( )					A( )			
Design	D											
Fabrication	F											
Installation	I											
Manuals	M											
Test Equipment	T											
Tools and Fixtures	X											
Line Item Documentation	L											
				S( )					S( )			
Organization	o											
Personnel	om											
Facilities	of											
Spares	os											
Transportation	ot											
Field	f											
Personnel	fm											
Facilities	ff											
Spares	fs											
Transportation	ft											
Depot	d											
Personnel	dm											
Facilities	df											
Spares	ds											
Transportation	dt											
Utilities	du											
Line Item	l											
Factory	y											
Total Cost	T											
Cost Difference	ΔT											

Figure 4-4.

5. SUMMARY

The proposed value analysis technique developed in sections 3 and 4 has been shown to possess the following characteristics:

a. Quantification of value consistent with established USAF specification of system utilization.

b. Value parameters which are predictable and measurable.

c. Systematic method of quantitative analysis which permit practical optimization in the least cost sense consistent with system value.

d. Technique structure which permits design tradeoff of discrete alternatives relating to cost and system value parameters.

e. Method of cost analysis which permits optimization with respect to total cost and is consistent with both design and operational value parameters.

f. Method of cost analysis based on difference principles which permits decisions through dominance of one alternative to another.

g. General method of analysis which permits cost in time and singling out areas significant cost differences between alternatives.

6. PLAN FOR PHASE II

6.1 General

The structure of value as developed in section 4 indicates the most fruitful areas of exploitation of the methodology. This comes about primarily as a result of the strict causal relations between system value and the total expected cost differences. Consequently, the major direction to be taken in the Phase II will be a general refinement and expansion of the value analysis methodology. (See figure 6-1)

6.2 Structure

The areas of refinement and expansion will be as follows:

a. Detailed breakout for acquisition cost specifically related to conceptual and definition phases.

b. Detailed breakout for support cost specifically related to conceptual and definition phases.

c. Expansion and refinement of technique to handle chance events. Some work has already been done in this area but involves making estimate of probability.

d. Development of causal relations between value parameters, system utilization rates, and total cost differences.

e. Development of detailed information requirements to be supplied by the USAF for support cost analysis. This would include a delineation of deployment and self-sufficiency constraints.

6.3 Validation

RCA proposes to validate the value technique developed under Phase I of the contract in the following manner.

