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STUDY REPORT
CAA-SR-91-9

**ARMY PROGRAM VALUE ADDED
ANALYSIS 90-97
(VAA 90-97)**

AUGUST 1991

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**PREPARED BY
FORCE SYSTEMS DIRECTORATE**

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SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE				Form Approved OMB No 0704-0188	
1a. Report Security Classification UNCLASSIFIED			1b. Restrictive Markings		
2a. Security Classification Authority			3. Distribution/Availability of Report		
2b. Declassification/Downgrading Schedule					
4. Performing Organization Report Number(s) CAA-SR-91-9			5. Monitoring Organization Report Number(s)		
6a. Name of Performing Organization US Army Concepts Analysis Agency		6b. Office Symbol (if applicable) CSCA-FSR	7a. Name of Monitoring Organization		
6c. Address (City, State, and ZIP Code) 8120 Woodmont Avenue Bethesda, MD 20814-2797			7b. Address (City, State, and ZIP Code)		
8a. Name of Funding/Sponsoring Organization Dir, DPAE; Tech Advisor, DCSOPS		8b. Office Symbol (if applicable)	9. Procurement Instrument Identification Number		
8c. Address (City, State, and ZIP Code) Washington, DC 20310			10. Source of Funding Numbers		
			PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.
11. Title (Include Security Classification) Army Program Value Added Analysis 90-97 (VAA 90-97)					
12. Personal Author(s) LTC Robert R. Koury					
13a. Type of Report Final		13b. Time Covered From Oct 88 To Aug 90		14. Date of Report (Year, Month, Day) 1991 August	
15. Page Count 220					
16. Supplementary Notation					
17. COSATI Codes			18. Subject Terms (Continue on reverse if necessary and identify by block number) Decision support, PPBES, programming, force development		
FIELD	GROUP	SUB-GROUP			
19. Abstract (Continue on reverse if necessary and identify by block number) The Value Added Analysis (VAA) methodology is a decision support system that will assist decisionmakers in evaluating and prioritizing competing alternatives in the POM building process. The Value Added Analysis concept uses a family of models to measure an alternative's explicit (objective) contribution to the program as an incremental or decremental change to the current program base. A hierarchical assessment framework is used to develop an alternative's scores. This assessment framework is used to evaluate changes against the current program base as the consequences of program alternatives are considered. Value Added Analysis results in measuring an alternative's relative value in the context of a larger value system. This relative value is either used directly by decisionmakers or is fed into a mathematical optimization model which simultaneously determines an alternative's cost-benefit and conducts a tradeoff between alternatives.					
20. Distribution/Availability of Abstract ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS			21. Abstract Security Classification		
22a. Name of Responsible Individual LTC Robert R. Koury			22b. Telephone (Include Area Code) (301) 295-5291		22c. Office Symbol CSCA-FSR

STUDY REPORT
CAA-SR-91-9

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August 1991

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J. (Name)	
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REPLY TO:
ATTENTION OF:

CSCA-FSR (5-5d)

27 JAN 1992

MEMORANDUM FOR

DIRECTOR, PROGRAM ANALYSIS AND EVALUATION (DPAE), OFFICE OF THE
CHIEF OF STAFF, U.S. ARMY, WASHINGTON, DC 20310-0200
TECHNICAL ADVISOR TO THE DEPUTY CHIEF OF STAFF FOR OPERATIONS
AND PLANS, WASHINGTON, DC 20310-0410

SUBJECT: Army Program Value Added Analysis 90-97 (VAA 90-97)
Study

1. Reference memorandum, Office of the Chief of Staff, U.S. Army, 10 May 1989, subject: Army Program Value Added Analysis 90-97 (VAA 90-97).
2. Reference memorandum requested that the U.S. Army Concepts Analysis Agency (CAA) conduct a study to provide the Director, Program Analysis and Evaluation and the Office of the Deputy Chief of Staff for Operations and Plans (ODCSOPS) an analytical methodology and decision support system for the development of a balanced and effective Army Program.
3. This final report documents the results of our analysis and incorporates your comments on the interim report. The Value Added Analysis (VAA) methodology is a decision support system that will assist decisionmakers in evaluating and prioritizing competing alternatives in the POM building process. The Value Added Analysis concept uses a family of models to measure an alternative's explicit (objective) contribution to the program as an incremental or decremental change to the current program base. A hierarchical assessment framework is used to develop an alternative's scores. This assessment framework is used to evaluate changes against the current program base as the consequences of program alternatives are considered. Value Added Analysis results in measuring an alternative's relative value in the context of a larger value system. This relative value is either used directly by decisionmakers or is fed into a mathematical optimization model which simultaneously determines an alternative's cost-benefit and conducts a tradeoff between alternatives.

27 JAN 1992

CSCA-FSR (5-5d)

SUBJECT: Army Program Value-Added Analysis 90-97 (VAA 90-97)
Study

4. This Agency expresses appreciation to all commands and agencies which have contributed to this study. Questions and/or inquiries should be directed to the Assistant Director, Force Systems Directorate, U.S. Army Concepts Analysis Agency, 8120 Woodmont Avenue, Bethesda, MD 20814-2797, DSN 296-1546.

for Philip S. Lower
E. B. VANDIVER III
Director



**ARMY PROGRAM VALUE ADDED
ANALYSIS 90-97
(VAA 90-97)**

**STUDY
SUMMARY
CAA-SR-91-9**

THE REASON FOR PERFORMING THE STUDY was to provide the Director for Program Analysis and Evaluation, and the Deputy Chief of Staff for Operations and Plans (DCSOPS) an analytical methodology and capability to support the development of a balanced and effective Army Program.

THE STUDY SPONSORS are the Director for Program Analysis and Evaluation (DPAE), Office of the Chief of Staff, Army, and the Technical Advisor, Office of the Deputy Chief of Staff for Operations and Plans (ODCSOPS), Headquarters, Department of the Army (HQDA).

THE STUDY OBJECTIVES were to:

(1) Formulate an analytic method for estimating the marginal value of competing management decision packages (MDEP) to the Army. The methodology will provide a common understandable basis for the analysis of affordability issues.

(2) Identify or develop prototype models that support the Value Added Analysis methodology and provide management tools for the analytic method developed.

(3) Establish within DPAE and ODCSOPS an in-house capability to conduct program issue tradeoffs.

(4) Conduct a proof of concept analysis during the building of the 92-97 Program Objective Memorandum (POM).

THE SCOPE OF THE STUDY included the research, development, and acquisition (RDA) appropriations for selected items of equipment in fiscal year (FY) 1999 and FY 2004.

THE MAIN ASSUMPTION of this study is that HQDA needs a relatively quick method for conducting program tradeoffs which has sound analytical underpinnings.

THE BASIC APPROACH of this study was to:

(1) Identify and develop an analytical approach to evaluate program issue tradeoffs.

(2) Develop a capability for implementing the methodology to include software modules where appropriate.

(3) Demonstrate the methodology and capability by using issues from the 90-97 POM issue cycle.

THE PRINCIPAL FINDINGS of the study were:

(1) Two generalized categories of measures of effectiveness (explicit and implicit) were determined to be important in judging relative value.

(2) A linear combination of value components appears to be useful in creating a single measure of an investment's marginal value.

(3) VAA uses a system of judgment weights which measures an investment's value in a dual context.

(4) The VAA methodology as demonstrated holds promise as the decision analysis framework that should be used for conducting Army program tradeoff analyses. Further work in the areas of quick turnaround combat modeling, dynamic costing, and data collection need to be conducted.

(5) A highly aggregated combat model can provide useful insights for answering macro-level program tradeoff questions and, to a more limited degree, is capable of providing specific program guidance.

(6) In order for aggregated combat models to be useful, they must be calibrated to more detailed models and data.

(7) HQDA has a perspective which does not include the Training and Doctrine Command's (TRADOC) blueprint of the battlefield per se. Their headquarters is organized along the lines of Planning, Programming, Budgeting, and Estimation System (PPBES) functions, and, although the headquarters has some overlap, the specific thrust is the generation of forces through planning and programming.

(8) The cost-benefit analysis in the form of the optimization model requires further research into the use of dynamic costing of the procurement costs.

THE STUDY EFFORT was directed by LTC James A. Richmann, Force Systems Directorate, US Army Concepts Analysis Agency (CAA).

COMMENTS AND QUESTIONS may be sent to the Director, US Army Concepts Analysis Agency, ATTN: CSCA-FSR, 8120 Woodmont Avenue, Bethesda, Maryland 20814-2797.

Tear-out copies of this synopsis are at back cover.

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CHAPTER 1

EXECUTIVE SUMMARY

1-1. **PROBLEM.** The leadership at Department of the Army needs analysis to support the development of a balanced and effective Army program that is within Department of Defense resource guidance.

1-2. **STUDY PURPOSE.** The purpose of the Army Program Value Added Analysis (VAA) was to provide the Director for Program Analysis and Evaluation (DPAE), and the Deputy Chief of Staff for Operations and Plans (DCSOPS) with an analytical tradeoff methodology and capability that would assist the development of a balanced and effective Army program through the use of a comprehensive cost-benefit analysis.

1-3. **BACKGROUND**

a. Traditionally, Army program development is accomplished during the Planning, Programming, Budgeting, and Execution System (PPBES) Program Objective Memorandum (POM) building process using some form of functional or mission area panels. The processes that evolved do not include adequate means of integrating these functional subprograms into a balanced total Army program. Furthermore, the traditional POM process allowed each panel to use its own methods for prioritization. This lack of standardization prevents the senior leadership from making the most effective tradeoffs across functional areas.

b. Virtually all analysis currently performed in program evaluation focuses on defining individual Management Decision Package (MDEP) issues. When MDEP analysis is conducted, the senior Army leadership lacks the visibility or analysis necessary to help identify the marginal value of resources within, or across, MDEPs.

c. Analysis of the total Army Program requires an understanding of how individual MDEPs contribute to the Army mission and strategy so as to determine which MDEPs and resource levels have the greatest return on investment. One approach to this problem is to estimate the "value added" by individual MDEPs, or groups of MDEPs--expressed as program enhancement packages or alternative solutions--to the total Army program as measured by their contribution to Army objectives.

d. The Value Added Analysis concept uses a family of models to measure an issue's explicit (objective) contribution to the program as an incremental or decremental change from the current program base. A pairwise comparison framework is used to develop an issue's implicit (subjective) contribution to the program through the development of individual alternative's scores. Saaty's analytical hierarchy technique is used to provide a structure for developing weights for both the explicit and implicit measures of value.

1-4. STUDY OBJECTIVES were to:

a. Formulate an analytic method for estimating the marginal value of competing MDEPs to the Army. The methodology will provide a common understandable basis for the analysis of affordability issues.

b. Identify or develop prototype models that provide management tools and support the Value Added Analysis methodology.

c. Establish within PAED and ODCSOPS an in-house capability to analyze program issue tradeoffs.

d. Conduct a proof of concept analysis during the building of the Fiscal Year (FY) 92-97 POM.

1-5. STUDY SCOPE. Only research, development and acquisition (RDA) appropriations and associated life cycle costs for selected items of equipment were included.

1-6. STUDY LIMITATIONS

a. Since this study is a proof of concept demonstration, the analysis included only the RDA appropriations. Only RDA was considered because of the need to limit the scope of the study to those appropriations with good data availability and issue definition. However, the final methodology should be capable of examining tradeoffs across the full range of program issues.

b. Because the modeling and effectiveness data for the noncombat issues are less developed than the combat areas, the study focused principally on combat tradeoff issues.

c. The original list of equipment issues for this study included 23 systems. Limited data available for combat

modeling did not permit the inclusion of more than 12 systems in the analysis.

d. The initial data collection design called for system effectiveness, force structure, cost, and production data for FYs 1991, 1999, and 2004. Effectiveness data could not be collected for all three years in a timely manner. Therefore, only FY 1999 and FY 2004 data were used.

e. RDA appropriations provide only 22 percent of the Army program dollars.

1-7. **TIMEFRAME.** This proof of concept analysis addresses tradeoff issues during the period beginning in FY 99 and ending in FY 04.

1-8. **KEY ASSUMPTIONS**

a. The methodology assumes that all tradeoff issues will only be those on the margin, and does not purport to realign previous (years prior to current POM) MDEP funding levels or quantities. The Value Added Analysis will not be used to build a completely new program from a zero base. All previous POM decisions which resulted in the current program would remain unaltered. VAA would only be used to deal with increments and decrements starting from a base represented by the current POM (FY 92-97) position.

b. The Value Added Analysis can be executable in a quick turnaround environment. Therefore, the combat models applied must process at a lower level of resolution using data that has been aggregated from more detailed models or data bases.

c. VAA must be compatible with the manner in which the senior Army leadership makes decisions.

d. The Value Added Analysis assumes a two-tier decision process wherein the senior Army leadership provides guidance regarding Total Obligation Authority (TOA) allocation (first tier), and the VAA methodology is used to decide on tradeoff issues within this guidance (second tier). However, the TOA guidance may or may not be developed using the Value Added methodology.

e. The methodology must allow for prioritizing between dissimilar program alternatives.

1-9. STUDY METHODOLOGY

a. The Value Added Analysis concept uses a hierarchical assessment framework for developing a single measure of benefit. This assessment framework is used to portray existing capability (current program levels) and evaluates capability changes against this base level as the impact of alternative solutions for program tradeoffs issues are considered. The contribution of a program alternative is measured both explicitly (using combat models and other quantitative methods) and implicitly (using Thomas L. Saaty's pairwise comparison technique¹). VAA results in measuring an alternative's relative value in the context of a larger value context. This relative value is used either directly by decisionmakers or is input into a linear program to determine an alternative's cost effectiveness, and, in turn, acquisition strategy

b. The current application of the VAA methodology uses four types of models: combat models, costing models, multiattribute models, and linear programming models. All of them use existing, well-accepted operations research techniques to eliminate any debate over those specific techniques used. Furthermore, by using techniques which many people are already familiar with, the learning curve for using the VAA methodology would be shortened. Figure 1-1 depicts the overall Value Added methodology.

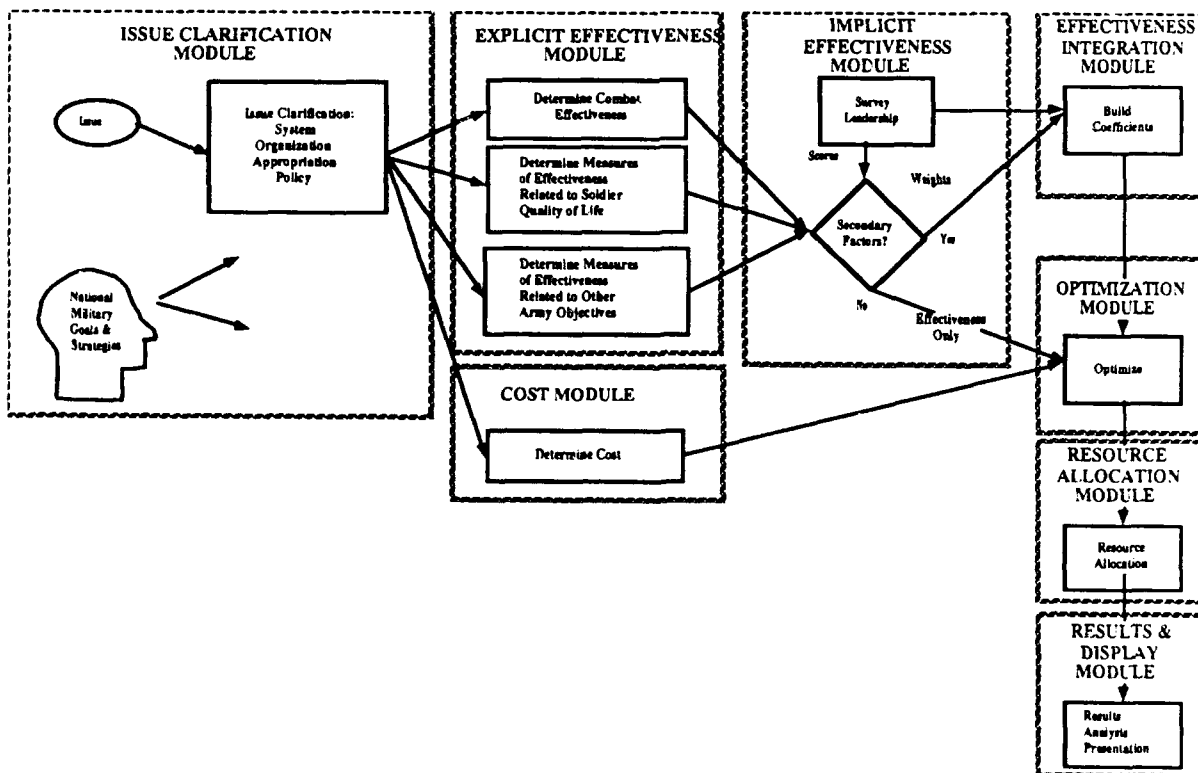


Figure 1-1. Value Added Analysis Methodology Overview

c. The combat and costing models are used to obtain the explicit (objective) measures of effectiveness of an investment alternative. The implicit measures of effectiveness are developed through the use of two surveys. The first survey is given to the Army leadership as a means of deriving decision weights for subjective decision criteria (e.g., Congressional opinion). These criteria are referred to as secondary impact analysis modifiers (SIAM factors) and are developed using Saaty's pairwise comparison technique. The second survey is given to subject matter experts, who are asked to value or score investment alternatives in light of the SIAM factors.

d. The explicit measures of benefit are combined with the implicit (subjective) measures using a model called TOPSIS (Technique for Order Preference by Similarity to Ideal Solution). This combined measure of benefit is evaluated against cost using a multiobjective linear program called FOMOA (Force Modernization Analyzer). FOMOA produces efficient acquisition strategy based upon a cost effective criterion. This display may be used as is or processed further using a future enhancement which will allow the analyst to distribute equipment or program items by unit or activity.

e. The previous paragraphs of this chapter provide a brief outline of the VAA methodology. Readers desiring a fundamental understanding of this study and the VAA methodology should read Chapters 2, 3, 10, and Appendix E. Those needing a more detailed explanation should read Chapters 2 through 10 and Appendices D and E. Individuals wishing to implement the VAA methodology should read Chapters 2 through 10 plus Appendices D through H.

1-10. ESSENTIAL ELEMENTS OF ANALYSIS (EEA). The essential elements of analysis and basic findings for each are as follows:

a. **EEA 1: What measures of effectiveness (MOE) are appropriate for judging relative value among all MDEPs in the program?** Two generalized categories of measures of effectiveness were determined to be important in judging relative value.

