COST AND OPERATIONAL EFFECTIVENESS ANALYSIS

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Abstract

The paper discusses Cost and Operational Effectiveness Analysis (COEA) in the context of a military study system. The objectives of a study system, development of study programs, and management of studies are addressed. Basic cost-effectiveness models are presented and the COEA planning steps, analytical processes, and implementation discussed.

INTRODUCTION

The forces of time acting on the Republic of Korea today require the application of a substantial portion of the human and economic resources of the country to the task of building up defenses.

These resources, acquired by previous decades of hard work and sacrifices to build the nation's educational and economic base, must be allocated wisely, on the basis of maximum reduction of the military threat for the expenditure of the available resources.

Cost and Operational Effectiveness Analysis (COEA) is a tool that can help us with this task. COEA can be defined as a documented study of the comparative effectiveness of alternative means of meeting a requirement for eliminating or reducing a force on mission deficiency against a threat, and the cost of acquiring and sustaining each alternative system in military environment preceeding its combat application.[1] The related term "Cost and Training Effectiveness Analysis" (CTEA) has recently been adopted by the U.S. Army for similar studies of training and training systems alternatives, and is frequently conducted in support of a weapon system's COEA, to assess the cost effectiveness of its training sub-system.[1]

The term "study" can be defined as "a critical examination or investigation of a subject, often requiring sophisticated analytical techniques to integrate a variety of factors, leading to conclusions or recommendations making substantive contributions to planning, programming, and decisionmaking"[2]. Cost effectiveness studies usually do not generate primary data, but are designed to organize and evaluate information inferred or extrapolated from data generated by other means, such as research studies; development, operational, and user tests;historical

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1) This is essentially the definition in U.S. Army Regualtion 71—9, *Materiel Objectives and Requirements*, 7 Feb 1975.

effectiveness, logistics, and cost records; intelligence efforts; economic analyses; surveys etc.— for the purpose of providing a greater understanding of relevant alternatives for meeting a requirement.

Although COEA's are especially well suited, and most commonly used, for comparison of materiel systems, they can also be used to determine the effectiveness and cost of organizattions with differing manpower and equipment allocations, and even operational concepts and tactics, such as the use of camouflage and other passive defense measures, or various logistics concepts.

To be an effective tool for decisionmaking the COEA must present pertinent and timely information,. in a format that is readily understandable and useful to the decision maker.

It follows that the COEA for a system must be an integral, properly planned and programmed, part of the life cycle management effort of a system. The analysis must be closely coordinated with development and user tests to assure availability of effectiveness and logistics data. As additional or better data become available, the COEA must be updated, on a schedule that makes the new version available in time for major resource allocation decision points. Further, the effort put into the COEA should be in proper proportion to the costs and risks associated with the decisions that have to be made on the basis of its results.

To meet these objectives, COEA's should be:

1. Planned, programmed, and budgeted within a comprehensive study system that provides for the optimum use of all the available study resources for all needed studies.
2. Adequately managed during their conduct.
3. Executed in a systematic fashion, in accordance with sound analytical principles, preferably using a standardized COA methodology.

Let us address each of these three topics in greater detail.

THE STUDY SYSTEM

Conduct of studies that fall into one general category is usually accomplished by the same pool of scarce and costly analytical resources, such as professional manpower or automated data processing facilities. It is therefore prudent to establish a system, by appropriate directives, regulations, and manuals, to assure the optimum use of these resources.

The objectives of such a system should be to:

—Insure that study efforts serve to conserve resources and make substantive contributions to planning, programming, and decision making process.

—Insure that each study effort is properly initiated, validated, and developed, and that results of the study are applied.

—Insure high-level visibility and adequate coordination of study efforts.

—Provide for dissemination of study results and information on the study program.

The documents establishing the study system should prescribe the requirements, procedures, and the responsibilities for planning, programming, budgeting, initiating, conducting, and reporting of studies; as well as applying of study results.

THE STUDY PROGRAM

Such a study system can be implemented by yearly study programs.

The programs are developed by submission of study proposals from subordinate commands and agencies (which thus become study sponsors), to the reviewing and approving command. The proposal should include justification, proposed schedule, estimated requirements for professional man-years and funds for completion, proposed study agency, e.g. the sponsoring command, a contractor, an ad hoc group, or a military study organization; and whatever other information the approving authority may deem necessary.

Such proposals, when approved and consolidated, constitute a study program that can be used as an authorization document for budgeting and other study resource allocations, and to provide input to the overall defense Planning, Programming, Budgeting System (PPBS).

STUDY MANAGEMENT

In addition to the management functions provided by the study programming process, specific management of each individual study is required in each phase of the study to assure that objectives are met.

STUDY PHASES

The life of a study is characterized by four phases: (1) initiation, (2) validation, (3) development and conduct, and (4) application.

To initiate the study, the sponsor must, prior to the submission of the study proposal to the authorizing command: (1) establish the need for the study; (2) define the problem; (3) determine the scope and a reasonable number of valid objectives for the study; and, (4) identify the users of study results, and determine when the results are needed.

To accomplish this, and to avoid duplication of previously conducted studies, it is essential to conduct an initial literature search and review of all available reference materials that contribute to the understanding of the problem.

In the validation phase, the validity of the proposed study is confirmed by making the proposal known to all interested agencies, soliciting their comments, and coordinating and changing, as necessary, the requirements for the study.

The development and conduct phase begins when the study group, formed by the study agency, actually starts work, and ends when the study advisory group (SAG) or study manager recommends approval of the final report.

The application phase consists of: (1) communicating the results to all affected agencies; (2) disseminating the results and lessons learned within the sponsoring organization; (3) making policy or program decisions, or recommendations to the decisionmaking authority; and (4) implementing the decisions by taking appropriate action.