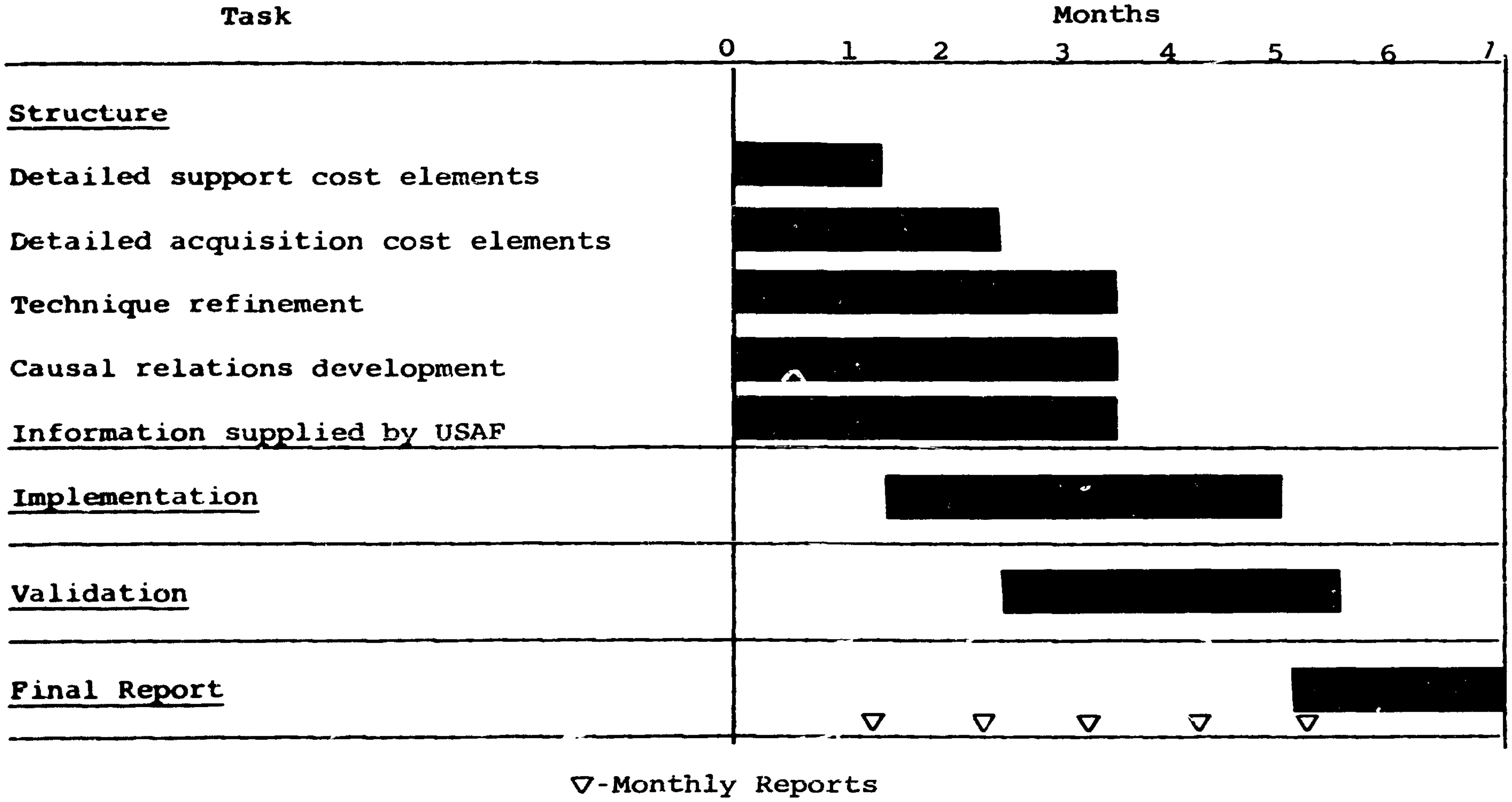


Figure 6-1. Development Schedule

6.3.1 Establishment of Errors - Establishment of error sources, anticipated error magnitude, and error bounds on the following aspects of the technique.

a. Capability of projecting design alternatives accurately into the support cost differences.

b. Capability of controlling acquisition cost.

c. Capability of forming a near minimum cost initial proposal.

d. Capability of performing within schedule constraints.

e. Capability of singling out tradeoffs between design, manufacturing and support costs.

6.3.2 Mode of Application - RCA proposes to use at least the following examples to illustrate the mode of application of the techniques.

a. Production Design Phase - Selection of wire wrapping process for MINUTEMAN.

b. Program Definition Phase - Selection of real time computer redundancy configuration for complex mobile missile system.

c. Proposal Phase - Several examples of cost minimization in a competitive environment, incorporating cost control check points in sequential phases, and involving tradeoffs between engineering and manufacturing.

6.3.3 Discussion - Although the validation above will not constitute a substitute for several test vehicles followed through the entire life cycle, it will establish feasibility of implementation. The proposed approach to validation is due to lack of information on previously designed systems; plus, the inability to project the requirements for testing and field use for systems that are presently in the design stage.

Approaching the validation in the manner proposed will test the technique for selective application across product lines along with decision making capability as related to program phasing.

6.3.4 Critical Points - The critical points of the validation will include the following:

a. Information availability and adequacy relative to

   1. Design value parameter

   2. Operational value parameter

   This will provide a critique of information adequacy as a function of the conceptual phases considered.

b. Computational problems in technique application.

c. Ability to project cost differences in both acquisition and support as a function of alternatives. This will permit:

   1. Testing for the principle of dominance among alternatives.

   2. Singling out sources of error in cost estimation.

d. The quantitative predictability and measurability of the system value parameter will be evaluated.

6.4 Implementation

The scheduled validation of the developed value analysis methodology will constitute a practical test of the implementability of the technique. The proposed technique is prima facie implementable from the basic structure, given the basic information required for decision making. Anticipated difficulties will invariably pivot about information availability and associated uncertainty.

The key to successful application of the technique will rest on the detection of potential cost affected areas coupled with the ability to eliminate, systematically, the more expensive alternatives. The proposed structure permits the latter. The first point will be satisfied, in the second phase of the program, by providing detailed cost element breakouts and cost projection techniques.

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APPENDIX

LITERATURE SEARCH

1. INTRODUCTION

The bibliography included is a selective one representing the present state-of-the-art in value engineering. During the literature search over 100 documents were examined; of these, the seventeen documents, included in the bibliography, were considered to represent the thinking currently in vogue with value engineers and represent the state-of-the-art.

2. SHORTCOMINGS OF STATE-OF-THE-ART

Several shortcomings permeates essentially all literature reviewed. These are:

a. Value/Job Definition: Generally value is defined loosely as getting the job done at least cost; however, invariably there is only a loose tie with how the job, as described, relates to the value of the end product, viz., accomplishment of mission.

b. Support cost and extrapolations to support cost is, at best, given only lip service. There has been no real attempt to evaluate, systematically, total resource cost variation as a function of design/development alternative selection.

c. Most examples of cost reduction result in increased performance, i.e., beyond requirements. This implies misdirection from the existing definition of value as well as value analysis. The difficulty arises from the tacit assumption that achievement of a quantitatively specified objective at minimum cost results in the absolute minimum cost. Figure 4-1, in the text, illustrates this.

d. Value engineering techniques, as they exist now, are exclusively oriented to acquisition or operation phases rather than the conceptual or definition phases.

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(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Radio Corporation of America RCA Service Company Division Alexandria, Va. 22314	2a. REPORT SECURITY CLASSIFICATION UNCL 2b GROUP

3. REPORT TITLE

Criteria for Value Engineering, Phase I, Feasibility Study

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Interim Report Jul 1965-Nov 1966

5. AUTHOR(S) (Last name, first name, initial)

Purvis, R. E.

McLaughlin, R. L.

6. REPORT DATE February 1966	7a. TOTAL NO. OF PAGES 39	7b. NO. OF REFS None
8a. CONTRACT OR GRANT NO. AF30(602)-3850 b. PROJECT NO. 5519 c. Task Nr. 551901 d.	9a. ORIGINATOR'S REPORT NUMBER(S) 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) RADC-TR-65-475	

10. AVAILABILITY/LIMITATION NOTICES

Distribution of this document is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Reliability Branch Engineering Division Rome Air Development Center, GAFB, N. Y.

13. ABSTRACT

This report summarizes the state-of-the-art of Value Engineering. A proposed structure for a general value analysis technique along with quantification of value is presented. Based on the proposed structure a general method for resource cost optimization is developed.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
System/Equipment Design Cost/Effectiveness Performance Operations Research Value						

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