(1) The first (called explicit effectiveness) consists of three subdivided elements (combat effectiveness, soldier quality of life, and other Army goals and objectives). They are those measures which can be directly quantified. These measures include such MOE as force exchange ratios (FER),

correlation of forces and means (COFM), day care days, amount of energy savings, etc. These MOE were selected for their ability to appropriately measure the issue in its own context.

(2) The second category of MOE (SIAM factors) measures implicit effectiveness and includes those measures which are inherently qualitative, such as political risk and institutional stability. These MOE were selected because they express subjective values which are best measured through expert judgment.

b. EEA 2: Should a linear combination of value components be used to arrive at a single measure of value added? If so, what system of judgment weights should be used?

(1) A linear combination of value components appears to be useful in creating a single measure of an issue's marginal value.

(2) VAA uses a system of judgment weights which measures the value of an issue in a dual context. The methodology seeks two sets of estimates. The first set of estimates is created by surveying the Army leadership to determine both the set of judgmental factors and their weights in accordance with the group's value set and world view. The second set of estimates is created by scoring individual issues using subject matter experts and the judgmental factors developed by surveying the leadership. Both sets of surveys appear to yield consistent and informative values. These approaches are successful in capturing the multiple attributes used by the decisionmakers in the PPBES programming decision process.

c. EEA 3: What decision analysis framework should be used? The VAA methodology as demonstrated in Phase I holds promise as the decision analysis framework that should be used for conducting Army program tradeoff analyses. Further work in the areas of quick turn-around combat modeling, dynamic costing, and data collection need to be conducted.

d. EEA 4: Does a highly aggregated combat model provide useful insights for answering program-wide tradeoff questions? If so, can such a model be calibrated to a more detailed model if necessary?

(1) A highly aggregated combat model can provide useful insights for answering macro-level program tradeoff

questions and, to a more limited degree, is capable of providing specific program guidance.

(2) In order for aggregated combat models to be fully useful, they must be calibrated. In order to calibrate them, one must be able to establish some benchmark values or calibration points using data or output from accepted and "known" sources. These points do not necessarily need to be developed from other models of higher resolution. Calibration can be done using other models, empirical data, or historical data. The VAA Study attempted to calibrate a medium resolution combat model (Corps Battle Analyzer [CORBAN]) with a more detailed medium resolution model (Vector-In-Commander [VIC]). This effort at calibrating one model with results from another was not fully successful because we did not have both models available to use (VIC was not run at CAA). The team was only successful at matching the tempo of the battles in CORBAN in relation to the 6.3 scenario in VIC. Further work on calibration should be conducted.

e. EEA 5: What Blueprint (of the battlefield) options provide the most useful framework for the analysis of change to the Army's materiel, force structure, etc? TRADOC's Blueprint of the Battlefield, which this EEA was directed towards, appears not to be useful within the context of VAA. The blueprint concept is oriented by its very nature toward a requirements perspective and does not necessarily address the issues of affordability or duplication of capability. The AHP process appears to hold the greatest possibilities in this regard.

1-11. OTHER KEY FINDINGS

a. The Value Added methodology is data intensive. Accuracy and timeliness of input data, especially production data, is of crucial importance in making the value added process operational.

b. The technique used to survey the Army leadership allowed decision making attitudes and behaviors to be accurately reflected.

c. The Value Added methodology will "buy" the most cost effective systems subject to constraints. However, in using a fixed average unit cost (AUC) in the optimization model the current configuration creates a shortcoming which needs to be addressed. The danger exists that in recomputing AUC after the optimization has been completed the total cost of the quantities recommended could exceed the TOA given. VAA Phase II must address dynamic costing within the optimization so as to recompute the procurement cost as part of the optimization process.

d. The study developed a modular "living" methodology with a high degree of flexibility which can be used with a variety of techniques and models.

e. The methodology provides a standardized quick reaction approach that uses operations research/systems analysis (ORSA) techniques. It evaluates program tradeoff issues by functional area experts and decisionmakers. ORSA expertise is required during the preparatory analysis, consisting of the combat modeling, costing, and surveying. The functional analysis which would take place during the POM building and defense, consisting of the actual tradeoffs, does not require extensive ORSA expertise when using the VAA methodology.

f. The scope of Value Added Analysis needs to be expanded beyond the RDA appropriations, since these contain only about 22 percent of the Army program dollars.

CHAPTER 2

INTRODUCTION

2-1. **OVERVIEW.** The purpose of this chapter is to provide a discussion of the background which influenced the development of the Value Added methodology. Chapter 3 provides an overview of the methodology without respect to those demonstration case studies that were actually conducted during this study. The case studies and their results are presented in Appendix E, which is published separately. Subsequent chapters (4-9) will present a more detailed discussion of the methodology using an example tradeoff issue for armor/antiarmor systems. It should be noted from the study directive that VAA was to be limited to development of a methodology and prototype models. By the very nature of this study, the team understood that subsequent efforts aimed at refinement would be necessary. Therefore, a section of the summary chapter will identify, where possible, those areas requiring further work. Chapter 2 is structured as follows:

- a. Problem Background
- b. Scope/Limitations/Timeframe
- c. Key Methodological Assumptions
- d. Influences on the Approach
- e. Summary

2-2. PROBLEM BACKGROUND

a. The growing federal budget deficit and the breakout of peace in Europe have put great pressure on all the armed services to re-evaluate and restructure their budget and programs. This is especially true for the Army because of the changing perception of the threat in Western Europe. There is more need now for cost-benefit analysis than ever before. This analysis must be conducted in support of developing a balanced and effective Army program within Department of Defense resource guidance. Traditionally, the Army has used functional area panels to build its POM. The processes that have evolved do not include adequate means of integrating and balancing the functional programs into the Total Army Program. The Value Added Analysis has been conceived as a means of assisting in accomplishing this integration and balancing.

b. The environment in which Value Added Analysis must be conducted is characterized by minimal time for analysis, ever-changing assumptions, often incomplete data, and increasing emphasis on verifiable results. Traditional staff processes and supporting operations research studies often do not meet this challenge. This failure occurs because traditional approaches require a long time and

highly trained personnel to produce high quality, fully integrated, and very detailed analysis.

c. The requirement for a Value Added Analysis (VAA) methodology was conceived by the Director, PAED as a means of conducting program tradeoff analyses. In early 1989, the Director, PAED, asked the Technical Advisor, Deputy Chief of Staff for Operations and Plans, to jointly sponsor a study to be conducted by the US Army Concepts Analysis Agency (CAA) to develop the methodology.

2-2. SCOPE/LIMITATIONS/TIMEFRAME

a. The VAA Study was designed as a proof of concept to include the building of a prototype decision support system. Because the work was developmental, we limited the scope to weapon system tradeoffs and did not attempt to address force structure, personnel, infrastructure, or other issues. The methodology is, however, designed to be generic and used across all the functional areas of the Army Program.

b. Because the first objective of this study was to develop a methodology, it was decided to limit the program alternative tradeoffs to weapon system mix issues. This limitation by its very nature focused the study on the RDA appropriation. Research, development, testing, and evaluation (RDTE) and other equipment-related appropriations such as operation and maintenance, Army (OMA) (for operation and sustainment (O&S)) were either not considered or used in a very limited manner. However, it is clear that the methodology must be capable of examining tradeoffs across the full range of program issues and therefore across all appropriations.

c. The VAA study directive required that the methodology consider both combat and noncombat measures of effectiveness. However, principally because of limited time, limited data, and inadequate noncombat models, the study focused primarily on combat related tradeoff issues.

d. The VAA study directive required that the methodology consider implementation in an IBM PC-compatible computer environment. This requirement was identified because PAED and other major Army Staff (ARSTAF) agencies conduct their work in the IBM environment.

e. The following terms of reference were used in developing the VAA Study.

- (1) FY 90/91 amended budget.
- (2) FY 94 program force for the base.
- (3) NATO Central Europe scenario.
- (4) Conventional conflict (no chemical or nuclear).

f. As part of the study directive, TRAC (TRADOC Analysis Command), Fort Leavenworth, was tasked to assist CAA in conducting the corps-level combat simulations. The VAA effort was a significant addition to TRADOC's Army Regulation (AR) 5-25 FY 90 study program. Because VAA represented an unplanned additional requirement, TRADOC requested that VAA be linked to the ODCSOPS Army Requirements and Capabilities Study (ARCPS). One outgrowth of this linkage was the selection of timeframes for the VAA Study. ARCPS required a set of dates that allowed for looking at program growth starting at the end of the budget year, going through the POM years and ending 7 years into the extended planning years. This requirement resulted in the following years being selected for data collection and combat simulations--FY 1991, FY 1999, and FY 2004. However, because of data limitations, FY 1991 was deleted from the study.

2-3. KEY METHODOLOGICAL REQUIREMENTS

a. The analysis will expand to other appropriations and issues as the methodology matures.

b. The decision support system and related models must be capable of operating in a quick turnaround environment, defined as 1 week or less.

c. The above requirement led to the following additional requirements:

(1) Combat models for use in Value Added Analysis must process aggregated data and be calibrated to higher resolution models, empirical data, or historical data.

(2) Data manipulation must be easy and very quick.

(3) The decision support system must tap major authoritative Army data bases such as the Total Army Equipment Distribution Program (TAEDP), Force Accounting System (FAS), and line item number (LIN) Price.

d. The methodology must accommodate the manner in which the senior Army leadership makes decisions.

e. The methodology must allow for prioritizing between dissimilar program alternatives (weapon systems versus training versus family member support).

f. Input data will come from a wide variety of sources, may prove to be difficult to obtain, and must be scrubbed for verification/validation.

2-4. INFLUENCES TO THE APPROACH

a. A Definition of Value

(1) As one thinks about the term "value," it becomes clear that value is always contextual. In making judgments about the value of something, we normally measure that item against a standard. These standards may be developed from a complex system of comparative examples, such as the value system we help imbue in our children. Or the standard may be as simple as a single measure such as, "How much does my house cost (in dollars) in relation to others on the market?" In both cases, criterion and means to measure an alternative against the criterion were established. Value is "in the eye of the beholder," and therefore is inextricably linked to the decision-makers' value system. This is also true for the Value Added Analysis. The process of determining value can be viewed as the defining of a context, the establishment of criterion and associated standard, and the selection of a means to measure choices (alternatives) against the criterion and standard.

(2) For the Value Added Analysis methodology, the idea of defining a context is the most important concept to understand. It is from context that the whole evaluation process obtains its meaning. For example, the demonstration case study uses a context of a NATO Central Europe battle (pre-CFE). However, it is just as valid to use a Southwest Asia or Northeast Asia scenario. In fact, one might want to look at all three scenarios to gain insights on how the value of a particular set of alternatives changes from theater to theater. Furthermore, this theater context may be modified by the fact that the Federal budget, and therefore the Army budget, is decreasing. VAA, as envisioned by the sponsors of this study, embraces the context of the importance of judging program alternatives against the overall Army objective of conducting combat operations. It would be just as valid to view the tradeoffs from the dual position of both peacetime and wartime. Each of these perspectives helps define a value system. For example, suppose as a decisionmaker, you have an additional million dollars to spend on procuring either Special Operations Forces (SOF) aircraft or additional M1 tanks. Assume SOF aircraft cost a third as much as the M1 and is equally effective in its mission. Furthermore, as the decisionmaker, if you think the next war to be fought will be an insurgency in a specific mountainous theater, then likely you will value SOF aircraft over tanks. If, however, you believe the next battle will be an armor-heavy fight on the plains of Europe, then tanks will be valued over SOF aircraft.

(3) It was clear that the Army leadership viewed the value of program alternatives in terms of their contribution to combat. In conducting interviews with decisionmakers, it became obvious to the study team that decisionmakers other than the sponsor viewed the problem from a slightly different perspective. There are other interest groups such as Congress, the Executive Branch, or the Office of the Secretary of Defense which may view the PPBES process somewhat differently. These "non-Army" groups may, in fact, view the armed forces as an agent of peaceful change within our own society. These groups, although ultimately interested in the ability of the Army to conduct combat operations, may be influenced by other objectives such as budget constraints, power projection, or social change. This fact not only reinforces the general concept of context, but points out

the need to categorize decisionmakers by interest group. Each interest group will have its own biases, criteria, and issue relationships.

(4) The idea of identifying interest groups and their value structure is only one aspect of the concept of context. Another, and equally important, aspect is the need to define the parameters of the issue. This process includes identifying the policies, systems, organizations, and other factors which influence the decisionmaking process. Policy statements will influence the choice made through identifying objectives or requirements which must be met. For example, analysis of Army energy investment alternatives are influenced by provisions in Title 10 of the US Code. Weapon systems and Army organizations provide a physical and structural context. For example, the Army may wish to look at the modernization of the antitank systems for the forward-deployed forces. And finally, there is a multitude of other items which may affect a decision including such things as the economy, a leader's world view (pre-CFE versus parity versus regional conflicts as the most likely war to be fought) or his (the decisionmaker) position in the organization.

(5) Chapter 4 (Issue Clarification) and Chapter 7 (Implicit Effectiveness) specifically address this idea of context. Chapter 4 focuses on the need to clearly frame the issue in a way that all decisionmakers, regardless of their interest group, have a common understanding of the issue parameters. Chapter 7 attempts to capture the decisionmaker's criteria for judging tradeoffs and at the same time trying to minimize bias.

b. Measuring Value

(1) As the study team conducted its literature search and reviewed associated work, it became evident that any Value Added concept must include a means to measure value. Two documents in particular influenced the study team in developing the Value Added Analysis methodology: a US Army Concepts Analysis report (Study of Effects of Alternate Allocation of Army Dollar Resources at Various Budget Levels - Phase II - Final Report), and a TRADOC White Paper (Combined Hierarchical Assessment and Capital Budgeting Framework, Ft. Leavenworth, KS.). A major contributor to the CAA document was particularly helpful in relating his observations and in discussing the need to include sufficient capability for decisionmakers to influence the decision when using the VAA methodology. Dr. Anderson's white paper was helpful in assisting the team in developing a construct for measuring value. Furthermore, the need to incorporate a means by which subjective decisionmaker judgment could influence the process became a fundamental requirement for the methodology. Often, attempts to develop a program development and tradeoff methodology, such as Value Added, failed because these methodologies concentrated on quantifiable measures of effectiveness almost exclusively. These preceding methodologies did not accommodate those other subjective factors which decisionmakers felt were important. This issue eventually was addressed by the development of two categories of effectiveness called explicit effectiveness

(directly quantifiable) and implicit effectiveness (subjective or indirectly quantifiable).

(2) The problem of how to measure value contextually was an essential issue during the development of the Value Added methodology. Furthermore, the study team knew that the methodology required a means of capturing subjective decisionmaker judgment. Solving these problems motivated the development of a judgment framework and two evaluation approaches for separately measuring explicit and implicit effectiveness.

(a) The analytical hierarchy technique is used to develop a framework for weighting the importance of the explicit and implicit measures of effectiveness. These subjective weights are used to depict (or capture) the decisionmaker's value system. The two evaluation approaches are then used to measure an alternative's capability.

(b) The study team calls the approach for measuring explicit effectiveness the hierarchical measures of effectiveness (MOEs). This approach provides a means of quantifying the value of an issue across functional areas so that each alternative can be evaluated in the appropriate context by the appropriate analytical tool. Even though this study uses a combat example, the concept applies to noncombat issues as well.

(c) The approach used to measure the implicit (subjective) factors uses a subjective scoring system. Each alternative is scored by subject matter experts against a set of criteria developed as part of the analytical hierarchy work.

c. Data Requirements

(1) One fact became very clear to the study team regarding data requirements for the Value Added Analysis. Data for this analysis was going to be complex, extensive, and varied. This fact alone became the driving factor in searching for a flexible computer architecture and environment for the Value Added Analysis.

(2) Our current thought about the Valued Added Analysis separates our data requirements into two categories--quantitative and narrative. These two categories cover a wide spectrum of data types ranging from cost data, which is mostly numerical, to policy data, which is mostly text. Furthermore, the integration requirements across the two categories are both horizontal and vertical. Keys may be as simple as the title of the alternative or as complex as linking appropriation pieces for the alternative with other related alternatives or issues.

(3) The data collected for Value Added Analysis serves two purposes. First, the spectrum of data must be sufficiently rich across functional areas to help inform (educate) the decisionmaker using VAA about the issues and choices. Access to the alternative's definition (performance specifications, support requirements, and

related equipment/systems), the issues associated with the alternative(s), cost data, organizational implications, and applicable policy data must be simple and easy to use. Second, the data must be in sufficient detail to feed the VAA models.

2-5. SUMMARY. The VAA Study was designed to develop a methodology to conduct program alternative tradeoffs. This report describes a comprehensive cost-benefit methodology which enables the conducting of these program issue tradeoffs. As a means of illustrating the methodology, Chapter 3 introduces an armor/antiarmor example tradeoff issue which is carried throughout the remaining chapters of the report. A case study of the Value Added Analysis methodology using realistic issues and data is presented in Appendix E

CHAPTER 3

VALUE ADDED ANALYSIS METHODOLOGY

3-1. INTRODUCTION. The purpose of this chapter is to provide a comprehensive discussion of the Value Added methodology. Subsequent chapters (5-9) will present a more detailed discussion of those portions of the methodology that were more fully implemented during this study. This chapter is structured as follows: (1) overview of the methodology; (2) description of each module in the methodology; and (3) summary.