THE STUDY DIRECTIVE

Study directive is the document that establishes the requirements and parameters for a study and also provides the guidelines for its management.

The study directive, although published by the command that exercises the authority for approving the study program, should usually be drafted by, or in coordination with, the agency that will conduct the study.

The directive is a management tool that describes the problem, states the objectives, and provides terms of reference; such as scope, limits, assumptions, essential elements of analysis (EEA), constraints, alternatives to be evaluated, measures of effectivess(MOE), methodology, models, and other applicable parameters.

In addition, the directive names the study sponsor and agency, outlines the support and resource requirements, e.g. the list of organizations tasked to contribute and the estimate of professional man-years required to conduct the study, and provides administrative instructions.

The administration paragraph provides the study schedule, action documents that must be produced by the study (e.g. policy directives, basis of issue plans (BOIP), or manpower authorization tables), security classification guidance, distribution of the study report, and control procedures.

Control procedures provide for the management mechanism for conduct of the study, such as a study manager, a steering committee, or a Study Advisory Group (SAG).

The Study Advisory Group, if used, is formed by the study sponsor, by appointing a chairman and deputy chairman, and inviting knowledgeable individuals from concerned agencies to provide either voting or observer members. Its function is to insure that the study remains oriented to the problem and to the established requirements, to review the progress of the study, to provide advice to the study sponsor and technical guidance for the conduct of study to the study group, and to coordinate between all concerned agencies.[1]

THE CONDUCT OF THE COEA

BASIC COST-EFFECTIVENESS MODELS

Establishing a relationship between various levels of operational effectiveness and costs associated with these is the essence of the COEA.

This relationship is established by integrating effectiveness and cost data, following normally one of the following three primary cost-effectiveness models:

(1) Fixed effectiveness, variable cost. In this case the same effectiveness level must be met by each system under study. The system with the lowest cost is, therefore, the most cost-effective.

(2) Fixed cost, variable effectiveness. In this model the cost is held same for the systems under study, and the most cost-effective is the one with the highest level of effectiveness.

(3) Variable costs, variable effectiveness. In this case comparisons are made between competing systems that vary in both cost and effectiveness. The most cost-effective system is determined on the basis of the best effectiveness to cost ratio, the highest return on invest-

1) For a detailed description of the functions of SAG see U.S. Army Pamphlet 5—5, *Guidance for Study Sponsors and Study Advisory Group*, (1976).

ment over time, or simply on judgemental assessments of the worth of the increase in benefits gained by increments of additional cost.

Integration of cost and effectiveness data is easiest accomplished by the first two models, where one variable is held constant. As a matter of fact, the use of these was prescribed by the early pioneers of cost-effectiveness analysis.[1]

Today, however, it is generally recognized that real-world feasible condidates for meeting real-world military mission requirements in differing ways, may also differ in effectiveness and resource requirements; especially when the total effectiveness measure is an aggregate of a large number of performance-oriented lower-level measures of effectiveness, or all resource requirements are not expressible in terms of money.

PERFORMANCE VERSUS EFFECTIVENESS

Although effectiveness and performance may be closely related, higher performance does by no means always result in greater effectiveness, and a distinction should therefore be made. The term "operational effectiveness", as applied to a weapon system, usually refers to the impact of the system on the outcome of a battle, whereas "performance" generally refers to the degree of accomplishment of a particular task or execution of a particular maneuver by the system.

An example, from pre-Vietnam days, of inverse effectiveness and performance relationship in a weapon system, is the assignment of close air support role to high-performance jet fighter-bombers by the U.S. Air Force. During the Vietnam war these aircraft, because of their great speed, were found unsuitable for delivering ordnance close to the ground troops they were attempting to support, and World War II vintage prop-driven fighter and tra ining aircraft had to be brought out of mothballs. The high-performance jets were later foundable to assist with the job—when guided by another pilot flying low and slow in a 180 horsepower light obsever aircraft.

STUDY PLAN

The study plan is the key document for the entire COEA process.

The study plan is based on the study directive. It elaborates on the topics covered in the directive, and provides the outline of technical and administrative procedures,a detailed study methodology, time schedule, and resource requirements.

If changes are required to the plan during the conduct of the study, they should be documented and approved by the command that issued the study directive. The thought and effort put into preparation of the study plan contributes directly to the study effort, and its quality is generally reflected in the study results.

Both the directive and the plan are designed to assure that the COEA is conducted in an orderly, systematic, and, preferably, standard fashion.

A flow diagram of the COEA process is shown in figure 1. Each step is discussed in detail in separate paragraphs below.

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1) Gene H. Fisher, *Cost Considerations in Systems Analysis*, New York: American Elsevier Publishing Company, Inc., 1973, p. 10.