3-2. OVERVIEW

a. Introduction. The first objective of this study, as outlined in the study directive, was to formulate an analytic method for estimating the marginal value of competing Army program alternatives. The VAA methodology has been developed to provide a road map for conducting these analyses. The methodology provides a generic approach for cost-benefit analysis. An important feature of this methodology is that it is flexible and may be used in both a standardized or *ad hoc* approach. The VAA standardized approach would use the complete methodology as described in this chapter, to include all of the current techniques developed. The *ad hoc* approach uses

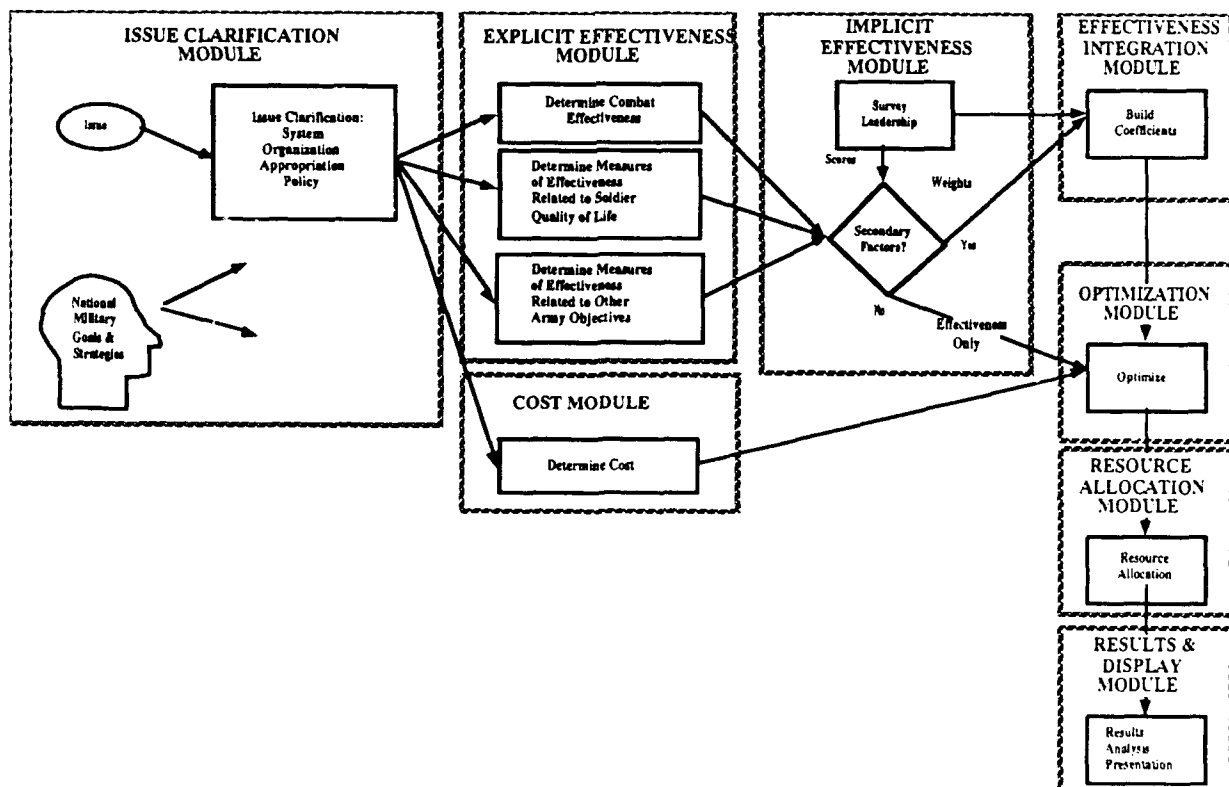


Figure 3-1. Value Added Analysis Methodology Overview

only those modules and techniques pertinent to the issue being inves

tigated. This flexibility is achieved by using a modular methodological framework . Figure 3-1 depicts the complete "standardized" VAA methodology with its eight modules.

b. VAA Modules. Each of the modules is designed to be self-contained in that they can stand alone if needed. This autonomous structure allows the analyst the flexibility to use the methodology in its entirety (standardized approach) or to customize the methodology in such a way that it addresses the needs of the current issue tradeoff analysis. The following is a listing of the modules contained in the standardized VAA methodology and a short description of each:

(1) **Issue Clarification.** This module is the initial step in the VAA methodology and consists of defining and understanding the issue.

(2) **Explicit Effectiveness.** The explicit effectiveness module is divided into three submodules whose purpose is to measure the direct or quantitative components of value. The explicit contribution of a program alternative is defined by the MOE derived from the combat, soldier quality of life, or other Army objectives submodules (see Figure 3-1).of the explicit effectiveness module.

(3) **Costing.** The costing module assists in identifying and calculating the costs associated with each alternative for the issue being investigated.

(4) **Implicit Effectiveness.** The implicit effectiveness module's purpose is to measure the qualitative or subjective components of value through the use of leadership surveys and subject matter experts. The implicit contribution of a program alternative is defined by a set of secondary impact analysis modifiers which in effect serve as implicit MOE.

(5) **Effectiveness Integration.** Both explicit and implicit measures of value are combined within the effectiveness integration module to develop a single measure of benefit.

(6) **Optimization.** The marginal value of program alternatives is calculated in the optimization module. This calculation is accomplished by relating the Value Added coefficients developed in the effectiveness integration module with the costs developed in the costing module according to established cost-benefit criteria. These cost-benefit criteria specify the appropriate conditions of optimality.

(7) **Resource Allocation.** The resource allocation module is used to distribute the optimized mix of program alternatives to the Army force structure and organizations.

(8) **Result and Display.** The purpose of this module is to present the result of the analysis.

c. **VAA Methodology Structure.** The dotted lines outlining various parts of Figure 3-1 are used to graphically depict the eight modules of the methodology. Each module is defined by a process, technique, input, assumptions, and output. Appendix D contains a set of two matrices which outlines these elements for each module. This modularity is an important aspect of the VAA methodology because it allows the analyst to investigate wide-ranging problems and issues which are inherent in the PPBES process. Although specific data, models, and techniques may change from analysis to analysis, the approach and the general form of each module remain unchanged.

d. **VAA Methodology Concept.** As currently envisioned, the VAA methodology concept characterizes a Value Added study or analysis as either using a standardized or an *ad hoc* approach. This distinction is important because it determines how the VAA methodology will be used. In the standardized approach, all modules and techniques of the methodology as described in this report would be implemented. The standardized approach would most likely be used by action officers for the more traditional program tradeoff exercises, such as the PEG (Program Evaluation Group) process, or POM issue defense. In an *ad hoc* approach, the analyst would use only those modules and techniques which are pertinent to the issue being investigated. An example of this type study might be the FY 90 QUICKSILVER reviews.

e. **Standardized VAA Methodology.** The current standardized VAA methodology contains eight modules, and within them, there are four generic types of models: expert systems, simulation, decision support, and optimization. All of the models use existing and well-accepted operations research techniques. The VAA methodology purposely relies on analytical tools which are well known in order to ease concern over modeling and computational adequacy. For purposes of this report, any reference to the VAA methodology will pertain to the standardized approach unless specific reference is made to the *ad hoc* approach instead. Each module of the Value Added Analysis methodology is discussed in its own paragraph of this chapter except for the three effectiveness modules which are discussed jointly in paragraph 3-4.

3-3. ISSUE CLARIFICATION MODULE

a. **Introduction.** The first module in the Value Added Analysis methodology is issue clarification. The first and most important step for the VAA methodology is to spend some time identifying the elements of the tradeoff issue and the issue-related questions and problems. In the prototype work, the study team has seen time and again the importance of this step. If this issue clarification step is not thorough and fully understood, the entire analysis from this point will be misdirected at best and irrelevant at worst. Figure 3-2 is an example of an initial VAA issue.

Representative Armor/Antiarmor Systems

Issue: Given limited dollar resources, which mix of A3 systems should be procured?

Base case Europe Scenario 6.3 with 25 systems

- AMS-H
- BRADLEY BLK III
- M1A2
- MLRS SADARM
- NLOS-AT

Figure 3-2. Example VAA Issue

In this example, the analyst is asked to conduct a tradeoff analysis to select the best mix of armor/antiarmor systems. The analyst is provided guidance in the form of a cost constraint, a European scenario (context), and a description of the baseline force and two proposed alternative weapon system mixes. The alternatives were developed as part of the Armor Antiarmor Study conducted at HQDA by the A3 task force. These two particular alternatives were selected by the task force as representative mixes and not necessarily to be prescriptive. Both alternatives were developed from a single list of systems. The A3 example will be used from this point on in the report to help illustrate the VAA methodology. In the final analysis, we will actually be trading off the single list of systems to provide what would amount to a VAA alternative.

b. Processes. The issue as depicted above may seem clear, but in terms of the VAA methodology more is required. There are three processes associated with the clarification module. The processes are:

- * Obtain Broad Guidance
- * Describe Issue Relationships
- * Determine how the Methodology Will be Used

(1) **Obtain Broad Guidance.** Figure 3-2 does not indicate what guidance or factors may be important to the decisionmaker in conducting this particular Value Added Analysis. The analyst must obtain answers to such questions as: is there a budget cut looming? Do we need to consider a particular investment strategy? What theaters and OPLANs do we need to consider, if any? These kinds of questions must be formulated and discussed by the analyst with the appropriate set of decisionmakers in order to obtain and clarify any

guidance he needs. Additionally, the analyst needs to conduct a thorough review of policy statements that may impact upon the issue being investigated.

(2) **Describe Issue Relationships.** Describe issue relationships by system, organization, policy, and appropriation. At this point, the Value Added methodology requires a clear description of the systems involved in each alternative, a breakout of other related systems with their equipment, costs, and other factors which may impact on the decision. For example, the analyst should ask such questions as, "Are there force development issues or Congressional appropriation guidelines which impact upon this analysis?" Table 3-1 provides some examples of the types of relationships the analyst might explore during the issue clarification step of the illustrative A3 Value Added Analysis.

Table 3-1. A3 Issue Clarification

Category	Issue Relationships		
	Procurement Data	System Definition	Capabilities
System			
Organization	Fielding	Force Structure	
Policy	AMM ¹ Priority	Investment Policy	Defense Guidance
Appropriation	Dollar Cost	Manpower	TOA Guidance

Each of the alternatives and the base case would be characterized using the four categories listed in the column on the left of the table. Figure 3-3 depicts (for three alternatives of the armor/antiarmor issue) a rudimentary example of the complexity of the data required to conduct a Value Added Analysis and the form in which that data might be presented. Procurement data is numerical and relates to the production line capacity and the ability of the industrial base to produce the quantities desired. Cost data is subdivided into appropriation categories in order to relate it in PPBES terms. The major item system map (MISM) tree (alphanumeric data) refers to a detailed breakdown of the system and associated items of equipment and provides a standard definition of the system for costing and modeling. Other pieces of information, such as the AMM priority and short notes, provide policy guidance and are both numeric and text in character. From this chart it should become readily apparent that the information needs of the Value Added Analysis are varied and complex.

¹AMM Priority - Army Modernization Memorandum priority is developed through the Concepts Based Requirements System conducted at TRADOC in support of the Long Range Research and Development Modernization Plan (LRRAMP).

Information Matrix: A3 Alternatives

System Attribute	Tank A	Antitank Missile A	Submunition B
Procurement Data			
Number of Lines	2	1	5
Number of Shifts	1	2	1
Hours/Shift	8	8	8
Systems/Month	180	54	68
Cost			
RDTE(\$M)	170	58	43
OMA(\$M)	14.7	4.5	1.2
Spaces(Pers/Unit)	NA	58	NA
MISM Tree	B54690	C67900	E66300
LIN	GA0167		
AMM			
Priority	5	44	23
Short Notes	These alternatives address shortfalls in maneuver, direct fire, and counterfire for the close combat heavy functional area.		

Figure 3-3. A3 Alternative Information Requirements

(3) Determine How the Methodology Will be Used.

Determine the degree or extent to which this application of the methodology will be standardized or ad hoc. Not until the issue is fully understood should the analyst decide on one of the two generalized forms of the methodology. This decision is a function of not only the issue itself, but of the particular analysis objective, data, models, and other input items to the methodology.

3-4. COSTING MODULE

a. Introduction. The second module in the Value Added Analysis methodology pertains to costing. This module is intended to identify all appropriate costs associated with each alternative for the issue being investigated. These costs will usually be monetary but are not limited to dollars alone. Other measures of cost may be included such as time lost, or force structure reductions/increases, and so forth. This module also includes three sections similar to those found in the explicit effectiveness module: develop a context, select or develop appropriate analytical models and tools, and implement analytical models and tools. Matrix 1 in Appendix D depicts the full framework for the costing module.

b. Develop A Context. The first section of the costing module is used to develop the costing context for the alternatives being investigated as part of this particular analysis. Three processes are associated with the section on "develop cost context." The processes are:

- * Identify Assumptions
- * Identify Cost Policy
- * Determine Lexicon

(1) **Identify Assumptions.** Develop a list of assumptions regarding the costing of the alternatives to be investigated. Identify costs which must be developed from surrogate information or analogous costs. Identify those alternatives which can use cost/quantity relationships and those which require different techniques for costing.

(2) **Identify Cost Policy.** Identify appropriate cost policies and their associated sources. Determine if the policies are relevant and applicable to the issue being investigated.

(3) **Determine Lexicon.** Identify and understand the cost terminology and coding to be used as part of the analysis. Define the resolution and composition of the costing to be conducted.

c. Select or Develop Appropriate Analytical Models and Tools. The second section of the costing module is exercised in order to determine the appropriate models and tools to be used in investigating the alternatives being analyzed. Five processes are associated with the second section. The processes are:

- * Identify Selection Criteria
- * Determine Lexicon
- * Determine Measures of Effectiveness
- * Review Alternative Costing Methods
- * Select Costing Models and Tools

(1) **Identify Selection Criteria.** Determine attributes needed in the costing model(s) required for this analysis.

(2) **Determine Measures of Effectiveness.** Identify model outputs required to conduct the analysis.

(3) **Review Alternative Costing Methods.** Conduct literature review for appropriate existing models and tools and determine feasibility for use in the analysis.

(4) **Select Costing Models and Tools.** Apply selection criteria in order to select appropriate models and tools for the analysis.

d. Implement Analytical Models and Tools. The third section of the costing module implements the models and tools

selected in section two. Seven processes are associated with the second section. The processes are:

- * Identify Data Requirements
- * Determine Lexicon
- * Obtain Modeling Capability
- * Develop an Experimental Design for Costing
- * Use Models and Tools
- * Analyze Results
- * Present Results or Pass Data to Next Module

(1) **Identify Data Requirements.** Determine attributes needed in the costing model(s) required for this analysis.

(2) **Obtain Modeling Capability.** The analyst conducting a Value Added Analysis would at this point obtain the capability to exercise the models and tools selected to be used for the analysis. This effort may require learning the models and how to use them, or developing from scratch a new model or tool. In the case of this prototype VAA Study, two costing models were revised and incorporated in the Value Added methodology--the Cost Quantity Model (CQM), and the Life Cycle Cost Model (LCCM). The CQM is used to provide the average annual weapon system cost, considering experience and production rate curves.(e.g., procurement cost) for input into FOMOA. CQM is used again to cost the optimal annual quantities computed by FOMOA. The LCCM can then be utilized to estimate the life cycle costs for the P92 cost elements, which are guidelines established by the US Army Cost and Economic Analysis Center (CEAC) for generating baseline cost estimates (BCE). A more detailed explanation of the models can be found in Chapter 6.

(3) **Develop an Experimental Design for Costing.** The cost analyst (or analysis team) needs to develop an experimental design based on the alternatives to be investigated. The experimental design step becomes more important if the analyst is working with costs which are not well understood, such as costs for developmental systems. If one could think of costs as a continuum with the left side being costs which are well known (such as historical data, through empirical data, to the right side which may consist of cost estimates), then the importance of a good experimental design becomes evident. The analyst needs to determine the appropriate experimental design using standard statistical techniques.

(4) **Use Models and Tools.** The analyst, using the experimental design developed in the previous step, conducts the appropriate model runs or calculations. The analyst should organize the results in a logical framework for displaying and documenting the results.

(5) **Analyze Results.** For the costing module there is a need to ensure that all costing elements are included and understood. Because some of the costs are developed through modeling, it is

important for the analyst to conduct some "common sense" checks against a sample of more rigorously obtained costing results.

(6) **Present Results or Pass Data to Next Module.** As indicated in step 5, the analysis team must analyze and save the results of the modeling work for later presentation. The results should be prepared in two forms. First, the analyst should prepare values for each MOE by each alternative to be passed to the optimization module. Secondly, the analyst should develop a "traditional" presentation of the modeling work consisting of vu-graph slides, graphs, and charts.

3-5. EFFECTIVENESS

a. Introduction

(1) This paragraph of Chapter 3, unlike the other paragraphs, combines the discussion of three of the VAA methodological modules--Explicit Effectiveness, Implicit Effectiveness, and Effectiveness Integration. The modules are combined under the heading of effectiveness because of their close linkage to one another and the manner in which they interact within the overall value assessment framework. As the Value Added Analysis Study progressed, it became clear that there were two components of issue effectiveness which were instrumental in the decision process. These components of effectiveness may be generally characterized as being either explicit (quantifiable) or implicit (qualitative or subjective). The implicit measures of effectiveness may be thought of as modifiers or supplemental to the explicit, and therefore "secondary."

(2) The Value Added Analysis concept uses a hierarchical assessment framework for developing a single measure of benefit. This framework is used in VAA to provide the logical skeleton in which to build an alternative's effectiveness value. The analytical hierarchy process (AHP) is particularly effective in building a decision framework and for eliciting experts' subjective judgments. Figure 3-4 outlines the current analytical hierarchy for a standardized Value Added Analysis.

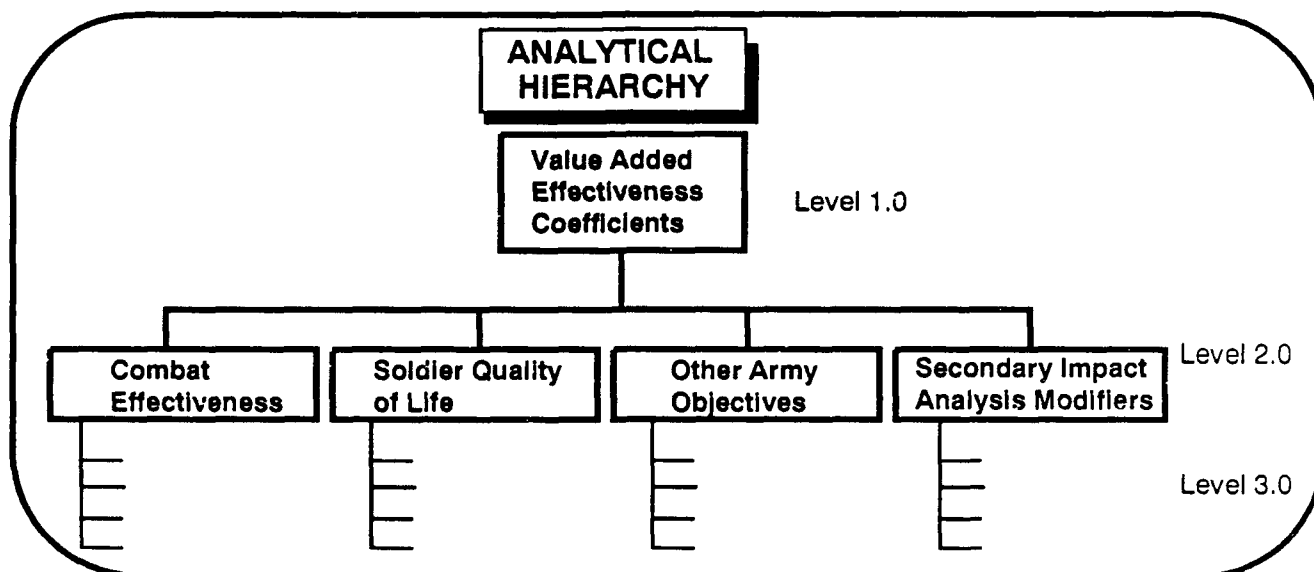


Figure 3-4. Alternative One Information Requirements

Each level of the hierarchy is weighted by the decisionmaker. Level 1.0 represents the overall objective of the hierarchy, which is to develop Value Added Effectiveness Coefficients (the single measure of benefit) for passing onto the optimization module. The intermediate boxes (level 2.0) are a hierarchical breakdown of level 1.0 and are used to represent the components of value. The MOE as represented by the lines beneath each box (level 3.0) in Figure 3-4 are the foundation of the hierarchy and are the fundamental measures of value. Each of these MOE is evaluated either using quantitative models or subjective scoring. This hierarchy is used in conjunction with the effectiveness integration module to build a single measure of value.

(3) The first component of value (explicit effectiveness) is measured by that category of MOEs which lend themselves to direct quantification. This first component of value is represented as the first three subdivisions of the 2.0 level of the Value Added analytical hierarchy.

(4) The second component of value (implicit effectiveness) is measured by that category of MOE which are qualitative or subjective in nature. In analyzing how program decisions are actually made within the Pentagon and the Department of the Army, it became very clear that other factors also influenced the decision process. These factors became known to the study team as secondary impact analysis modifiers (SIAM factors) and are shown in Figure 3-4 as the fourth subdivision of level 2.0 of the hierarchy.

b. Explicit Effectiveness Module

(1) **Introduction.** The purpose of the third module in the Value Added Analysis methodology is to develop the explicit effectiveness values. The Explicit Effectiveness Module contains three submodules. These submodules are: Combat Effectiveness,

Soldier Quality of Life, and Other Army Objectives. Although each submodule measures a different functional area of the Army, they all have two things in common. First, the techniques associated with the submodule can measure the output of an alternative directly, and second, each submodule uses a common structure. This structure includes three sections: develop a context, select or develop appropriate analytical models and tools, and implement analytical models and tools. Matrix 1 in Appendix D depicts the full structure for the combat submodule. Even though there are three submodules in the methodology, only the Combat Effectiveness Submodule will be discussed because of the limited scope of this prototype study.

(a) The Combat Effectiveness Submodule is as its name implies. The techniques used are the traditional combat analysis approaches currently accepted in the Army.

(b) The second submodule refers to those Army programs and functions which address military personnel and family member issues. These include such issues as pay, child care, commissaries, medical care, etc. These issues must be considered separately because they cannot currently be measured directly in any of the current combat approaches. However, their impact on readiness is accepted by all of the decisionmakers interviewed.

(c) The last submodule refers to all the other objectives, functions and missions that the Army is required to meet. These items would include such things as nation building missions, equal opportunity, sustaining base, etc. These too are not easily related to combat but are certainly important to the overall Army mission.

(2) **Develop A Context.** The first section of the modules is used to develop the explicit effectiveness context for the alternatives being investigated as part of a Value Added Analysis. Six processes are associated with the section on context development. The processes are:

- * Identify Assumptions
- * Identify Force Structure
- * Identify Appropriate Doctrine
- * Identify Resources
- * Develop Scenarios
- * Determine Lexicon

(a) **Identify Assumptions.** Develop a list of assumptions regarding explicit effectiveness. The analyst must understand the issue(s) and associated alternatives well enough to identify critical elements of information. Furthermore, the analyst must recognize which critical elements of information may not have data available. This lack of data must be handled either through the use of assumptions (which allows the use of surrogate data) or analogous approaches to data development. For example, in the illustrative A3 problem, a European scenario was assumed to be the most important world view and therefore the one to use in these tradeoffs.

(b) **Identify Force Structure.** Identify the force structure and levels that are consistent with the context being developed.

(c) **Identify Appropriate Doctrine.** Identify all appropriate doctrine to be used or which would influence the combat modeling.

(d) **Identify Resources.** Identify all the resources to be played.

(e) **Develop Appropriate Scenarios.** Develop scenarios consistent with the context being developed.

(f) **Determine Lexicon.** Identify and understand any unique terminology associated with the issue and alternatives.

(3) **Select or Develop Appropriate Analytical Models and Tools.** The second section of the module is exercised in order to determine the appropriate models and tools to be used in investigating the alternatives being analyzed. Five processes are associated with the second section. The processes are:

- * Identify Selection Criteria
- * Determine Lexicon
- * Determine Measures of Effectiveness
- * Review Alternative Analytical Methods
- * Select Models and Tools

(a) **Identify Selection Criteria.** Determine the set of attributes required to evaluate the applicability of a model for the Value Added Analysis to be conducted. A set of judgment criteria needs to be developed to allow the analyst to select the appropriate models and tools for the study. For the armor/antiarmor illustrative example, the team determined that a corps-level combat simulation capable of measuring the synergistic effects of weapons systems was needed. Furthermore, a model was needed which had sufficient resolution and breadth to adequately reflect changes in weapon system characteristics (such as probability of kill [PK], rate of fire, basic load, etc.).

(b) **Determine Measures of Effectiveness.** Identify model outputs required to conduct the analysis. The explicit MOE have been, for the most part, the traditional criteria for judging effectiveness. These MOE might include such things as system exchange ratios, loss exchange ratios, tons of supply moved, days of supply, soldiers per month retained by category, child care days, etc. The results of this module (MOE values for each alternative) are passed to the effectiveness integration module. Table 3-2 shows an example of output values from this module to be passed for three of the alternatives from the A3 illustrative example.

**Table 3-2. Explicit Effectiveness Output
(Selected A3 Alternatives)¹**

Systems	MOE		
	COFM	MFCM	BFS
M1A2	2.39	134.4	39
NLOS-AT	3.81	133.1	41
MLRS SADARM	2.95	132.6	39

(c) **Review Alternative Analytical Methods.** Conduct literature review for appropriate existing models and tools and determine feasibility for use in the analysis.

(d) **Select Models and Tools.** Apply the selection criteria in order to identify appropriate models and tools for the analysis.

(4) **Implement Analytical Models and Tools.** The third section of the explicit effectiveness module implements the models and tools selected in section 2. Seven processes are associated with the second section. The processes are:

- * Identify Data Requirements
- * Determine Lexicon
- * Obtain Modeling Capability
- * Develop An Experimental Design
- * Use Models and Tools
- * Analyze Results
- * Present Results or Pass Data to Next Module.

(a) **Identify Data Requirements.** Based on the issue and alternatives to be analyzed, review the models and tools selected for input data requirements. The analyst should develop a data collection plan and means by which to manipulate the data. For the A3 illustrative example, the analysis team would collect scenario, weapon characteristics data, and force structure data. As envisioned by the study team, the final form of the Value Added Analysis Decision Support System will contain a centralized data base engine to assist in this step.

(b) **Obtain Modeling Capability.** The analyst conducting a Value Added Analysis would at this point obtain the capability to exercise the models and tools selected to be used for

¹Table 3-2 shows example data output by system. This may also be calculated by package. In our example the base case and the two alternatives would be packages. A selected set of systems from the A3 alternatives are presented here in order to show how a full matrix might look. The following definitions are provided for the acronyms found in the table:

1. COFM = Correlation of Forces and Means (a measure of Red strength vs Blue strength)
2. MFCM = Movement Force Center of Mass (a measure of performance based on the distance the center of mass of a force has moved toward its objective).
3. BFS = Blue Force Surviving (the number of blue units still combat effective)

the analysis. This effort may require learning the models and how to use them, or developing from scratch a new model or tool. For the armor/antiarmor example, the study team developed a capability to use the Corps Battle Analyzer (CORBAN) Model. The effort to obtain this capability required the building of a modeling team, training the team, obtaining physical space, and obtaining the use of appropriate computer hardware.

(c) Develop An Experimental Design. The analyst (or analysis team) needs to develop an experimental design based on the solutions to be investigated. An essential requirement is to determine if any groupings of solutions should be considered. The issue clarification module can be helpful as a source for identifying initial groupings. The groupings may grow out of alternative dependencies such as physical, operational or doctrinal. The development of groupings assist greatly in scaling down the size and extent of the experimental design. After all groupings have been completed, the analyst needs to determine the appropriate experimental design using standard statistical techniques.

(d) Use Models and Tools. The analyst, using the experimental design developed in the previous step, conducts the appropriate model runs or calculations. The analyst should organize the results in a logical framework for displaying and documenting the results.

(e) Analyze Results. Always an important aspect of any study, this step is extremely important for the Value Added Analysis methodology. At first reading, one may feel that the VAA methodology only requires a set of output numbers. The methodology does indeed require the results to be boiled down to MOE values (for passing to follow-on modules). However, the reasons for the MOE values must be identified and kept visible and available to provide detailed explanations of the results. Detailed results are always important for the insights they provide, but in the case of the VAA methodology, the detailed results specifically become important as a means of building decisionmaker confidence in the VAA process results.

(f) Present Results or Pass Data to Next Module. As indicated in step five, the analysis team must analyze and save the results of the modeling work for later presentation. The results should be prepared in two forms. First, the analyst should prepare spreadsheet values for each MOE by each alternative to be passed to the effectiveness integration module. Secondly, the analyst should develop a "traditional" presentation of the modeling work consisting of vu-graph slides, graphs, and charts. Using the illustrative example from the A3 issue, the analyst would develop a cost and quantity stream presentation by weapon system by year.

c. Implicit Effectiveness Module

(1) **Introduction.** The fourth module in the Value Added Analysis methodology develops the hierarchical weights for both the explicit and implicit components of value and develops the implicit effectiveness values. This module is intended to accomplish two objectives. The first objective consists of weighting all the levels of the assessment hierarchy and the individual criteria. The second objective consists of scoring each alternative using the SIAM factors. Both of these objectives are aimed at capturing the subjective aspects of the decisionmaking process. As discussed in Chapter 2, previous attempts at program tradeoff methodologies did not accommodate the decisionmaker and the process by which decisions are made. The implicit effectiveness module was specifically designed to quantify the subjective elements of the decision process in a way that it could be used to conduct tradeoff analyses. This module also includes three sections similar to those found in the explicit effectiveness module. Matrix 1 in Appendix D depicts the full framework for the Implicit Effectiveness Module.

(a) The implicit (subjective) value component of the VAA methodology consists of a set of decision criteria, called SIAM factors. These SIAM factors are the implicit criteria. There were 11 SIAM factors established for the Value Added Analysis and a complete discussion of these factors, including full definitions for each, can be found in Chapter 7. These factors are considered to measure implicit value because their intent is to capture those items which influence the decisionmaking process but resist being quantified directly. These factors are shown in Figure 3-5.

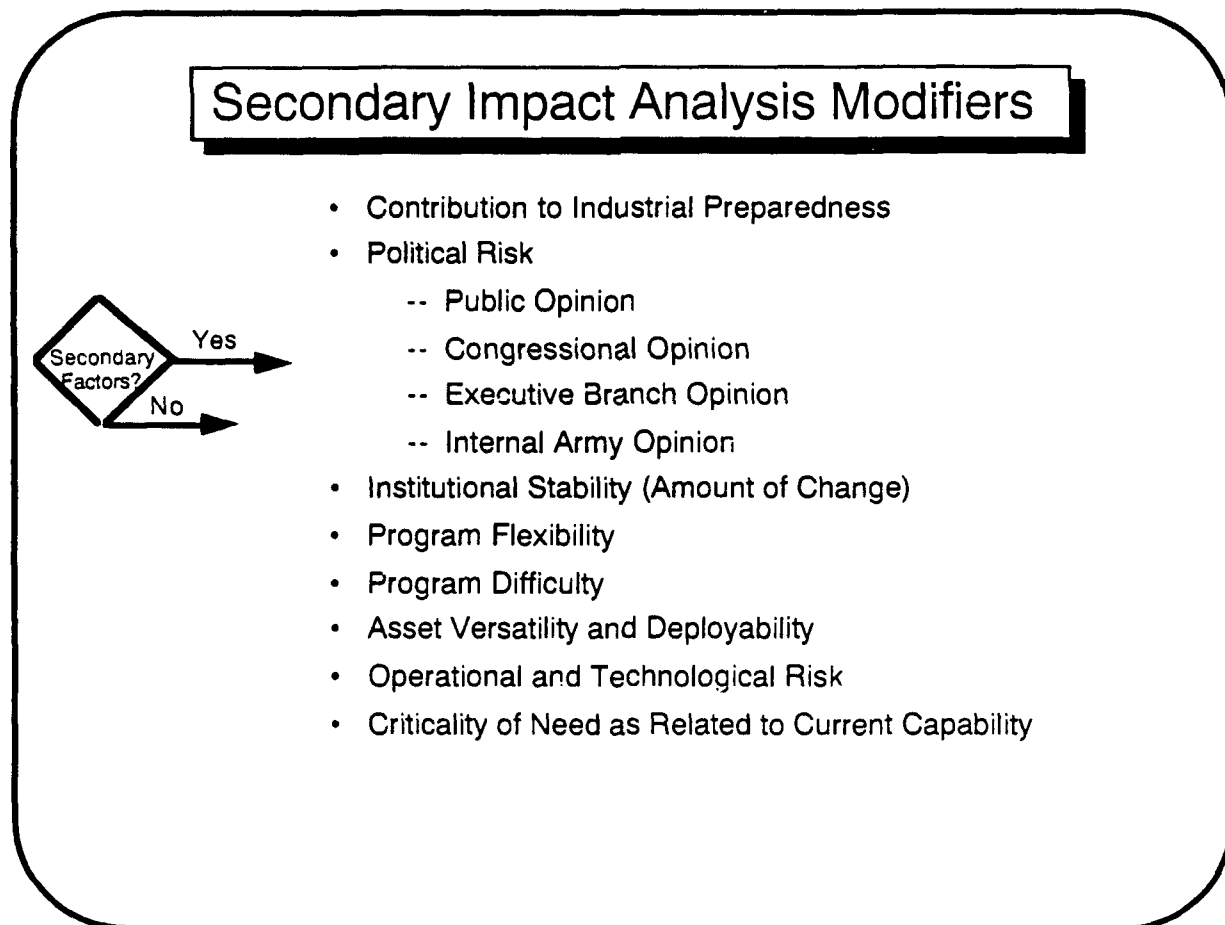


Figure 3-5. Secondary Impact Analysis Modifiers

(b) Values for the SIAM factors were developed through the use of two surveys.

1. The first survey was given to decisionmakers at the senior executive service and general officer level. The VAA SIAM factors were developed prior to the implementation of the survey and were modified, added, or deleted as part of the weighting process. Teams interviewed and surveyed the Army leadership residing in interest groups such as the Army Staff (ARSTAF), major Army commands (MACOMs), commanders in chief (CINCs), Office of the Secretary of Defense (OSD), etc. The final result of this first survey is a set of secondary factors that have been weighted as well as the remainder of the analytical hierarchy (see Figure 3-4, page 3-10).

2. The second survey was given to a group different from the decisionmakers. This second group consisted of subject matter experts (SME). An individual is selected to be part of this SME group because of his expertise regarding the systems (or issues). These experts are asked to score a system (or issue) on its own merit in relation to the SIAM factors. The end result of this portion of the implicit effectiveness module is a set of scores for each system

which are equivalent to the MOE values coming out of the combat modeling.

(c) These three elements--decisionmaker weights, explicit MOE values, and SME scores--can be used either directly by decisionmakers or fed into a multiobjective linear program to determine an alternative's cost effectiveness and, in turn, acquisition strategy. In either case, the explicit MOE and the implicit MOE are given a weight by the decisionmakers as a means of rank ordering the MOE as to importance.

(2) **Develop a Context.** The first section of the module is used to develop the implicit effectiveness context for the alternatives being investigated as part of this particular analysis. Two processes are associated with the section on "develop context." The processes are:

- * Identify Assumptions
- * Determine Degree or Extent of Secondary Factors

(a) **Identify Assumptions.** Develop a list of assumptions regarding the alternatives to be investigated. In the A3 illustrative example, a key assumption was the decreasing federal budget and therefore the need to decrement the procurement accounts.

(b) **Determine Degree or Extent.** Determine if the secondary factors are to be applied.

(3) **Select or Develop Appropriate Analytical Models and Tools.** The second section of the module is exercised in order to determine the appropriate models and tools to be used in investigating the alternatives being analyzed. Five processes are associated with the second section. The processes are:

- * Identify Selection Criteria
- * Determine Lexicon
- * Determine Measures of Effectiveness
- * Review Alternative Methods
- * Select Models and Tools

(a) **Identify Selection Criteria.** Determine attributes needed in the model(s) required for this analysis. For our example, we needed to capture the factors which decisionmakers that the Department of the Army felt were important in trading off alternative programs.

(b) **Determine Measures of Effectiveness.** Identify model outputs required to conduct the analysis. In our illustrative example, this was the scoring for the 11 SIAM factors on a scale of 1 to 9.

(c) **Review Alternative Methods.** Conduct literature review for appropriate existing models and tools and determine feasibility for use in the analysis. During the building of the

prototype methodology, the literature review resulted in two approaches, to include a decision tree analysis and Saaty's pairwise comparison technique.

(d) **Select Models and Tools.** Apply selection criteria in order to select appropriate models and tools for the analysis. We selected the pairwise comparison technique because it was quick, easily understood by the decisionmakers, and easy to implement.

(4) **Implement Analytical Models and Tools.** The third section of the module implements the models and tools selected in section two. Seven processes str associated with the third section. They are:

- * Identify Data Requirements
- * Determine Lexicon
- * Obtain Modeling Capability
- * Develop An Experimental Design
- * Use Models and Tools
- * Analyze Results
- * Present Results or Pass Data to Next Module.

(a) **Identify Data Requirements.** Determine attributes needed in the model(s) required for this analysis. The strawman SIAM factors were helpful in focusing the data requirements. It was determined that a survey of military judgment based on a standardized scale would be sufficient to meet the data needs.

(b) **Obtain Modeling Capability.** The analyst conducting a Value Added Analysis would at this point obtain the capability to exercise the models and tools selected to be used for the analysis. This effort may require learning the models and how to use them, or developing from scratch a new model or tool. In our example, we created a standardized survey briefing and scoring instrument. We developed a survey team and conducted some practice surveys to refine the techniques.