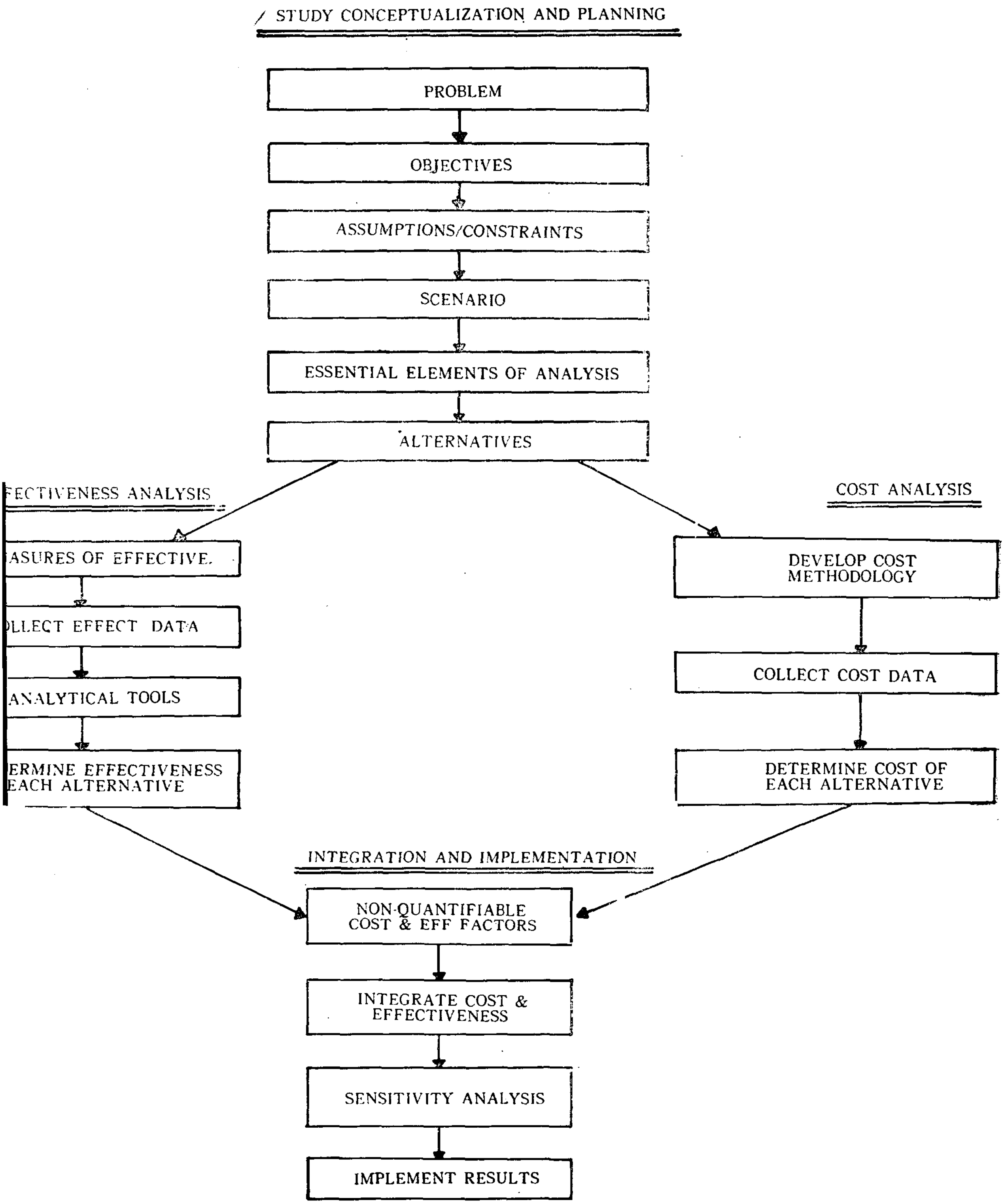

Figure 1. The COEA Process

STUDY CONCEPTUALIZATION AND PLANNING

The study conceptualization and planning phase consist of the analysis and activities required to: (1) define the problem, (2) develop assumptions, (3) develop constraints, (4) de termine the operational environment and scenario for the system alternatives under study, (5) develop essential elements of analysis (EEA), and (6) determine the alternatives that can be applied to solve the problem.

Statement of the Problem and Objectives

A clear, concise statement of the problem must be made. The problem that prompted the study is usually generated by the inability to reduce or eliminate a threat as effectively and economically as may be possible by the use of some materiel, organizational, or tactical system. A problem statement based on this deficiency is contained in the study directive. This statement should either be confirmed, further clarified, or amended in the study plan. The problem statement is the basis for developing and stating the objectives for the study.

Assumptions

Assumptions can be defined as unproved considerations accepted as facts for the purpose of providing, together with facts, a logical basis for the study. Many aspects of the threat can frequently only be assumed. Other examples of areas that may have to be covered by assumptions are timely availability of resources and components, methods of employment, or the strategic situation that forms the background for the requirements for the system. Assumptions must be stated clearly and explicitly, to assure that study results are not misapplied when assumptions on which results depend are subsequently found to be invalid.

Constraints

Constraints that affect the alternatives under study must be identified and considered during the study effort.

Constraints may be imposed by: scarcity of economic, material, or manpower resources; the state of the art of technology; data base; time; or regulatory, legal, and political factors.

Identifications of constraints helps to achieve valid study results and also simplifies the study by making possible an early elimination of alternatives that cannot cope with the constraints.

Environment/Scenario

This step provides the environmental context and scenario,including the threat, deployment and tactics of the opposing forces, and, based on these, the mission profiles for evaluating the alternatives. The scenario must be based on all relevant intelligence information and expert military judgement. It should therefore be provided or approved by the highest echelons of the military command.

Essential Elements of Analysis (EEA)

The EEA are questions, or sub-problems that must be answered to meet the study objectives. The inclusion of EEA assures an in-depth treatment of the problem and provides evaluations of the critical issues. As the study progresses and the analysts gain greater understanding ofthe issues, the EEA listing may need to be updated. The primary EEA may suggest secondary EEA that must be answered first. An EEA network diagram may be useful to determine sequential relationships between EEA.

Alternatives

All systems which are being applied or can be applied to solve the problem should initially be considered as alternatives. The primary system currently in operation is the alternative that usually serves as the base case. From the list of all possible alternatives a list of feasible alternatives is culled for detailed analysis, by applying the previously stated assumptions and constraints.

OPERATIONAL EFFECTIVENESS ANALYSIS

Operational effectiveness phase is normally conducted in parallel and in close coordination with cost analysis.