(c) **Develop an Experimental Design.** The analyst (or analysis team) needs to develop an experimental design based on the alternatives to be investigated. The experimental design step becomes more important if the analyst is working with data which are not well understood. The analyst needs to determine the appropriate experimental design using standard statistical techniques. The decisionmakers and PA&E and the technical advisor's office helped to identify the appropriate respondents for this first cut prototype effort.

(d) **Use Models and Tools.** The analyst, using the experimental design developed in the previous step, conducts the appropriate model runs or calculations. The analyst should organize the results in a logical framework for displaying and documenting the results. The survey team conducted the surveys over a 3-week period.

(e) **Analyze Results.** The methodology also requires the results of the implicit effectiveness module to be boiled down to MOE values (for passing to follow-on modules). However, the reasons for the MOE values must be identified and kept visible and available to provide detailed explanations of the results. This is much more difficult for this module than for the explicit effectiveness because the weights and scores are developed in the minds of both the decisionmakers and the subject matter experts. Whenever possible, the study team tried to capture narrative comments regarding the weighting and scoring to provide a flavor of the reasoning behind the final numbers developed. The study team created a series of spreadsheets from the results of the surveys and conducted both correlation analysis and consistency analysis on the data. Appendix E contains the detailed results of this analysis. Because of the classification of the results, Appendix E is published separately in order to keep this report unclassified.

(f) **Present Results or Pass Data to Next Module.** As indicated in step 5, the analysis team must analyze and save the results of the modeling work for later presentation. The results should be prepared in two forms. First, the analyst should prepare spreadsheet values for each MOE by each alternative to be passed to the optimization module. Secondly, the analyst should develop a "traditional" presentation of the modeling work consisting of vu-graph slides, graphs, and charts. The team created a composition spreadsheet and passed the data contained therein to the TOPSIS (Technique for Ordered Preference by Similarity to Ideal Solution) Model in the Effectiveness Integration Module.

d. Effectiveness Integration Module

(1) **Introduction.** The fifth module in the Value Added Analysis methodology combines the explicit and the implicit effectiveness values with the decisionmakers' weights. The current configuration of the standardized Value Added Analysis methodology for this module uses a model called TOPSIS. This technique allows us to develop a single measure of benefit. This single measure is passed as a program value coefficient into the linear programming model. Matrix 1 in Appendix D depicts the full framework for this module.

(2) **Develop a Context.** The first section of the module is used to develop the effectiveness integration context for the alternatives being investigated as part of this particular analysis. Three processes are associated with the section on "develop context." The processes are:

- * Identify Assumptions
- * Identify Policy
- * Determine Degree or Extent of Effectiveness Integration

(a) **Identify Assumptions.** Develop a list of assumptions regarding the alternatives to be investigated. The single most important assumption associated with this module refers to the objective function of each SIAM factor. The TOPSIS model requires the analyst to declare if the factor is to be maximized or minimized. This max/min declaration is applied to all alternatives and therefore assumes that the objective function will not change from one alternative to the next.

(b) **Identify Policy.** Identify appropriate policies and their associated sources. Determine if the policies are relevant and applicable to the issue being investigated. In the illustrative example, the objective function for program flexibility was set to "maximize" based on the policy that programs should be flexible.

(c) **Determine Degree or Extent of Effectiveness Integration.** Determine if the effectiveness is to be completely integrated or partially. If effectiveness to be incorporated in the follow-on modules or extracted at this point and provided as raw output.

(d) **Determine Lexicon.** Identify and understand the terminology to be used. Ensure that the max/min relationship for each factor is understood and fully defined.

(3) **Select or Develop Appropriate Analytical Models and Tools.** The second section of the module is exercised in order to determine the appropriate models and tools to be used in investigating the alternatives being analyzed. Five processes are associated with the second section. The processes are:

- * Identify Selection Criteria
- * Determine Lexicon
- * Determine Measures of Effectiveness
- * Review Alternative Methods
- * Select Models and Tools

(a) **Identify Selection Criteria.** Determine attributes needed in the effectiveness integration model(s) required for this analysis. The need to combine multiple attributes was the key criterion in selecting a model for this module. Furthermore, VAA needed a way in which this combination could be quantified and consolidated into a single value.

(b) **Determine Measures of Effectiveness.** Identify model outputs required to conduct the analysis. The MOE for this module was set by EEA 2 in which we hypothesized that a linear combination of value components could be used to arrive at a single numeric measure of value. For this prototype effort, the TOPSIS value measuring the distance of an alternative from an ideal solution in a Euclidean space became this single measure of value.

(c) **Review Alternative Methods.** Conduct literature review for appropriate existing models and tools and determine feasibility for use in the analysis. Our literature review did not identify candidates other than TOPSIS.

(d) **Select Models and Tools.** Apply selection criteria in order to select appropriate models and tools for the analysis. TOPSIS was selected because it was available and met the need to create a linear combination of value components.

(4) **Implement Analytical Models and Tools.** The third section of the module implements the models and tools selected in section 2. Seven processes are associated with the second section. The processes are:

- * Identify Data Requirements
- * Determine Lexicon
- * Obtain Modeling Capability
- * Develop an Experimental Design
- * Use Models and Tools
- * Analyze Results
- * Present Results or Pass Data to Next Module.

(a) **Identify Data Requirements.** Determine attributes needed in the model(s) required for this analysis. The data needed for this module is directly provided by the explicit and implicit effectiveness modules and includes the decisionmaker's weights, the combat simulation results (MOE), and the scoring of the 11 SIAM factors.

(b) **Obtain Modeling Capability.** The analyst conducting a Value Added Analysis would at this point obtain the capability to exercise the models and tools selected to be used for

the analysis. This effort may require learning the models and how to use them, or developing from scratch a new model or tool. The TOPSIS model was written in "C" programming language by the team for inclusion in the METAPHOR^{TM1} environment and subsequent VAA Decision Support System. For more information on TOPSIS, see Appendix G.

(c) **Develop an Experimental Design.** The analyst (or analysis team) needs to develop an experimental design based on the alternatives to be investigated. For this prototype analysis, we developed a design which investigated the differences in the single measure of value when we chose different MOE for the explicit effectiveness module. In particular, there was concern expressed regarding the nontraditional MOEs of Blue force surviving, correlation of forces and means, and movement force center of mass. The team looked at loss exchange ratios (LER), system exchange ratios (SER), and fractional exchange ratios (FER) as substitutes for the MOE we originally selected.

(d) **Use Models and Tools.** The analyst, using the experimental design developed in the previous step, conducts the appropriate model runs or calculations. For our illustrative example, this step was very simple and took a matter of seconds.

(e) **Analyze Results.** Some parametric analysis was conducted on the input data (especially the combat MOE) to gain insight into which factors truly influenced the outcome. For example, we used both the original set of explicit MOE (BFS, COFM, and MFCM) and the fractional exchange ratio to see how the range of the TOPSIS values would change for each alternative.

(f) **Present Results or Pass Data to Next Module.** As indicated in step 5, the analysis team must analyze and save the results of the modeling work for later presentation. The results for this module for our illustrative example were prepared in two forms. First, a spreadsheet of program value coefficients for each alternative was prepared and passed to the optimization module. Secondly, a "traditional" presentation of the modeling work was developed consisting of vugraph slides.

3-6. OPTIMIZATION MODULE

a. **Introduction.** The sixth module in the Value Added Analysis methodology uses the program value coefficients developed in the Effectiveness Integration Module and the costs from the Costing Module to conduct a cost-benefit analysis. The optimization tool provides the means for integrating the costs and benefits into a comprehensive cost-benefit analysis. There is a shortcoming in the present configuration of the cost-benefit analysis. We consider only procurement costs here. O&S costs are used in the prototype for accounting purposes only. Furthermore the cost values used for the

¹¹ METAPHORTM is a trademark of the Metaphor Computer Corporation. Metaphor software provides an icon-based user interface to Standard Query Language (SQL)-based relational data bases.

optimization constitute average unit costs. Costs are actually a function of the quantity produced (see chapter 6). No provision was made in this formulation to take into account this functional relationship. Therefore the possibility exists that using average unit costs as an approximation could result in a violation of the budget constraint when the true cost is considered. Another possible result is suboptimality in the solution. Unfortunately, this problem has plagued analysts for years, and its solution was beyond the scope of this study. This problem should be addressed in future Value Added Analysis applications

b. The cost-benefit analysis is characterized as an optimization of an alternative mix and affordability problem. It is within this module that the marginal value of an alternative is translated into meaningful tradeoffs. The current configuration of the standardized Value Added Analysis methodology for this module uses an optimization model called FOMOA (Force Modernization Analyzer). Matrix 1 in Appendix D depicts the full framework for this module.

b. **Develop a Context.** The first section of the module is used to develop the optimization context for the alternatives being investigated as part of this particular analysis. Three processes are associated with the section on "develop context". The processes are:

- * Identify Assumptions
- * Identify Policy
- * Determine Lexicon

(1) **Identify Assumptions.** Develop a list of assumptions regarding the alternatives to be investigated. For this prototype study, an objective of maximizing the total value subject to force structure and dollar constraints.

(2) **Identify Policy.** Identify appropriate policies and their associated sources. Determine if the policies are relevant and applicable to the issue being investigated. As part of the issue clarification work conducted for the VAA proof of concept case study policies regarding production line start dates and capacities were identified as key policy factor.

(3) **Determine Lexicon.** Identify and understand the terminology to be used. Define the resolution and composition of the constraints.

c. **Select or Develop Appropriate Analytical Models and Tools.** The second section of the module is exercised in order to determine the appropriate models and tools to be used in investigating the alternatives being analyzed. Five processes are associated with the second section. The processes are:

- * Identify Selection Criteria
- * Determine Lexicon
- * Determine Measures of Effectiveness

- * Review Alternative Methods
- * Select Models and Tools

(1) **Identify Selection Criteria.** Determine attributes needed in the model(s) required for this analysis. The key modeling attribute needed for this module was the ability to optimize alternatives using a cost-benefit framework.

(2) **Determine Measures of Effectiveness.** Identify model outputs required to conduct the analysis. The MOE selected for this module included ease of optimization formulation, the ability to handle production line constraint information, a generalized algebraic formulation which created a very flexible and robust model, and the ability to run on multiple platforms.

(3) **Review Alternative Methods.** Conduct literature review for appropriate existing models and tools and determine feasibility for use in the analysis. The literature review for this module was not extensive because of previous work completed at CAA. The Value Added team incorporated this previous work because of its direct applicability to the VAA Study.

(4) **Select Models and Tools.** Apply selection criteria in order to select appropriate models and tools for the analysis. The selection criteria were in part created as we reviewed the previous optimization work completed at CAA. This step was, in effect, simultaneous with step 2 above.

d. Implement Analytical Models and Tools. The third section of the module implements the models and tools selected in section two. There are six processes associated with the second section. The processes are:

- * Identify Data Requirements
- * Obtain Modeling Capability
- * Develop An Experimental Design
- * Use Models and Tools
- * Analyze Results
- * Present Results or Pass Data to Next Module

(1) **Identify Data Requirements.** Determine attributes needed in the model(s) required for this analysis. The data required that was unique to this module was focused on dollar and production line constraint information.

(2) **Obtain Modeling Capability.** The analyst conducting a Value Added Analysis would at this point obtain the capability to exercise the models and tools selected to be used for the analysis. For the prototype study, the team used an optimization approach and formulation develop by CAA for use in building modernization plans. We modified this model and installed it on a Macintosh IICx. The team was up and using the new model approximately 2 days after installation.

(3) **Develop an Experimental Design.** The analyst (or analysis team) needs to develop an experimental design based on the alternatives to be investigated. The experimental design for our illustrative example was driven by the budget decrement exercises being conducted at the Pentagon during the spring and summer of 1990. We also included in the design a set of runs which would allow us to investigate the sensitivity of the model to selected input parameters.

(4) **Use Models and Tools.** The analyst, using the experimental design developed in the previous step, conducts the appropriate model runs or calculations. We conducted two sets of model runs based on two views of the 92-97 POM. The first was based on a pre-CFE view, and the second was based on a post-QUICKSILVER (post-CFE view) dollar decrement.

(5) **Analyze Results.** For our illustrative example, we looked at the interactions taking place because of the various constraints and input data. The team tried to isolate the most important data for future investigation.

(6) **Present Results or Pass Data to Next Module.** As indicated in step five, the analysis team must analyze and save the results of the modeling work for later presentation. The results of our illustrative example were presented as "typical" funding and quantity streams one would find presented in the Army POM.

3-7. RESOURCE ALLOCATION MODULE. The seventh module in the Value Added Analysis methodology uses results of the optimization module to distribute the mix of alternatives to the appropriate Army organization or agency. For this prototype study, we did not develop this module. Matrix 1 in Appendix D depicts the full framework for this module.

3-8. RESULTS AND DISPLAY MODULE. The eighth module in the Value Added Analysis methodology contains the set of models and tools required to analyze and present the results in a meaningful manner. The VAA methodology requires a flexible data base manipulator to provide responsive data handling for both output and input data. Furthermore, this methodology requires a computer environment which will assist the analyst in the task of integrating all of the modules into a coherent decision support system. The METAPHOR™ environment has permitted this integration by providing a single architecture for manipulating issue description data, system definition data, the TOPSIS Model, the FOMOA Model, and a variety of display screens, and by combining these elements into a single decision support system. We have not developed a set of presentation formats nor reports. Our objective for this module during this prototype study was to identify the requirement and propose a capability to be further developed in the future.

CHAPTER 4

ISSUE CLARIFICATION

4-1. INTRODUCTION

a. The purpose of this chapter is to provide a discussion of the Issue Clarification Module of the Value Added Analysis methodology. The chapter addresses the four processes contained within this module. The chapter is structured as follows:

- (1) Introduction
- (2) Receive the Issue
- (3) Obtain Broad Guidance
- (4) Describe Issue Relationships
- (5) Determine How the Methodology Will be Used

b. Figure 4-1 depicts the elements of the module to include the receiving of an issue, a description of the issue in the context of four subelements (system, organization, appropriation, and policy), and the concept of understanding issues in light of national military goals and objectives.

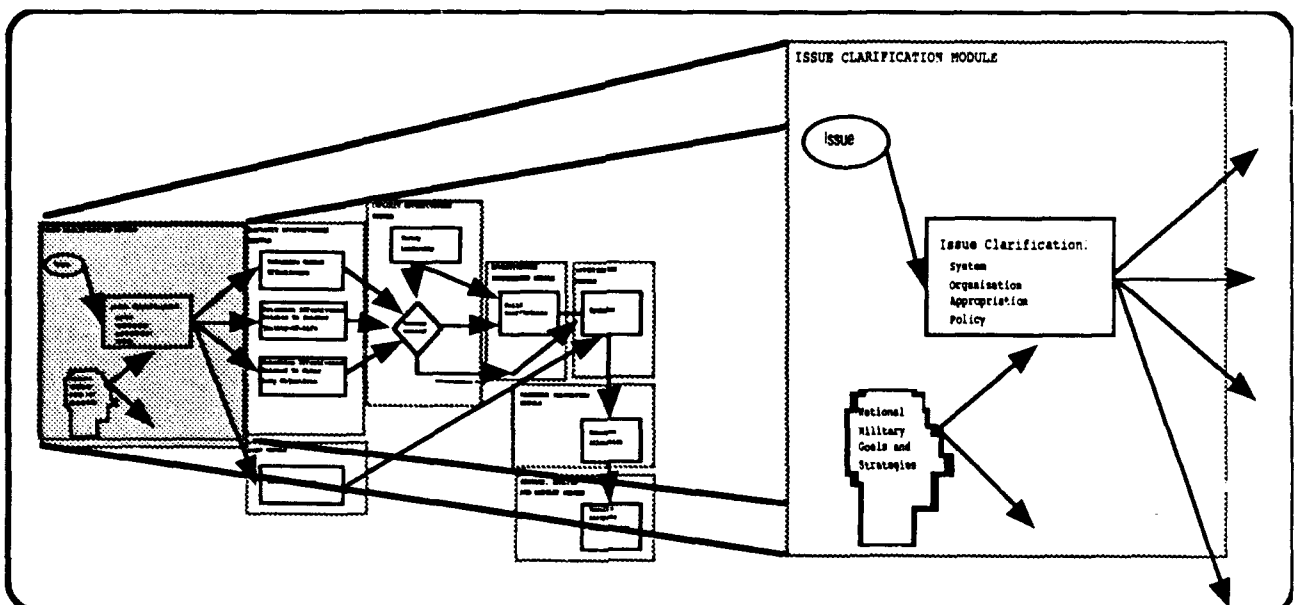


Figure 4-1. VAA Methodology - Issue Clarification Overview

c. Issue clarification is perhaps the most important module in the Value Added Analysis methodology because its purpose is to define the problem that needs to be analyzed, and, as such, establishes the

framework for the entire analysis. Thus, an inadequate issue clarification phase translates directly into a poorly defined problem and a misleading or irrelevant solution.

d. The actual methodology development of the Issue Clarification Module accomplished in this study is related primarily to defining the information needed, establishing critical relationships, and identifying the types of analytical tools and methods that might be useful to perform the tasks associated with the module. No specific tools or methods were developed or used in this study for issue clarification. As the Value Added Analysis methodology matures, these tools and methods will be produced to expedite and automate the issue clarification portion of the overall methodology.

4-2. RECEIVE THE ISSUE. An example of an issue that might be analyzed using the Value Added methodology is shown in Figure 4-2.

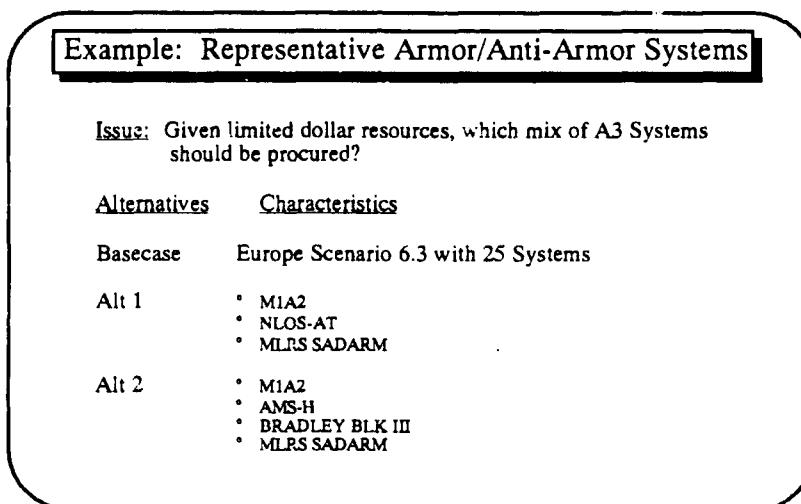


Figure 4-2. Example VAA Issue

Issues received by the analyst are likely to be, at first cut, very fuzzy. Thus, the issue clarification step is inherently iterative. As the analyst gathers more and more information in the conduct of the analysis, systems may change or be added or deleted, scenarios could be modified, additional alternatives could be considered, and the like. Consequently, the analyst must begin with a broader perspective and, as more information is obtained, narrow the focus of the issue to get to the heart of the matter. This narrowing and clarification is accomplished using the three remaining processes associated with the Issue Clarification Module. These processes are: obtain broad guidance, describe issue relationships, and determine how the methodology will be used. These processes will be described in detail in subsequent sections.