To analyze operational effectiveness, or anything else for that matter, requires judgement based on an in-depth understanding of the system under study. E.S. Quade, the well know Rand Corporation analyst, states:

"The point is that every quantitative analysis, no matter how innocuous it appears, eventually passes into an area where pure analysis fails, and subjective judgement enters. This is important; in making these choices the real decisions may be being made. In other words, judgment and intuition permeate every aspect of analysis: in limiting its extent; in deciding what hypotheses and approaches are likely to be more fruitful; in determining what the "facts" are and what numerical values to use, and in finding the logical sequence of steps from assumption to conclusions."[3]

In the conduct of effectiveness analyses judgement is crucial in the choice of quantitative measures and the relative importance assigned to each of these, as well as in the other steps in the analytical process. In fact, it may not even be possible to quantify all the aspects of operational effectiveness. It is therefore essential that the study group's effectiveness analysis team include members with expertise on operational employment and effectiveness measurement of the system under study, rather than merely analysts whose expertise is restricted to application of quantitative analytical techniques and tools.

The operational effectiveness phase of the analysis consists of: (1) selection of measures of effectiveness (MOE), (2) determining data requirements and sources, and collecting data, (3) selection of analytical tools, techniques, and methodology, and (4) performance of the analysis, ranking the alternatives on the basis of an overall effectiveness index, or selected individual measures of effectiveness.

Selection of MOE

A measure of effectiveness is a quantitative indicator of the ability of a system to accomplish the task for which it was designed. Because COEA's are concerned with operational effectiveness, the MOE's for military equipments should indicate their impact on the outcome of the battle.

It follows that the selection of MOE's should be done on the basis of military judgement, by the people who are well qualified to assess the employment of the system under study in military operations. To facilitate analysis, each MOE should be related to one or morespecific EEA.

Various definitions of effectiveness have been proposed. One of the more general, used by the US Army Training and Doctrine Command, views battlefield effectiveness as a function of the capability of the material, the proficiency of the soldier, and tactic or technique of employment [4]. A more useful model for analytical purposes was developed by the Weapon System Effectiveness Industry Advisory Committee (WSEIAC), created by the US Air Force in 1964. WSEIAC defined systems effectiveness as "a measure of the extent to which a system may be expected to achieve a set of specific mission requirements", and considered this to be a function of three primary components: availability, dependability, and capability, which are, in turn, functions of various performance characteristics, such as survivability, probability of kill etc [5].

A good discussion of effectiveness methodologies is contained in the KIST/KAIS publication, Cost-Effectiveness Analysis Methodology for Weapons Systems[6].

Data Requirements and Collection

Although literature search and data collection should start even before the study is officially initiated, the main data collection effort takes place when the MOE are reviewed and analyzed to determine data requirements for developing quantitative measures of effectiveness.

A listing of requirements can be expanded into a data collection plan by adding a list of data sources and the collection schedule and method. The identified data elements should be organized in terms of MOE and EEA.

Primary data may be generated by: (1) the scenario, which provides the organization and tactics for accomplishing the mission of the system under study, and expected utilization, logistics, and attrition factors; (2) combat data, provided these data are applicable or can be made applicable by extrapolation or inference to the current scenario; (3) field tests and experiments, conducted under as realistic combat conditions as possible; (4) laboratory type tests and experiments; and (5) historical effectiveness, logistics, and cost data on resembling systems.

Most data sources are identified during the initial literature search. In addition to data in document repositories, data are usually also available from specialized agencies, such as the comptroller for cost data; supply and maintenance facilities for logistics data; intelligence agencies; materiel development, analysis, and testing agencies; industrial organizations; and foreign governmental and private agencies.

Adequate data base is the key to the conduct of a successful analysis. For new systems it is therefore essential that testing, both engineering development and operational, is closely coordinated with the conduct of the COEA, to assure that tests are designed to generate the needed data.

Selection of Analytical Tools, Techniques, and Methodology

A fundamental step in any analysis is the creation of a detailed description of the processes of the system being analyzed. Such a description, or model, as it is most commonly referred to in operations research, can be used to predict the consequences of the variations we choose to make in the processes, and thereby help us to identify the system whose processes produce the best results.

A model may be defined as "a representation of certain characteristics of a well defined system by implicitly or explicitly denoting their interrelations"[7].

Models can be classified in many ways; according to their purpose, complexity, field of application, computer or manual, static or dynamic, qualitative or quantitative etc.

A generally accepted classification scheme puts them in three general categories: iconic, analog, and symbolic.

Iconic models use pictorial or visual representation of a system. Although they tend to closely resemble the actual system, they seldom reveal complex relationships among its components. Maps can be considered iconic models of the surface of the earth. Model aircraft used in wind tunnel testing are another example of highly precise, small-scale iconic models.

Analog models represent the actual system by some functionally corresponding properties. Examples are flow diagrams, graphical models, diagrams, and simulations. All of these can be highly useful for effectiveness analysis.

Symbolic models use mathe matical symbols to show the relationships among the components or properties of a system. They fall into two basic sub-categories: deterministic and stochastic (or probablistic). The main characteristic of deterministic models is that all of the variables used in the model are assumed to have exact relationships. This does not rule out the use of parameters that have probability distributions, but in that case the statistical distribution is not considered. Deterministic models can range from chemical formulas to equations developed or derived from logic or various data.

Stochastic models are used when uncertainty is present. Input data is generally obtained from one or more distributions. Similarly, these models yield probabilistic and statistical solutions related to the assumed forms of the distributions, and solutions are probabilistic or statistical, related to the assumed forms of the distributions. If only the expected value of the result is provided, the model is generally referred to as "expected-value" model, and if distributions are obtained by drawing random samples of other distributions associated with the operations being analyzed, the model is ferequently called a "Monte Carlo" simulation.