4-3. OBTAIN BROAD GUIDANCE. In order to provide the best possible information and assistance to the decisionmaker, the

analyst must have a clear idea of the viewpoint of the decision-maker, his "World View," and the decisionmaking environment with respect to the factors that are most important to consider. For example, the decisionmaker's opinion as to the most probable next conflict scenario must be considered when evaluating alternatives. Another example involves the investment strategy of the decisionmaker. If the strategy entails more emphasis on research and development and less on procurement, the thrust of the analysis would be different. One must also be cognizant of the constraints under which the decision will be made. For instance, if Congress has mandated that a particular system should or should not be fielded, or if a particular program is highly unpopular politically, the analysis should take these factors into consideration.

4-4. DESCRIBE ISSUE RELATIONSHIPS

a. Introduction. In order to properly place an issue or group of issues into the appropriate context, the analyst must be able to describe the relationships of the issue by system, organization, policy, and appropriation. Only then can the impacts of the decision be evaluated in the broadest sense. In order to accomplish this portion of the analysis, a significant amount of research is required on the part of the analyst to ensure that all areas affecting the issue and affected by the issue are examined. For the most part, this research must be done by consulting subject matter experts, documents, and data bases to obtain this necessary information. The possibility exists that some expert system approach to data identification and collection would be useful in this process. An example of the type of software/model combination needed in this module is the Stakeholder software/model developed at the University of Arizona, Tucson, as part of their Group Decision Support Laboratory. The models and software designed for this section of the module must help identify interest groups, categorize data, and discern relationships between various factors.

b. Organizational Relationships. Of equal importance to the impacts of a decision from a systems perspective are impacts relating to organizations. For example, the theaters that would be affected and the types of impacts on those theaters must be considered. One impact might be the need to modify operation plans (OPLANS) as the result of the implementation of some alternative. Consideration must also be given to the units that are affected by these decisions.

c. Policy Relationships. Policy relationships are directly related to the decisionmaking environment that exists. Policy statements will influence the choices made through identifying objectives or requirements that must be met. For the Value Added Analysis methodology, this portion of the module should be closely aligned to major policy documents such as the Defense Guidance (DG), The Army Plan (TAP), or the Army Long-Range Plan. Additionally, any policy decisions which have been

specifically made regarding the issue to be analyzed must be fully understood. One example of this type of policy is the decision to try and develop armor/antiarmor systems using a common vehicle chassis.

d. **System Relationships.** The Value Added Analysis methodology requires a clear description of the systems involved in each alternative. The Army Resource Integration and Management (ARIM) Study performed by CAA suggests a method of management of systems (AMIS - Army Major Item Systems) through the use of a comprehensive coding logic. In this method, each system is defined with respect to its primary equipment, associated items of equipment (ASIOE), personnel requirements, associated facilities, secondary items, and training items. Through the coding schema, the system definition can be related to its costs, budgeting, force structure considerations, and the like. The ARIM methodology can be used to identify the impact, from a system perspective, of the various issue alternatives. ARIM was designed for incorporation into the Value Added Analysis Methodology. Figure 4-4 depicts this incorporation.

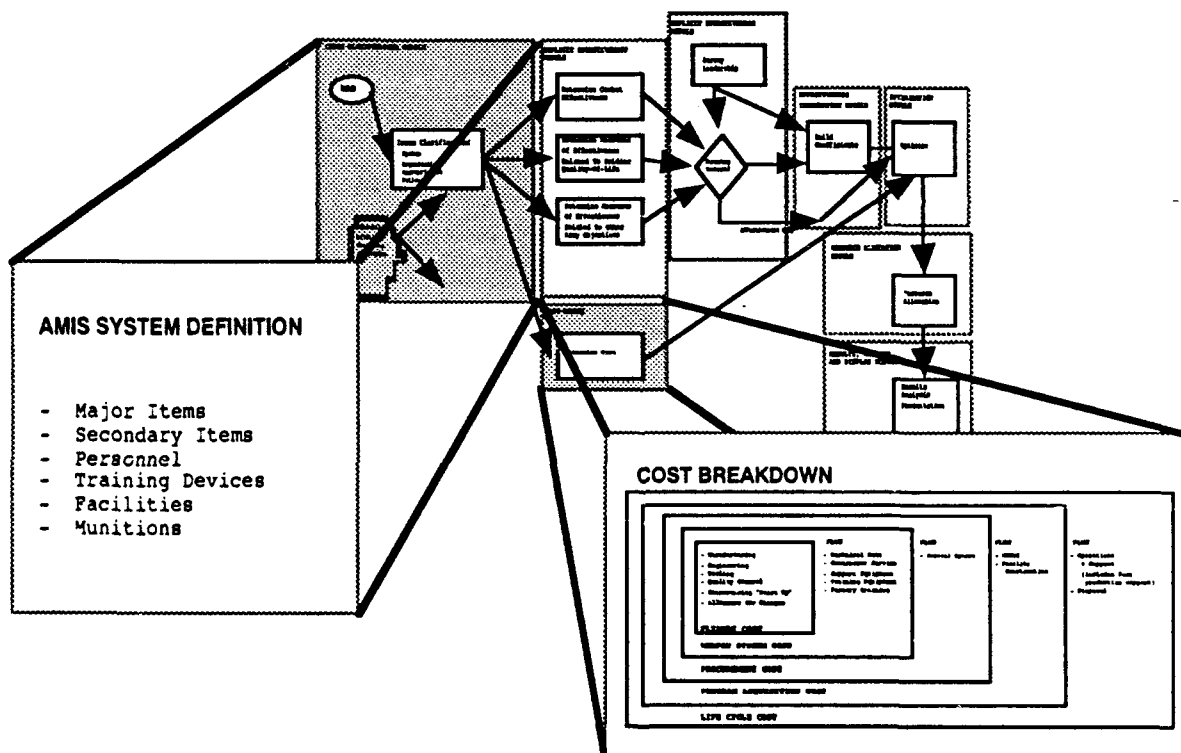


Figure 4-3. Value Added/ARIM Relationship

4-5. DETERMINE HOW THE METHODOLOGY WILL BE USED

a. **Introduction.** The Value Added Analysis methodology is comprised of many components and modules. Each part serves a particular purpose and provides a certain portion of the information needed to support the decisionmaking process.

Factors such as the scope of the study, the alternatives being considered, the type of decision that needs to be made, and the timeframe in which study results must be provided will drive the information and analysis requirements of the investigation. Often these and other factors will dictate whether or not the entire methodology will be utilized. In some cases, only a few of the VAA modules will be needed to respond to analytical requirements. For these cases, the methodology is sufficiently flexible to allow individual models and methods to be used separately to provide input to the decisionmakers. Clearly, a complete understanding of the problem to be solved is critical in determining what approach should be used to attack the problem. This understanding will have been generated in the three processes of the Issue Clarification Module. This knowledge can then be used to determine whether a full-scale, standardized, implementation of the VAA methodology should be used, or if some reduced scale, ad hoc, method is appropriate.

b. Standardized Methodology. The full-scale implementation of the Value Added Analysis methodology involves the coordinated and comprehensive use of all the modules. As such, large amounts of data will need to be collected, potentially great numbers of simulation runs will need to be made, new surveys will need to be developed and administered, and all of the assembled information will need to be analyzed and checked for consistency in order to use the rest of the VAA models and tools, and ultimately, to ensure high-quality input to the decisionmaker. Obviously the expected duration of such a study effort would be on the order of months, and a great deal of prior planning is necessary to produce results in a timely fashion. The standardized implementation of the VAA methodology will be required whenever major changes in study assumptions, input data, or decisionmakers occur. The standardized VAA methodology is the subject of subsequent chapters of this study report.

c. Ad Hoc Implementation. An *ad hoc* implementation of the Value Added Analysis methodology is characterized by less than full utilization of the entire VAA system. In these instances, the output of some intermediate module is sufficient to answer the question that is asked. For example, a recent study was performed concerning command and communication systems where the issue was already clarified, and only the output of the implicit and explicit modules and the effectiveness integration module was needed. Care must be exercised, however, to ensure that all questions are satisfactorily addressed.

CHAPTER 5

EXPLICIT MEASURES OF VALUE

5-1. INTRODUCTION

a. The purpose of this chapter is to provide a discussion of the Explicit Effectiveness Module of the Value Added methodology. The chapter addresses one of the three submodules in detail, Combat. The other submodules, Soldier Quality of Life and Other Army Objectives, are not discussed in much detail because of the limited scope of this first Value Added Study. These submodules are included in the methodology in order to lay out completely the methodology as currently envisioned. This chapter is structured as follows:

- (1) Introduction
- (2) Combat Effectiveness
- (3) Noncombat Effectiveness
- (4) Summary

b. Figure 5-1 depicts the three submodules of the Explicit Effectiveness Module. Although the chart implies that all three submodules are used, this is not necessarily true for all issues to be investigated. The effectiveness of some program issues and their associated alternatives may, in fact, develop explicit effectiveness values from all three of the submodules. However, experience has shown that most issues will require only one or two of the submodules be used to develop the explicit effectiveness for a program issue. The decision to use single or multiple measures of explicit effectiveness will grow out of the work completed in the Issue Clarification Module.

c. Most decisionmakers interviewed for this study indicated the need to explicitly relate issues to the Army's number one objective of conducting combat operations. However, not all Planning, Programming, Budgeting, and Execution System (PPBES) issues are measured by their direct contribution to combat effectiveness. Some issues, such as base operations or soldier retention, do not lend themselves to combat simulation or combat-related analysis. Some PPBES issues, by their very nature, do not directly contribute to combat, but without these functions, the Army would not be prepared to conduct combat operations. It was from this fact that the need to measure explicit effectiveness as more than combat MOE was identified.

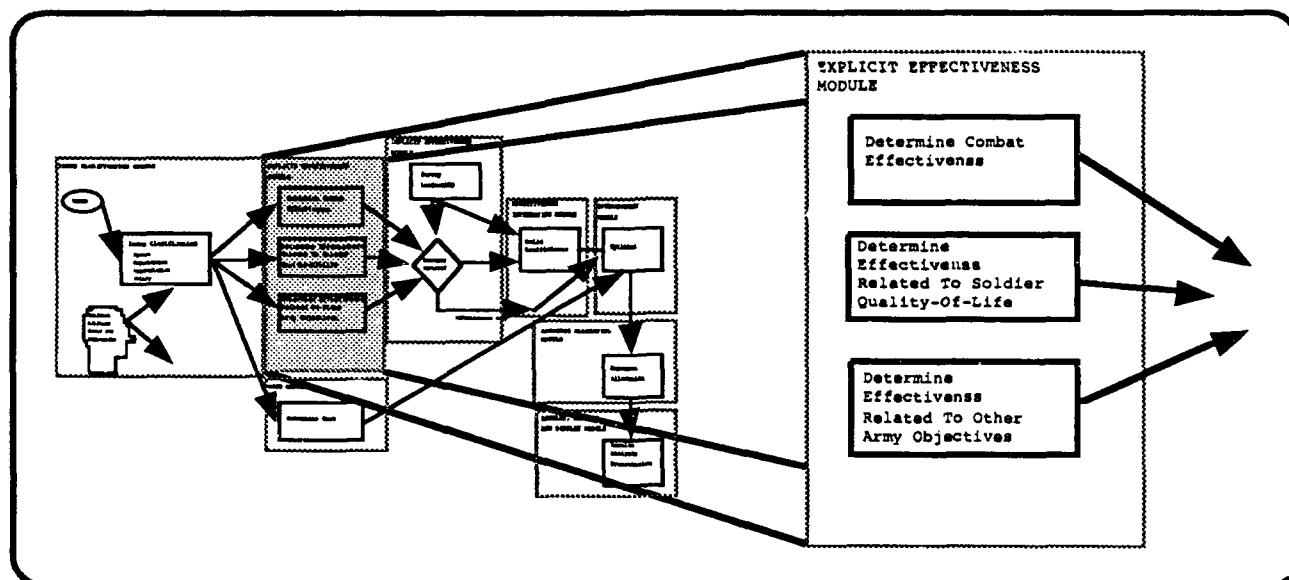


Figure 5-1. VAA Methodology - Explicit Effectiveness Overview

d. Because VAA is a marginal analysis, the MOE are computed as incremental changes from some known baseline. In the example, the baseline is determined by developing a base case scenario for the combat simulation. This base case represents a known point such as the current program force and Red threat for a particular fiscal year (FY). After the base case is verified and accepted as representative of current capability, each alternative is investigated by incorporating the alternative into the base case. This new simulation is called an excursion. Changes in the MOE values as a result of an excursion are recorded. It is this incremental change from the base that becomes the explicit value of the alternative portrayed in the excursion.

e. Although our example uses only a combat framework for determining the explicit effectiveness, the preceding approach would be used for the other modules as well. An issue being investigated may need to be measured by one of the explicit effectiveness submodules, or two, or all three. The decision to use one or multiple submodules will be based on identifying all of the appropriate MOE. The explicit MOE chosen must be pertinent to the issue, must directly measure output, and must be sensitive enough to measure changes as a result of trading off alternatives.

5-2. COMBAT EFFECTIVENESS

a. Development of Combat Context

(1) The purpose of the combat effectiveness aspect of Value Added Analysis is to develop a cohesive, rational framework for measuring combat effectiveness. As a result of the survey of Army leadership, it was found that the importance of

combat effectiveness was as much as 6 to 1 over the SIAM factors and the noncombat effectiveness. Because of the importance given to combat effectiveness by the decisionmakers, it is necessary to carefully establish the environment in which the combat effectiveness values are developed. It is from the scenarios modeled, the force structure (both Red and Blue) portrayed, the doctrine used, and a variety of assumptions that the combat context will be defined. This context sets the perspective for the explicit effectiveness. It is important that the assumptions, policies and terminology used are consistent with the decisionmaker's view of the world. The decisionmaker's confidence in the programming decisions resulting from the VAA approach depends entirely on his acceptance of the combat simulations conducted.

(2) Another important aspect of combat context deals with the adequacy of a model to analyze the alternatives associated with the issue being investigated. For the combat output to be accepted, the models used must be capable of investigating the alternatives at the appropriate level of resolution. The need to have the appropriate level of resolution leads to the requirement for multiple models, some of which will be designed to look at the whole battle and some whose purpose is to model functional areas. In order to conduct the marginal value tradeoffs inherent in the VAA methodology, all of the alternatives must be modeled using the same model or equivalent models. This problem of resolution can only be solved by using a hierarchy of models. A linkage between functional area models of high resolution and larger "force structure models" of lesser resolution must be achieved. The linkage that is required is difficult to achieve because of problems of model synchronization, data resolution, and battle dynamics.

(3) In order to overcome the linkage problem, a form of calibration must be accomplished between the models residing at different levels of the hierarchy. The study team developed a concept of hierarchical MOEs which, when used in conjunction with standard scenarios, equivalent data, and equivalent assumptions, can provide the linkage necessary. The hierarchical MOEs are characterized as overarching MOEs, translational MOEs, and functional MOEs. These MOEs are used in combination with one another to explore an alternative's benefit within its functional arena while relating it to a larger context. The overarching MOEs are calculated in a larger context "force structure model" and are used to measure the comprehensive "whole" battle. The model used to do this must capture all of the effects of the systems or force structure alternatives to be investigated and will probably be a lower resolution model. The output for each alternative will vary in level of detail. Some of the output will be of sufficient detail to be used directly in the Value Added Analysis without further high-resolution modeling. However, there will be other alternatives for which this larger (low-resolution) model will not provide sufficient

detail. In order to investigate these other alternatives, we must find a way to link the low-resolution model with higher-resolution models (usually functional area models). The translational MOEs are the link. These MOEs can be measured in both the low-resolution and the higher-resolution model. The translational MOE is used to transfer the results of the low-resolution model (in terms of sufficiency criteria) to the higher-resolution model. The functional MOE are used to measure output in the higher-resolution model. Figure 5-2 depicts how models and these MOEs are linked.

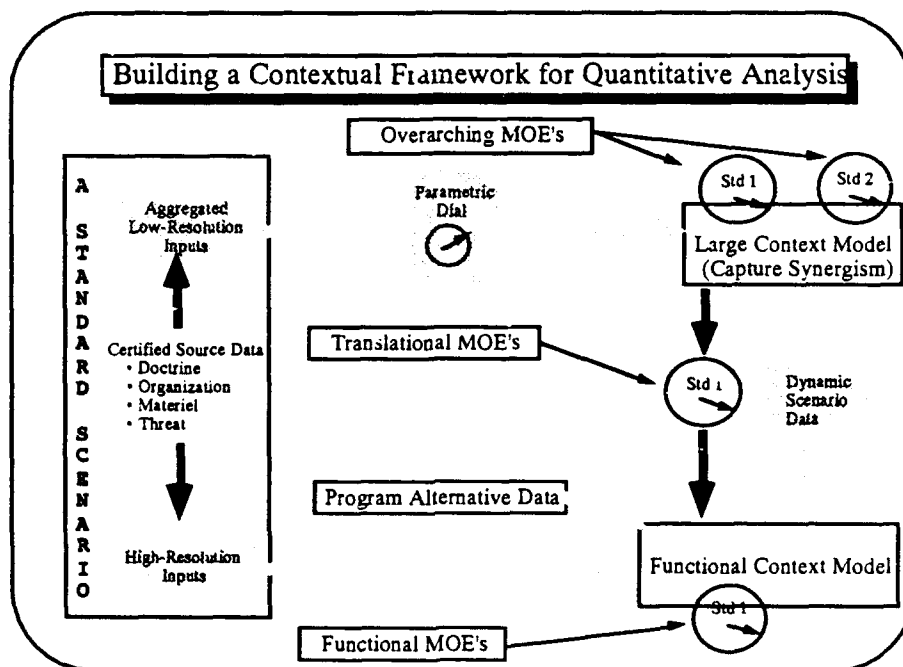


Figure 5-2. Combat Contextual Framework

(4) The overarching MOE is derived from a model which is used to put the issue in the largest context possible. In our example, Vector-In-Command (VIC) or Corps Battle Analyzer (CORBAN) is identified as the highest (in terms of our hierarchy) level model. The overarching MOEs used in this figure are COFM, BFS, and MFCM. The overarching MOE are selected based on two criteria. First, does the MOE measure parametric changes (input) in the model with sufficient discrimination to conclude that the change was the cause of the new MOE value? And second, can we *a priori* provide a level of sufficiency for the MOE? The concept of sufficiency allows for setting goals or levels of value which, when defined by the decisionmaker(s), indicate a breakpoint or culminating criteria.

(5) The idea of sufficiency does not necessarily have to be an *a priori* value. There are occasions when the use of the higher-level model will help define where this point exists. In the above figure, the parametric dial represents the ability to explore criterion by varying input. An analyst may run the larger context model to discover the breakpoints. In either case, the purpose for

using the Overarching MOE is to allow the analyst and decisionmaker to identify at the highest contextual level a point at which an acceptable solution has been achieved. Once this acceptable solution has been reached, we can determine from the simulation a set of translational MOEs. These translational MOEs are selected because they are found in both the lower-resolution model (larger context) and in the higher-resolution functional model (more narrow context). Because these translational MOEs exist in both categories of models (the Translational MOE is a measure which is found in both the higher-level model [VIC/CORBAN, etc.] and the lower-level model [MACATK/COMO III, etc.]), they can be used to translate sufficiency from the higher-level model to the lower-level model. The ability to translate sufficiency is important because we can use these translational MOE to calibrate across many different functional models. The calibration allows us to create equivalent model runs which then can be compared against one another. By setting all of the functional models to equivalent scenarios, data, and levels of performance (sufficiency), we believe one can assume that a 10 percent change in one model is equivalent to a 10 percent change in another. Some example translational MOEs may be loss exchange ratios, repair return rate, system exchange ratios, and so forth. Ultimately, this concept is useful because it allows the analyst to investigate issues in their "Native" environment by the use of functional models and reporting the results using functional MOEs.

(6) The ability to investigate issues within a functional context is important because it allows analysts and decisionmakers from these functional areas to describe value in terms they understand and with which they are familiar. It also eliminates the need to force a result into an MOE which may not meet the need. The translational MOE provide decisionmakers at one level the ability to communicate in a very structured way their view of the need or level of sufficiency to decisionmakers and analysts at another level. Furthermore, this ability to set criteria at a level which accommodates the whole allows one to set criteria in many different functional areas.

b. Analytical Models and Tools

(1) **Introduction.** As part of the methodology development, the study team conducted a review of currently available combat models. One important criterion for selection of the combat model for the VAA Study was the need for a fast running model. In fact, the team had initially decided to use a highly aggregated spreadsheet combat model called Corps Model (CORMO), developed under contract to PA&E by CACI, Inc.-Federal. CORMO was selected because of its speed and ability to give good "ball park" effectiveness output. However, as the methodology matured, it became apparent that selecting the resolution of the model was extremely important. This insight was important enough that the team abandoned its original model choice and developed an entirely new capability that would simulate, in detail, a weapon system's effect on a large-scale conflict.

(a) CORBAN (the Corps Battle Analyzer) was chosen to simulate the large-scale battle. VAA required the use of a corps-level combat model to help determine the combat effectiveness value added to the corps battle by various weapon systems.

(b) This focus on the corps level is important because this level encompasses a fuller mixture of maneuver, fire support, environment, logistics, and command and control (C2) than other levels that we currently model. CORBAN, as a fast-running corps-level model, has the sensitivity necessary to evaluate weapon systems and their effect on the corps battle in sufficient detail for the VAA methodology.

(2) Model Overview

CORBAN is a time-stepped, closed-loop, stochastic, combat simulation that models combat at the corps/army level.

CORBAN is a data driven model: values are entered by the analyst, not fixed by the code.

CORBAN can simulate a range of battles from one battalion versus another, to eight corps versus eight Red armies. Resolution of the model is at battalion level. However, individual weapon types and their characteristics are modeled.

CORBAN runs on the VAX family of computers. The model is written primarily in FORTRAN. A MIDAS compiler is used to compact the code and data. The model consists of approximately 30,000 lines of code and an equal amount of input data.

While running on a VAX 8600, the model executed most VAA runs at 8 to 1 (simulation hours to CPU hours).

(3) **Input Data.** Figure 5-3 depicts the CORBAN data flow as used for the Value Added Analysis Study.

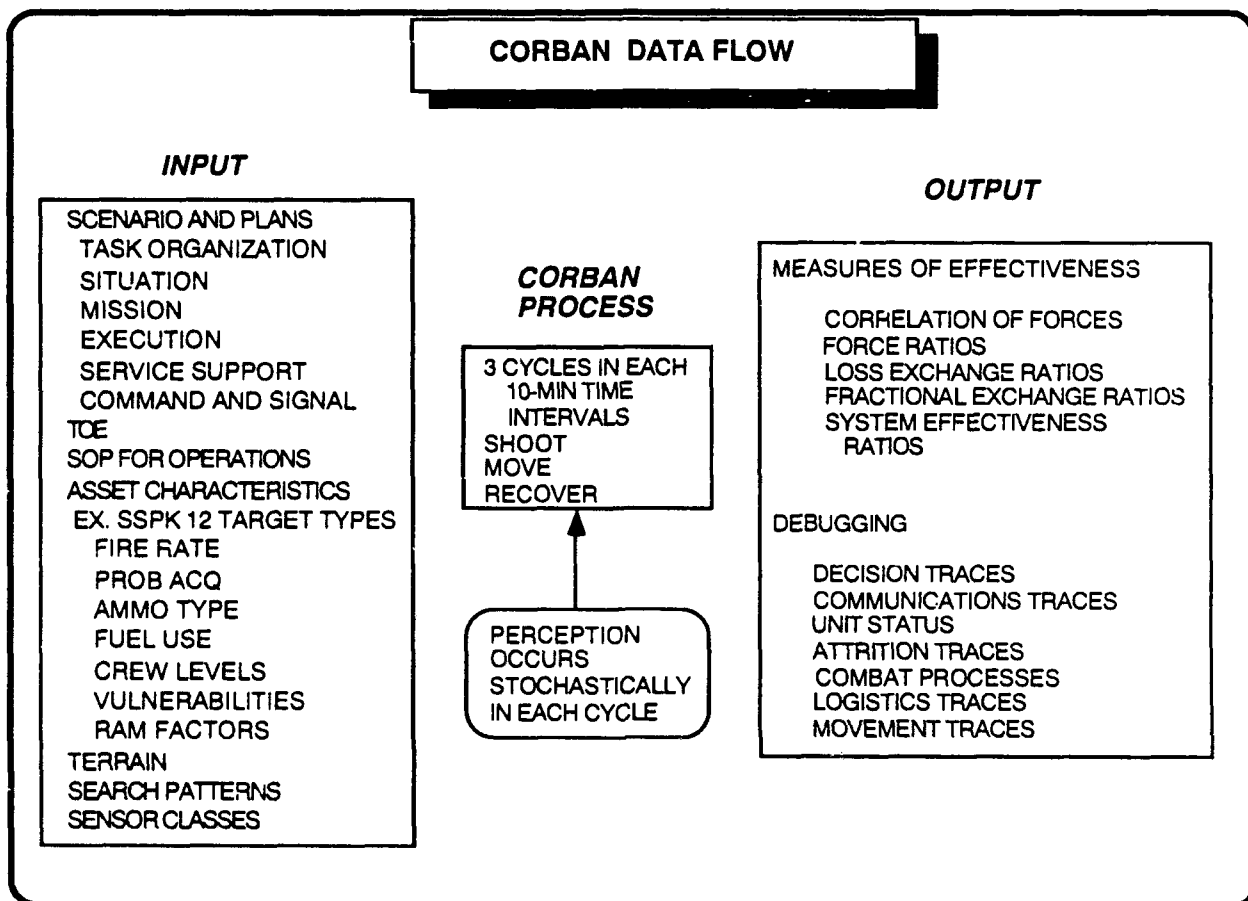


Figure 5-3. CORBAN Data Flow

(a) **Scenario and Plans**

Task organization. CORBAN allows the analyst to task-organize combat formations using a chain of command approach.

Situation. The situation defines the environment of the simulation including the terrain and notes, if any. Missions of other units are given in the orders. The CORBAN battlefield is overlaid with a nested-hexagonal coordinate system (each large hex has a number of smaller hexes contained within). This nested-hexagon coordinate system can define hex diameters from 729 m to 8,575 km. Currently, there are three levels of hexagons defined, at the 25-km level, the 9-km level, and the 3.5-km level (size is defined as center of the hex to center of the adjacent hex). Terrain features are defined only for the lowest hexagon level (currently the 3.5-km level).

Terrain within a hex is homogeneous and is described by a combination of five factors: level of urbanization, level of forestation, level of ruggedness, the quality and direction of the road network within the hex, and the fordability and location of rivers. Effects of urbanization, forestation, and ruggedness cover the entire hex. Roads run from hex center to hex center, and rivers flow along the borders of the hex. Originally, terrain data bases were developed by TRAC-FLVN for the CORDIVEM Model based on digitized terrain. This data was then translated into CORBAN terrain data. Currently, Korea, Persian Gulf, and Central European terrain has been defined.

Mission. Both sides (Red and Blue) are given forces, objectives, contingencies, and time constraints under which to achieve these objectives.

Execution. Every unit is given one or more orders, either at the start of the simulation or later when a contingency arises. There are three types of orders in CORBAN--simple, complex, and templated. The simple order is a one-line entry giving a mission and an objective. The simple order is generally used for separate units that do not have unique phases or subordinate units. A complex order is given to larger units that have subordinate units and that require unique phasing of operations. Complex orders are usually given to Blue divisions and corps and to Red armies. Templated orders are usually given to Blue battalions and brigades and to Red battalions, brigades, and divisions. Each templated order is given a unique designator that can be passed as a mission by means of a simple or complex order. Templated orders can be thought of as a unit standing operating procedure (SOP).

Service Support. CORBAN models several aspects of service support. First, every unit is given ammunition and fuel amounts. Then assets of the unit, as they move or engage in combat, consume the unit's supplies. As the battle progresses, requests for resupply are made, and logistical units dispatch convoys to resupply the combat (fighting) units. Additionally, CORBAN models the repair of assets and distribution of major end items to units.

Command and Signal. To execute the missions assigned, CORBAN uses an ingenious command and control system. Every unit on the battlefield has its status defined with a series of 64 1-bit flags. When certain user-defined events occur, a flag for the unit is turned on. Based upon these flags, the mission which is currently being executed could change. Superior units have the ability to change their missions based upon reading subordinate postures. This allows a commander to reassign logistic priorities, inform helicopter units to support maneuver units, and give priorities to artillery support. Units in CORBAN can pass information to a commander, a subordinate, or to all units. Through the command

and control system, information can also be passed globally to all units, Red or Blue.

(b) **TOE.** Units consist of a collection of equipment and assets given to the unit by the TOE. These TOEs are not like regular TOEs known by most people associated with the Army. Most CORBAN TOEs represent a battalion task force equipped for combat. Some TOEs represent separate companies or batteries in order to portray their characteristics more accurately e.g., MLRS battalion. Both the Blue and Red sides are modeled at these levels of resolution. The modeler has the capability to portray any unit at any echelon determined appropriate, based on other input data available. The type and amount of equipment in each unit is scenario dependent and can be different for each unit (e.g., two different armor task forces may contain different amounts and types of equipment).

(c) **Asset Characteristics.** CORBAN explicitly plays the majority of all major weapon systems. Additionally, fuel and ammunition (including tank, artillery, and special weapons) are modeled. Also, support assets such as supply trucks are represented. The capabilities of every asset are defined by the analyst. These capabilities include:

1. SSPK versus 12 target types over 4 range bands and 8 firer-target postures (e.g., stationary firer versus stationary, fully exposed target).

2. Type of ammunition fired versus each target type.

3. Fire rate.

4. Maximum and minimum ranges.

5. Allocation of fire among target types.

6. Acquisition capability of the onboard sensors.

7. The vulnerability of the weapon system to different ammunition types.

8. Fuel usage and loss factors.

9. Ammunition usage and loss factors.

10. Crew-level requirements.

11. RAM (reliability, availability, and maintainability) factor

Sensor classes are used by assets to acquire enemy assets during combat. The capability of the sensor is defined for four ranges, and the probability of detecting a target asset type in various postures, for both day and night.

(d) **Search Patterns.** Search patterns represent a unit's ability to detect enemy units. The search pattern is used when attempting to evaluate a unit's environment (location of enemy units for movement purposes) and to build target lists. Additionally, information about enemy units that are detected may be transferred to other friendly units.

(4) Combat Analysis (Figure 5-4)

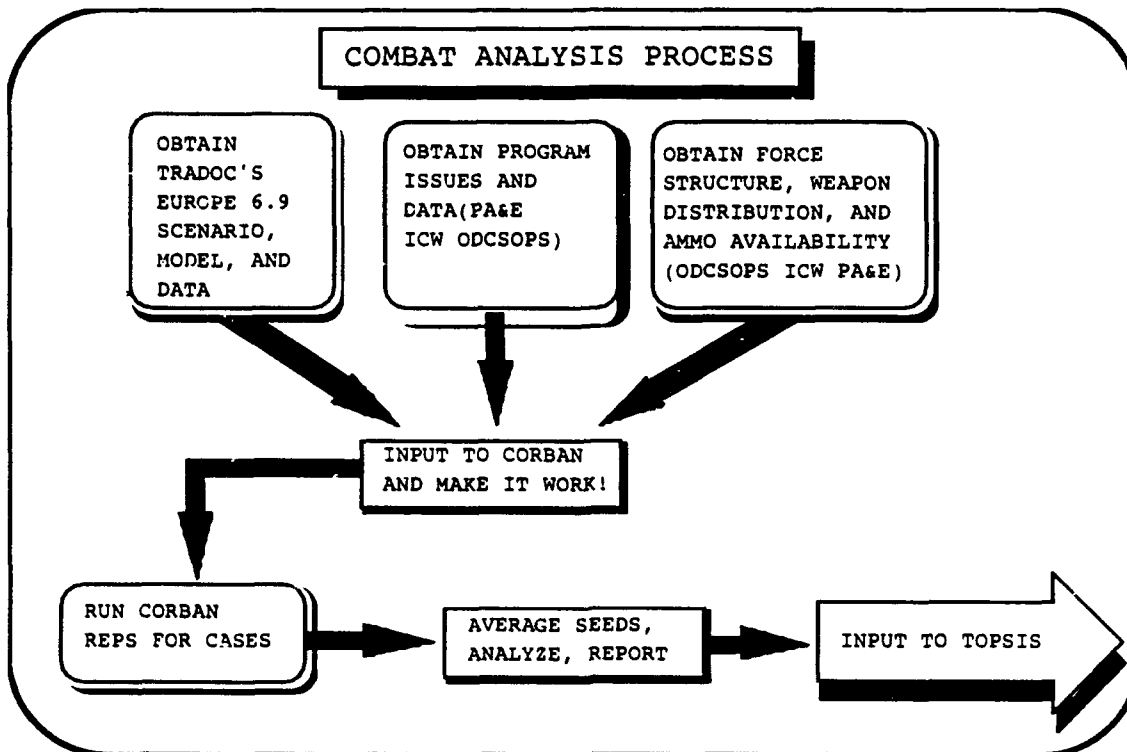


Figure 5-4. Combat Analysis Process

(a) CORBAN uses a time-stepped and simultaneous combat process. All units go through three cycles in each time interval. These three cycles are shoot, move, and recover. Analysts can set the time interval. The VAA CORBAN Model interval was set for 10 minutes.

(b) Most of the processes in CORBAN are deterministic. These include combat, logistics, fire support, and movement. The only stochastic process in CORBAN is perception. As a result, the detection of target units and evaluation of enemy threats is stochastic.

(c) Shoot cycle: during each shoot cycle, every ground unit does the following--evaluates its own strength, determines threats and subsequent force ratios, builds target lists, determines target priorities, performs combat, calls for fire support, and requests logistical support. HQ units assign fire support missions to supporting units.

(d) Move cycle: during each move cycle, every unit perceives the environment, evaluates its own strength, selects a movement path, and moves if required. Air bases, helicopter units, and logistic units create sorties and convoys and move them.

(e) Recover cycle: during the recover cycle, all units apply attrition and suppression received during the shoot cycle, recover from effects of previous suppression, reconstitute, resupply, and maintain units.

(5) Output

(a) The CORBAN Model is rich in the output that it provides. There are three main categories of output that the model provides. First, through "debug" flags, errors in data can be found and corrected. Second, various types of simple measures of effectiveness can be created from a model run. Finally, CORBAN has a number of postprocessing programs that will manipulate output data to look at more complicated measures of effectiveness.

(b) The MOE that CORBAN analysts most commonly use are:

1. Correlation of forces and means (COFM): this is a measure of the Red force strength in an attack corridor with respect to the Blue combat strength in the same corridor.

2. Force ratios (FR): this is a measure of the overall Red forces remaining with respect to the overall Blue forces remaining.

3. Loss exchange ratios (LER): this is a measure of the combat value of Red systems lost to the combat value of the Blue combat systems lost.

4. Fractional exchange ratios (FER): this is a ratio of proportion of Red systems value lost to the proportion of Blue systems value lost.

5. System effectiveness ratios (SER): this is a ratio of the number of Red systems killed by a Blue system to the number of Blue systems killed.

6. Killer-victim tables: these tables show losses and killers by asset and asset category

7. Effective battalions remaining (EBR): this measure evaluates the number of battalions (generally maneuver, artillery, rocket, and helicopter) remaining on each side that are still combat effective.

8. Movement of force center of mass (MFCM): this measure evaluates the performance of an attacker by examining the distance the center of mass of all of his forces has travelled.

9. Mission accomplishment (MA): qualitative measure of whether or not each side's missions have been accomplished.

10. Front line trace: this qualitative measure is used to evaluate such items as potential, or real breakthroughs, and key objectives siezed or lost.

11. Plots of unit locations: allows an analyst to evaluate a specific unit's performance based on its position relative to the enemy and to evaluate a large formation's (e.g., division) intermediate, or final dispositions.