Quantification is easiest accomplished by mathematical models. Analysts trained in quantitative sciences tend, therefore, favor the exclusive use of such models. This can lead to totally misleading results when applied to military effectiveness analyses. There are problems in weapons performance analyses that can be solved by purely quantitative methods, but the vast majority of problems dealing with battlefield effectiveness of complex man-machine systems do not fall in that category.

The selection of analytical tools should therfore be made by operations research analysts and military subject matter experts working together.

The analytical tools that furnish the most realistic results are unfortunately also the most demanding of resources and time. The relationships between quality of information and realism, and resource and time requirements are depicted in figure 2.

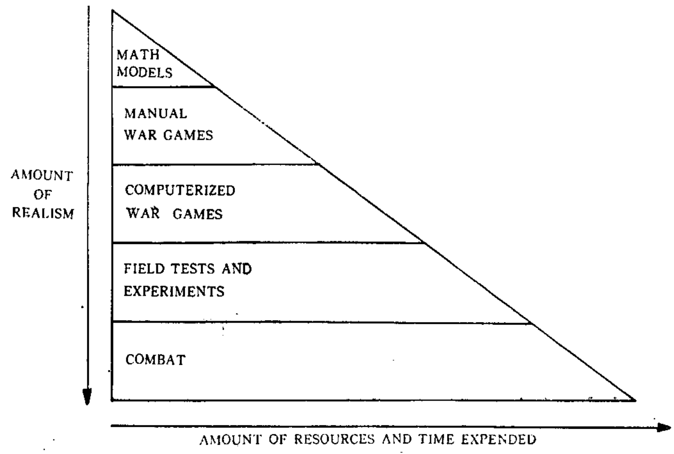

Figure 2. Analytical tools.

Although the use of empirical combat data can yield by far the most realistic results, the problem is that in peacetime these results pertain to some past war. Introduction of new tactical and organizational concepts and weapons systems has changed in the past, and can be expected to change in the future, the results of battles between otherwise similar forces. Best data for new materiel systems and organizational and tactical concepts can undoubtedly be obtained in peacetime by field testing and experimentation, under as realistic combat conditions as possible. However, the high cost of fighting mock battles in the field with real people and equipment is making increasingly popular the fighting of mock battles on terrain boards or maps, assisted by computers for rapid computation of assumed attrition rates and expenditures of materiel.

Such wargaming, when done with attrition/exchange, weapons effectiveness, and logistics data that have been validated in the field, can be a useful analytical tool. When done with unproven, assumed data, however, it would be a serious mistake to expect the results of the game to yield anything more useful than the attrition/exchange, weapons effectiveness, and logistics factors originally built into it. The most important point to keep in mind throughout such analysis is that the factors that have historically proved to be dominant and decisive on the field of battle, such as operational readiness of military units acquired through training, amorale, espirit de corps, leadership, ability to achieve surprise etc., are not readily quantifiable or predictable, and are therefore generally not used in analytical war games. This lack tends to yield results that consistently overestimate the effect of force ratios and the certainty of battle outcomes. Relationships between historical win-loss and exchange ratios are graphically shown on figures 3 and 4.

No one has yet been able to design a war game that would be capable of predicting the possibility of success for a naval attack by a fleet of 12 ships against 365, as was done by Admiral Yi Sun Shin; or the achievement of a 15-1 favorable kill ratio by the military fo rces of a tiny nation against the might of one of the largest and militarily strongest countries in the world, as the Finns managed against the Soviet Union.

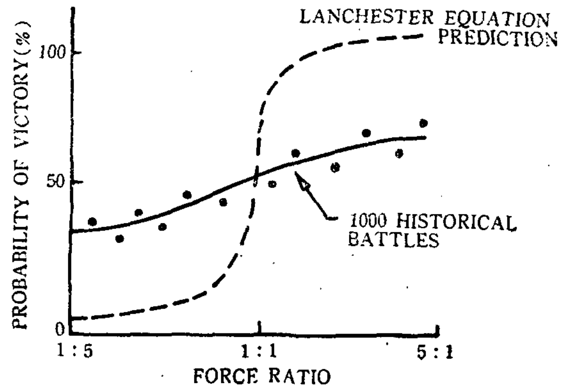

Figure 3. Historical and theoretical win-loss probabilities
Source: D. Willard, Research Analysis Corporation, Technical Paper No. 74, Nov. 1972.

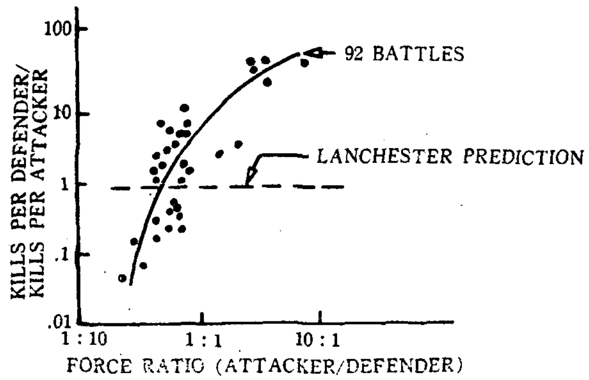

Figure 4. Historical and theoretical exchange ratios
Source: *Robert L. Helmbold, paper presented at the NATO Conference on Recent* ~evelopments in Lanchester Theory, July 3—7, 1967.

In summary, to the extent that analytical models fail to account for essential factors of the real world, the results provided by the use of these models may not be applicable for measurement of effectiveness of weapons in battle. Such results must therefore be properly interpreted and understood, to assure that invalid conclusions are not drawn.

Ranking of the Alternatives

After the available data has been developed into MOE by the analytical tools selected for that purpose, it is necessary to interpret and evaluate, and integrate, if possible, this information on the various quantities of effectiveness. Such interpretation and evaluation includes determination of the signficance of differences between effectiveness of alternatives under study by statistical means and by judgemental evaluations. Integration of the several MOE into a smaller number, or into one single index of effectiveness requires nearly always judgemental weighing and evaluation of the individual MOE, and should be, therefore, undertaken with the advise of the best available military subject matter experts.

The alternatives under study are then ranked in accordance with the properly interpreted and evaluated measures of effectiveness or effectiveness indices. It should be clearly understood at this point that such ranking does not reflect the relative worth of each alternative, which can be determined only in conjunction with costs, but merely reflects their relative effectiveness under the conditions specified by our study scenario, assumptions, limits, and constraints.

COST ANALYSIS

Cost analysis should be conducted simultaneously with effectiveness analysis. All relevant costs cannot be estimated until concepts of organization and operation have been defined. There should, therefore, be a continuous interchange of information between cost and effectiveness analysts.

The costs considered for comparison of alternate systems should include, to the maximum extent possible, all future expenditures of resources which are altered by the decision to acquire and operate the system.

The cost estimate should clearly identify elements which represent inherited assets and sunk costs. Since sunk costs no longer represent viable alternatives, and costs common to all alternatives are irrevelant for decision making, these costs should not be used for comparison. However, because future costs must be understood in the context of the total cost, the entire life cycle costs should be initially determined.

Total life cycle costs for material systems consist of acquisition costs and ownership costs. The life cycle cost model used by the US Army for materiel -systems is shown in figure 5, and the matrix for presentation of life cycle cost elements in figure 6 [8].

The total cost for materiel systems is usually expressed only by money expenditures and other costs that can be evaluated in terms of money, e.g. value placed on alternative uses of facilities or common expendable items withdrawn from accumulated stocks. However, whenever appropriate, incommensurable expenditures and resource requirements should be considered.

Incommensurables can be defined as those factors which cannot be measured in terms common to other factors. Casualties, for example, cannot be readily measured in terms of money but can be measured in terms of fatalities or type and extent of injury, and may have a major impact on decision making. Other, not readily quantifiable incommensurables, such as requirements for management information or political and public relations factors, may nevertheless be important for choosing among alternatives, and should at least be listed and desribed for considerattion by the decisionmaker.

Depending on the nature of an incommensurable factor, it de addressed by ether the effectiveness or cost portion of the analysis, or only at the cost-effectiveness integration phase.

A methodology for determining the relevant cost data must be developed that relates cost data to effectiveness analysis and provides visibility to these relationships, and benefits derived from expenditures. Further, the same basic set of data must be used for each alternative under consideration, to assure that valid comparisons can be made.

A block diagram describing a general cost methodology is shown in figure.

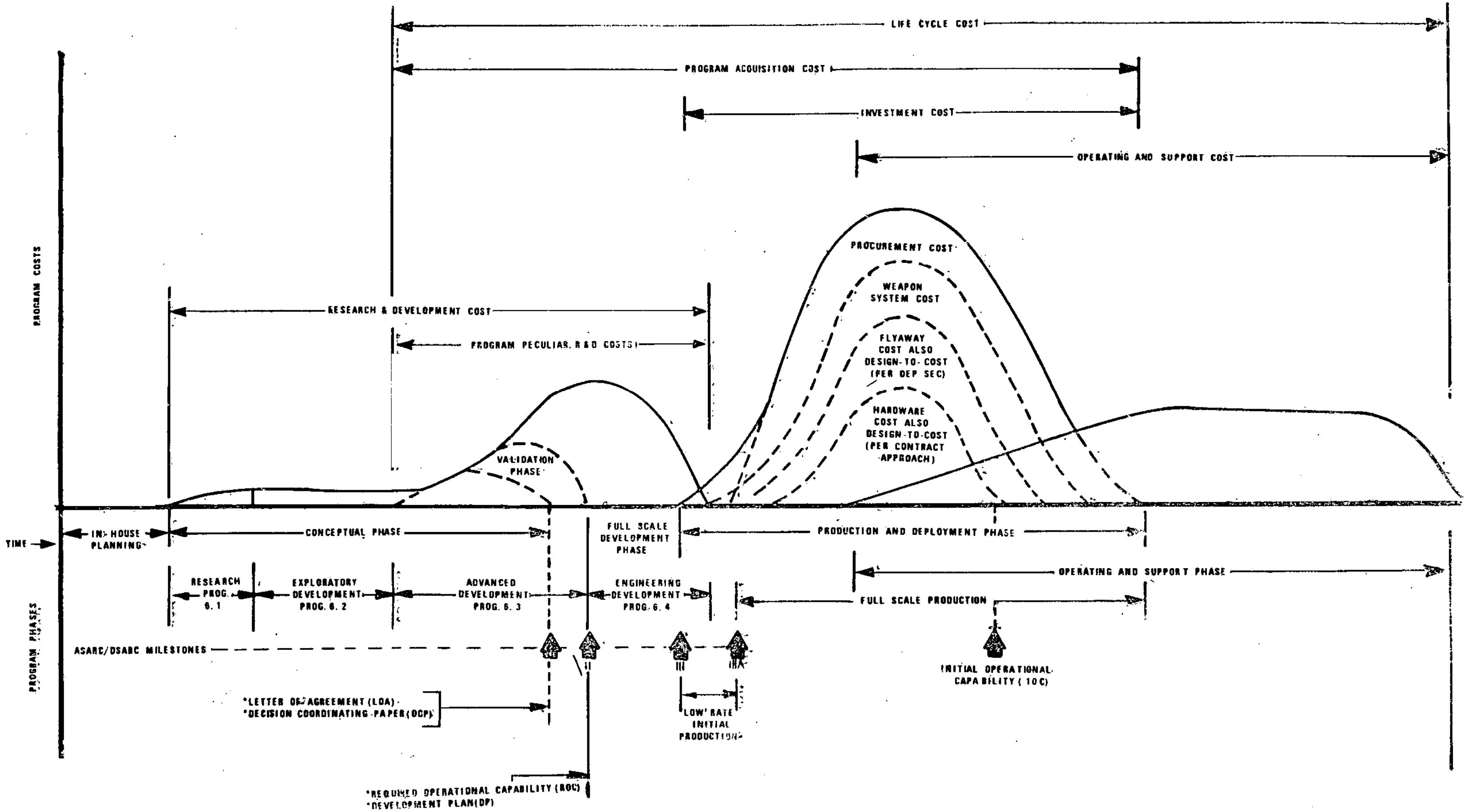

Figure 5. Life Cycle of Materiel Systems

Source: DA PAM 11-5, Standards for Presentation and Documentation of Life Cycle Cost Estimates for Army Materiel. Systems, May 1976.

ROW	PRIME APPRO	DEFN REF	COST ELEMENT / SYSTEM STRUCTURE*	(1) FRAME	(2) PROPULSION	(3) GUIDANCE CONTROL/ COMMUNICATION	(4) FIRE CONTROL	(5) ARMAMENT	(6) PAYLOAD/ AMMUNITION	(7)** (TO BE SPECIFIED)	(8) PECULIAR SUPPORT EQUIPMENT	COMMON SUPPORT EQUIPMENT	(10) OTHER	(11) TOTAL	(12) PERCENT
1		1.0	RESEARCH AND DEVELOPMENT												
2	RDTE	1.01	DEVELOPMENT ENGINEERING												
3	RDTE	1.02	PRODUCIBILITY ENGINEERING AND PLANNING (PEP)												
4	1.03	RDTE	TOOLING												
5	RDITE	1.04	PROTOTYPE MANUFACTURING												
6	RDTE	1.05	DATA												
7	RDTE	1.06	SYSTEM TEST AND EVALUATION												
8	RD/ OM	1.07	SYSTEM/ PROJECT MANAGEMENT												
9	RD/ OM	1.08	TRAINING												
10	RD/ MC	1.09	FACILITIES												
11	RDTE	1.10	OTHER												
12		2.0	INVESTMENT												
13	PR/ MC	2.01	NON-RECURRING INVESTMENT												
14	PROC	2.02	PRODUCTION												
15	PROC	2.03	ENGINEERING CHANGES												
16	PR/ OM	2.04	SYSTEM TEST AND EVALUATION												
17	PR/ OM	2.05	DATA												
18	PR/ OM	2.06	SYSTEM/ PROJECT MANAGEMENT												
19	PR/ MC	2.07	OPERATIONAL/ SITE ACTIVATION												
20	PR/ OM	2.08	TRAINING												
21	PR/ OM	2.09	INITIAL SPARES AND REPAIR PARTS												
22	PR/ OM	2.10	TRANSPORTATION												
23	PR/ OM	2.11	OTHER												
24		3.0	OPERATING AND SUPPORT COST												
25		3.01	MILITARY PERSONNEL												
26	MPA	3.011	CREW PAY AND ALLOWANCES												
27	MPA	1.012	MAINTENACE PAY AND ALLOWANCES												
28	MPA	3.013	INDIRECT PAY AND ALLOWANCES												
29	MPA	3.014	PERMANENT CHANGE OF STATION												
30		3.02	CONSUMPTION												
31	PR/ OM	3.021	REPLENISHMENT SPARES												
32	OMA	3.022	PETROLEUM, OIL AND LUBRICANTS												
33	PROC	3.023	UNIT TRAINING, AMMUNITION AND MISSILES												
34		3.03	DEPOT MAINTENANCE												
35	OMA	3.031	LABOR												
36	PR/ OM	3.032	MATERIEL												
37	OMA	3.033	TRANSPORTATION												
38	PROC	3.04	MODIFICATIONS, MATERIEL												
39		3.05	OTHER DIRECT SUPPORT OPERATIONS												
40	OMA	3.051	MAINTENANCE, CIVILIAN LABOR												
41	OMA	3.052	OTHER DIRECT												
42		3.06	INDIRECT SUPPORT OPERATIONS												
43	MP/ OM	3.061	PERSONNEL REPLACEMENT												
44	MPA	3.6062	TRANSIENTS, PATIENTS AND PRISONERS												
45	OMA	3.063	QUARTERS, MAINTENANCE AND UTILITIES												
46	MP/ OM	3.064	MEDICAL SUPPORT												
47	OMA	3.065	OTHER INDIRECT												
48			TOTAL STYSTEM COST (LESS ERDA)												
49	ERDA	4.0	ERDA COST												
50			TOTAL SYSTEM COST (WITH ERDA)												

100%

* THE COLUMN HEADINGS SHOWN ARE GENERIC, USED FOR DISCUSSION OF SYSTEMS IN GENERAL. FOR SPECIFIC STUDY, SPECIFIC COLUMN HEADINGS ARE THOSE PROVIDED IN APPENDIX A.

** USED FOR A SPECIFIC HARDWARE COMPONENT/SUBSYSTEM OF HIGH MANAGEMENT INTEREST, NOT CAPTURED ELSEWHERE

Figure 6. Army Life Cycle Cost Matrix

Source: DA PAM 11-5, Standards for Presentation and Documentation of Life Cycle Cost Estimates for Army Materiel Systems, May 1976.

Identify Alternatives and Quantities Needed

↓

Initiate Requests for Cost Data

↓

Devell op Probable Operational and Support Concepts

↓

Develop Quantitative Changes to Force Design

↓

Check Force Design Changes Against Other Subfunctions

↓

Develop Input Resources Required for Each Alternative Capability

↓

Develop Operating Costs for Each Alternative

↓

Develop Life Cycle Costs For Each Alternative

↓

Adjust All Costs to Same Basis, Refine Data

↓

Calcuate Comparative Costs

Figure 7. General cost methodology
Adapted from USATRADOC PAM 11-8, *Cost and Operational Effectiveness Analysis Handbook*, Draft.

INTEGRATION OF EFFECTIVENESS AND COST

The results of the cost and operational analyses must be synthesized to determine the cost-effectiveness of the alternatives under study and provide information that makes possible a rational choice.

Before this is attempted, non-quantifiable cost and effectiveness factors that may have an impact on the system, e.g. public opinion, environmental impact, or troop morale, should be listed and described, to allow to the maximum extent considerations of these in the final ranking of alternatives.

Integration of cost and effectiveness is relatively simple in analyses where one of these two variables is held constant for each alternate under study. However, as stated earlier, most alternatives for meeting real-world mission requirements tend to differ in the ways the mission is accomplished, in the effectiveness of mission accomplishment, especially if various ways of measurement of mission accomplishment are equally logical, and in the amounts and types of resources method required to acquire and sustain each alternative.

A common Method is to make tha ranking on the basis of the best cost to effectiveness ratio(CER). One of the two ways that such ratios can be developed is on the basis of the cost and effectivenss of the entire military force into which an alternative is introduced, these are called Force Unit Cost (FUC), and Force Unit Effectiveness (FUE).

The other method considers only the changes caused by the addition of a candidate system, these are called incremental costs (△UC), and incremental effectiveness (△UE).

Four ratios can be described:

$$CER\,1=\frac{FUC}{FUE} \qquad CER\,2=\frac{\triangle UC}{FUE}$$

$$CER\,3=\frac{FUC}{\triangle UE} \qquad CER\,4=\frac{\triangle UC}{\triangle UE}$$

The value of the four ratios, using the same data base, can differ greatly. Development of entire force costs and effectivenss is obviusly more difficult thanthe alternative but CER, is generalythe soundest method te use.

obviusly, the methodology of effectiveness analysis and judgemental evaluations of the rəlative importance of effectiveness used in the analysis, have determined the final aggregate FUC or △UE. The CER is hterefore in effect determined in the course of prior steps inthe analytical process.

The analysts should therefore clearly identify and state the rationale for their judgemental and iutuitive decisions. Analysts are generally well educated and their judgement tends to compare favoɹable with the judgement of people in most other professions. Even then, to quote again E.S. Quade [9]

"Here lies a danger. Not in the use of judgement but in the failure to emphasize the difference in results and recommndations based on judgement alone. An analysts' judgement is more likely to be inerror than his research, and the use of his unaided judgement is more likely to reflect on quantit ative analysis unless the process are kept distinct in the user's mind.

"For many analyses a good casecan be made for not presenting an aggregate, numerical CER, or other cost-effectiveness indicator. Instead, the values for each MOE and its associated cost for each candidate can be presented in a matrix format. It will be then left to the decision maker to use his own judgement to determine the relative value of each contributing factor to effectiveness, and whether it is worth the cost.

SENSITIVITY ANALYSIS

Sensitivity analysis can give us useful insights about the uncertanties contained in the models used for analysis, or the inevitable uncertainties about the future that pertain to the

COEA, such as enemy capabilities or changing technology.

In sensitivity analysis various reasonable values are used for key parameters about which doubt exists, to see how sensitive the results are to these variations. If one alternative is superior for all values, it is referred to as the "dominant" solution. If a dominant solution cannot be found, the selection of the preferred alternative has to be made on judgemental evaluations of the probabilities and risks associated with the most likely values.

Contingency analysis is a form of sensitivity analysis which is used to investigate the effect on the alternatives if major changes in the environment are assumed, or a change in the criteria for evaluating alternatives is postulated.

"A Fortiory Analysis" is another type of sensitivity analysis. In this case major uncertainties are resolved in favor of the lower ranking alternatives to see if this changs. the rankines. If the rankings are unchanged, the results can be accepted with greater confidence. If changes occur, further analysis and judgemental evalution may be needed.

IMPLEMENTION OF COEA RESULTS

The final report prepared by the study agency is the primary vehicle for implementation of the COEA results.

The final COEA report should be distributed to all affected agencies, and the results briefed to the primary decision makers.

The final report must be written with the decision maker in mind, to assure that the decision options and recommendations have beenclearly stated. Discussions of complex technical issues and presentation of supporting data, if needed, should be placed in appendices. The actions taken by the decision authority on the issues addressed in the COEA are based on the presented information and the judgement and experience of the decision maker. If the COEA helps him to make that decision better, it has achieved its purpose. If it does not help, it is a failure even though the analysis may have been technically excellent.

To assure that work done on the COEA is readily available to others who may be investigating related or similar problems, and to avoid duplication of analytical work, the report should be placed in central technical libraries and listed in all publications catalogs.

In conclusion it should be remembered that although the COEA can be an aide to the decision maker, many complex factors that are used to come to a decision can not be adequately quantified or analyzed.

Judgement is needed by the analysts to produce a useful COEA, and judgement will be needed to make decisions based on the COEA results.

Confucius, pondering and thinking on the relationship of learning and thinking stated: "Learning without thinking is useless, thinking without learning is dangerous". Today, in the age of modern analytical techniques and computers, it may be appropriate to paraphrase his wisdom as follows: "Trying to gain understanding without analysis is useless, analyzing without understanding is dangerous."

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