(6) **Debugging.** Much of the information for the measures of effectiveness comes from setting certain output flags in the model. Raw data that can be quickly output from the CORBAN Model includes:

(a) **Decision Trace.** This information informs the analyst when a unit sets a situation flag and when a unit responds to a contingency based upon those flags. It also tells an analyst what mission or tactical SOP a unit is executing. Finally, it gives information on the movement pattern and location of all units in the simulation.

(b) **Communications Trace.** This file informs the analyst when information is sent to a superior, a subordinate, or to all units.

(c) **Unit Status.** This information, gained at intervals throughout the run, tells the analyst where all units are, what they are doing, and their posture and strength.

(d) **Engagement Trace.** Similar to the decision trace, this file records all engagements by time step, unit, and location.

5-3. NONCOMBAT EFFECTIVENESS

a. **Introduction.** The purpose of this section is to illustrate a method for analyzing a noncombat effectiveness issue in the Army. In particular, what are the costs and benefits of using photovoltaic (PV) solar systems to recharge batteries versus the conventional method used currently for recharging batteries that power pop-up targets used in Army tank training. This application illustrates the issue clarification, cost, noncombat effectiveness (NCE) and optimization modules of the Value Added methodology (see Figure 5-5).

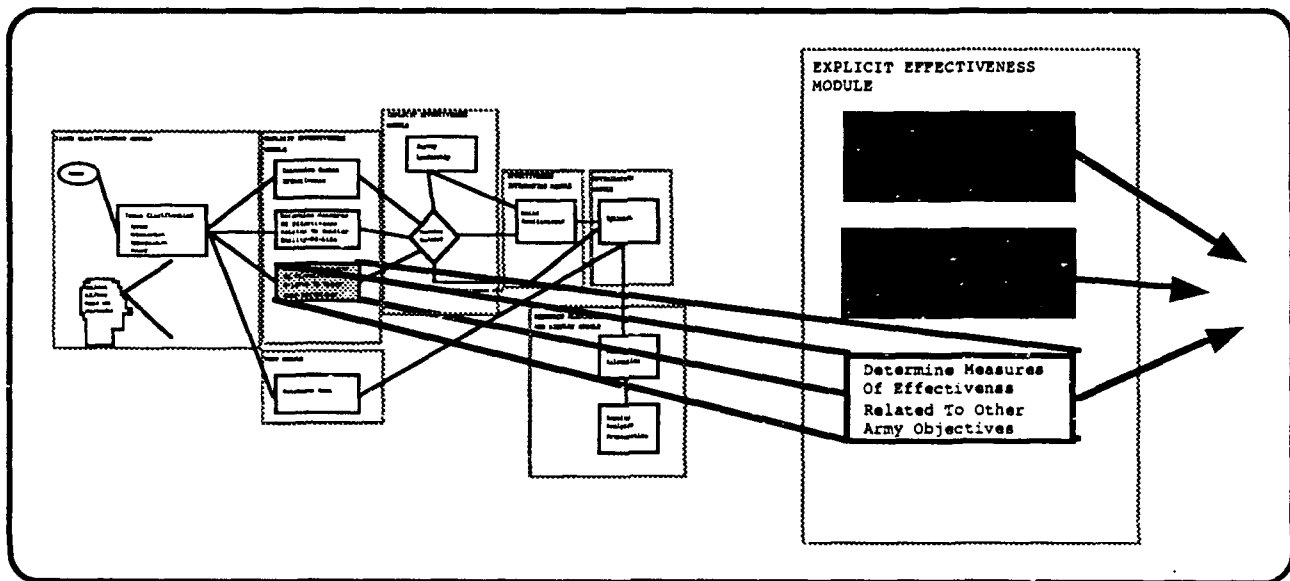


Figure 5-5. VAA Methodology - Energy Alternative Effectiveness

b. **Photovoltaic (PV) Systems Background.** Photovoltaic cells convert solar energy to electricity which can be used in many different tasks such as battery charging and supplying power to pocket calculators. There are numerous PV applications in government and industry. The Tank and Automotive Command (TACOM) is currently testing PV-powered trickle chargers for use in trucks, tanks, and armored personnel carriers which have long periods of inactivity between uses. Communications and Electronics Command (CECOM) is investigating the use of PV systems for battery charging portable communication sets. PV systems have the following beneficial features: high reliability, modularity, low or no maintenance, nonpolluting, silent power, and no fuel or water requirements. Arthur D. Little, Inc., under contract to US Army Construction Engineering Research Laboratory (CERL), conducted a study on potential PV applications in selected Army facilities. The following PV the applications for the Army were cited in the CERL study:

- (1) "A" Stations (measures target distances for testing weapon systems)
- (2) Battery Chargers (for emergency power of water wells)
- (3) Clearance Lights
- (4) Bugle Recorders
- (5) Global Positioning Systems (GPS)
- (6) Mobile Firing Ranges
- (7) Mobile Generators
- (8) Radio Repeaters
- (9) Firing Range Guns
- (10) Range Surveillance Videos
- (11) Microwave Towers
- (12) Remote Data Acquisition
- (13) Meteorological Towers
- (14) Storage Facilities (Igloos)
- (15) Microwave Repeaters
- (16) Pop-up Targets

c. Issue Clarification. The issue selected as the noncombat effectiveness case study was whether to acquire photovoltaic panels or to continue using conventional means to recharge batteries that power radio operated pop-up targets used in tank training Army-wide. Table 5-1 gives an estimate of the quantity of radio operated pop-up targets powered by batteries in the Army. According to the Army Training Support Center, there are batteries at the 3,320 battery-powered pop-up targets used for tank training in the Army (not including USAREUR). Pop-up targets exist in USAREUR, but data on the quantity is not currently available. The specific issue addresses whether the batteries at the 3,320 radio controlled pop-up targets should remain battery powered continue to be recharged at battery shop facilities (conventional method) or should be recharged by on-site PV panels. The noncombat measure of effectiveness applied in this case study is energy required to operate the pop-up targets.

Table 5-1. Estimated Number of Pop-up Targets in the Army
(Excludes USAREUR)

Battery Operated Radio Controlled Pop-up Targets	
Armor	
8th Army	73
FORSCOM	993
Total	1066
Infantry	
8th Army	199
FORSCOM	1668
WESTCOM	387
Total	2254
Armor and Infantry Total	3320

Source: Training Support Center, Ft Eustis.

d. DOD and Army Energy Policy

(1) **DOD Energy Policy.** Figure 5-6 displays Title 10, US Code Section 2394 guidance for DOD energy policy. The policy requires procurement of renewable forms of energy (e.g., PV) when it is cost effective, provides guidelines for the computation of the life cycle costs of renewable energy systems, and mandates reports to Congress by the Secretary of Defense within two year intervals, of the results of studies conducted with respect to the use of renewable forms of energy in supplying the energy needs of DOD. Cost effectiveness refers to the lowest cost energy source that can meet a given set of energy requirements in support of specified mission objectives. The pop-up target case study presented here serves as a simple example of the kind of analysis that could be conducted in support of DOD energy policy.

Title 10, U.S. Code Section 2394

2394a. Procurement of energy systems using renewable forms of energy

(a) In procuring energy systems the Secretary of a military department shall procure systems that use solar energy or other renewable forms of energy whenever the Secretary determines that such procurement is possible and will be cost effective, reliable, and otherwise suited to supplying the energy needs of the military department under his jurisdiction.

(b)(1) The Secretary of Defense shall from time to time study uses for solar energy and other renewable forms of energy to determine what uses of such forms of energy may be cost effective and reliable in supplying the energy needs of the Department of Defense. The Secretary of Defense, based upon the results of such studies, shall from time to time issue policy guidelines to be followed by the Secretaries of the military departments in carrying out subsection (a) and section 2857 of this title.

(2) The Secretary of Defense shall submit to the Committees on Armed Services of the Senate and House of Representatives not less often than every two years a report on the studies conducted pursuant to paragraph (1). Each such report shall include any findings of the Secretary with respect to the use of solar energy and other renewable forms of energy in supplying the energy needs of the Department of Defense and any recommendations of the Secretary for changes in law that may be appropriate in light of such studies.

(c)(1) For the purposes of this section, an energy system using solar energy or other renewable forms of energy shall be considered to be cost effective if the difference between (A) the original investment cost of the energy system using such a form of energy, and (B) the original investment cost of the energy system not using such a form of energy can be recovered over the expected life of the system.

(2) A determination under paragraph (1) of whether a cost-differential can be recovered over the expected life of a system shall be made using accepted life-cycle costing procedures and shall include -

(A) the use of all capital expenses and all operating and maintenance expenses associated with the energy system using solar energy or other renewable forms of energy, and not using such a form of energy, over the expected life of the system or during a period of 25 years, whichever is shorter;

(B) the use of fossil fuel costs (and a rate of cost growth for fossil fuel costs) as determined by the Secretary of Defense, and

(C) the use of a discount rate of 7 percent per year for all expenses of the energy system.

(3) For the purpose of any life-cycle cost analysis under this subsection, the original investment cost of the energy system using solar energy or other renewable forms of energy shall be reduced by 10 percent to reflect an allowance for an investment cost credit.

(Added Pub. L. 97-321, title VIII 801(a)(1), Oct. 15, 1982, 96 Stat. 1569, and amended Pub. L. 98-525, title XIV, 1405(36), Oct. 19, 1984, 98 Stat. 2623.)

Figure 5-6. Title 10 US Code, Section 2394 Guidance

(2) **Army Energy Policy Objectives.** The Army Energy Office in ODCSLOG presents the Army's current energy goals in the Army Energy Resources Management Plan (FY 86-95). The Plan includes goals regarding the Army's use of renewable energy sources--sunlight, wind, geothermal, hydropower, ocean thermal, and biomass. In particular, the Army aims to increase its use of renewable energy technologies between FY 86 and 95 by 5 percent or 27,975 MBtu (millions of British Thermal units). This estimate is based upon FY 1985 renewable energy use of 559,510 MBtu in the Army. The amount of energy required to power the pop-up targets in this time period (1985-1995) is estimated to be 22,180 MBtu.¹ If this energy requirement were "cost effectively" met by PV technologies, then about 80 percent of the Army's renewable energy objectives would be satisfied. Although not addressed in this report, a more complex case study would compare the economics of conventionally recharged batteries against all technically applicable renewable technologies - not just photovoltaics. This kind of analysis should consider both pop-up target energy requirements and the change in the Army's renewable energy usage as noncombat MOE. However, because of the Army's success with photovoltaic applications and to simply illustrate the concept, the discussion will be limited to photovoltaics.

e. **Cost-Benefit Analysis.** The issue of whether to continue recharging batteries conventionally or to invest in photovoltaics for pop-up targets requires identification of the relative costs and benefits. The focus of this case study will be on monetary costs and benefits (cost savings) as stipulated by Title 10, U.S. Code Section 2394. The investment criterion applied (as required by Title 10) is the number of years that the photovoltaic alternative "pays back" (in discounted dollars).

(1) **Cost Assumptions.** The following assumptions were used in estimating Life Cycle Costs (LCC) for both the conventional and PV methods for recharging batteries used to power pop-up targets:

Economic useful life of a PV system: 20 years²

Economic useful life of a battery: 2 years³

¹Based on: Applications Survey for Remote Photovoltaic Power Systems, Arthur D. Little, Inc., October 1989, Table 1. (Estimated energy savings from PV recharging: 3320 batteries x 480 WH/day x 120 days = 191.2 MWH x 11.6 BTU/WH = 2218 MBTU).

²Source: Life Cycle Cost Analysis of Photovoltaic Power Systems, U.S. Army Engineering and Housing Support Center. (Engineering and Housing Support Center).

³Average figure for operating training center ranges and life of battery based on discussions with ODCSOPS (DAMO-TR) and CERL.

Economic useful life of a battery with PV: 5 years¹
 Pop-up targets are used 120 days a year operating at
 10 hours a day.^{1;2}

Batteries are recharged after each training exercise
 (25 miles round trip to pick up and return battery
 after recharging - one training exercise per day)

A fully discharged 55 Amphour (Ah) 12 Volt battery
 requires $55\text{Ah} \times 12\text{ Volts} = .66\text{ KILOWATT (kWh)}$ of
 electrical energy to return a full state of charge²
 Cost per kWh = \$.05²

Batteries are replaced every other year¹

Battery loss rate: 5 percent¹

Nominal Discount Rate (NDR): 7 percent³

Annual inflation factor: 4 percent

(2) Conventional Battery Costs. A 12-volt battery, replaced every other year, is the conventional energy source used to power the pop-up targets specified. Battery costs were based on information obtained from the National Training Center (NTC) located at Ft Irwin, California and from CERL. The battery procurement cost is approximately \$100. Assuming that all 3320 battery-powered pop-up targets in the Army are utilized 120 days per year and the batteries are replaced every other year (with a 5% loss rate incurred in transportation) then 1826 batteries should be procured annually (i.e. 1660 batteries plus $3320\text{ batteries} \times .05 = 1826\text{ batteries replaced annually}$). Based upon this procurement, the annual cost for pop-up target battery replacement is \$182,600 ($\$100 \times 1826\text{ batteries}$). O&M costs over 20 years were estimated to be \$2.65M annually. This includes \$2.39 for transportation costs (annual transportation costs = $3320\text{ batteries} \times 120\text{ rechargings per year} \times 25\text{ miles} \times \$.24\text{ per mile}$)⁴ and \$.013M for electrical energy costs (annual electrical energy costs = $3320\text{ batteries} \times 120\text{ rechargings per} \times .66\text{kWh/battery} \times \$.05/\text{kWh}$).² The \$.24 per mile O&M cost factor excludes manpower costs for the two man crew used to transport and install 50 batteries per 10 hour day. (With 3320 battery recharges estimated daily for 120 training days, 796,800 man-hours would be expended annually for battery recharging). The present values for battery procurement and O&M costs, over 20

¹Discussions with CERL personnel.

²Based on: Applications Survey for Remote Photovoltaic Power Systems, Arthur D. Little, Inc., October 1989, Table 1. (Estimated energy savings from PV recharging: $3320\text{ batteries} \times 480\text{ WH/day} \times 120\text{ days} = 191.2\text{ MWH} \times 11.6\text{ BTU/WH} = 2218\text{ MBTU}$).

³Title 10, U.S. Code Section 2394. Guidance includes use of 7 percent discount rate for all expenses of energy systems.

⁴Source: Life Cycle Cost Analysis of Photovoltaic Power Systems, U.S. Army Engineering and Housing Support Center. (Engineering and Housing Support Center).

years, amounted to \$1.93M and \$34.55M, respectively¹. The present value of conventional battery life cycle costs for the 20 year period is \$37.4M.

(3) **PV Costs.** PV investment costs per pop-up target were estimated at \$300 by CERL. The 3320 operating pop-up targets in CONUS require 3320 PV systems. Thus, the total initial investment for PV amounts to \$.996M (3320 batteries x \$300.00) with an annual recurring cost for operation and maintenance at 7.5 percent of investment cost or about \$74,500 per year.² Since battery life is extended to 5 years and there is no requirement to transport batteries with PV systems, battery costs are reduced to \$66,400 annually ($1/5 \times 3320$ batteries x \$100 per battery). The present value (over 20 years) for the initial PV investment is \$.996M, \$1.08M for PV O&M costs and \$.96M for battery replacement costs. Total present value costs for the PV alternative is \$3.04 million.

f. **Cost Benefit Results.** The use of PV as an energy source to recharge batteries for pop-up targets was found to be more cost beneficial when compared to the use of conventional batteries as a power source. Over the 20-year economic useful life of a PV system, total present value cost savings from PV investment was estimated to be \$37.4M-\$3.04M = \$34.36M. This amounts to an average annual rate of return of 56.5 percent. The discounted payback for an initial investment of \$.996M would be less than 2 years.

g. **Cost Benefit Finding.** Title 10, US Code, Section 2394, indicates that renewable energy investment with a payback within its economic life (20 years) is considered to be cost effective and should be undertaken. The PV case study described in this chapter pays back in less than 2 years. Furthermore, it has been indicated that the PV investment specified significantly contributes to the Army's renewable energy objectives. Additional benefits would be realized by PV investment, such as its contribution to Army environmental goals (such as less handling and disposing of batteries), but were not quantified in this study. The execution of the remaining modules in the VAA methodology (e.g., implicit factors) was not considered necessary for this particular issue, since the PV investment described met the cost effectiveness criterion provided in Title 10.

5-4. SUMMARY. The development of the Value Added methodology specifically included two components (Explicit and Implicit) to the valuation portion of VAA. The explicit effectiveness

¹Title 10, U.S. Code Section 2394. Guidance includes use of 7 percent discount rate for all expenses of energy systems.

²Source for cost factors: *Photovoltaics for Military Applications*, Meridian Corporation, May 1988.

investment described met the cost effectiveness criterion provided in Title 10.

5-4. SUMMARY. The development of the Value Added methodology specifically included two components (Explicit and Implicit) to the valuation portion of VAA. The explicit effectiveness component was specifically designed to measure the quantifiable element of value. The methodology, as currently envisioned, uses traditional analysis tools such as combat simulations, historical data, or mathematical formula to measure the explicit contribution an alternative would provide to the Total Army Program. This explicit value is always measured from a baseline position, e.g., in our illustrative example, we used the FY 94 Program Force. The module appears to be flexible enough to handle a wide range of quantification models and methods. The results of this module are passed to the Effectiveness Integration Module as changes from the baseline position.

CHAPTER 6**VALUE ADDED COSTING****6-1. INTRODUCTION**

a. The purpose of this chapter is to provide a discussion of the Costing Module of the Value Added methodology. Included in this discussion are the methods and processes selected and their relationship to the optimization module. The Value Added methodology required a breakdown of life cycle weapon system(s) cost elements coupled with a mechanism for adjusting costs to account for variations in procurement quantities. Consequently, two PC-based models were developed--the Cost Quantity Model (CQM) and the Weapon System Life Cycle Cost Model (LCCM). In addition to the two PC-based models, the Costing Module uses a methodology for developing weapon system definitions based on the Army Resources Integration Management (ARIM) Study. This chapter is structured as follows:

- (1) Introduction
- (2) Costing Context
- (3) Select or Develop Models and Tools
- (4) Implement Analytical Models and Tools
- (5) Summary and Observations

b. Figure 6-1 depicts the placement of the Costing Module in the overall Value Added methodology. The majority of the inputs for this module are fed to it from the Issue Clarification Module. The outputs generated in the costing module are passed to the optimization module for the conduct of a cost benefit analysis. Costing output also can be passed to the Results and Display Module for direct analysis and presentation.

1

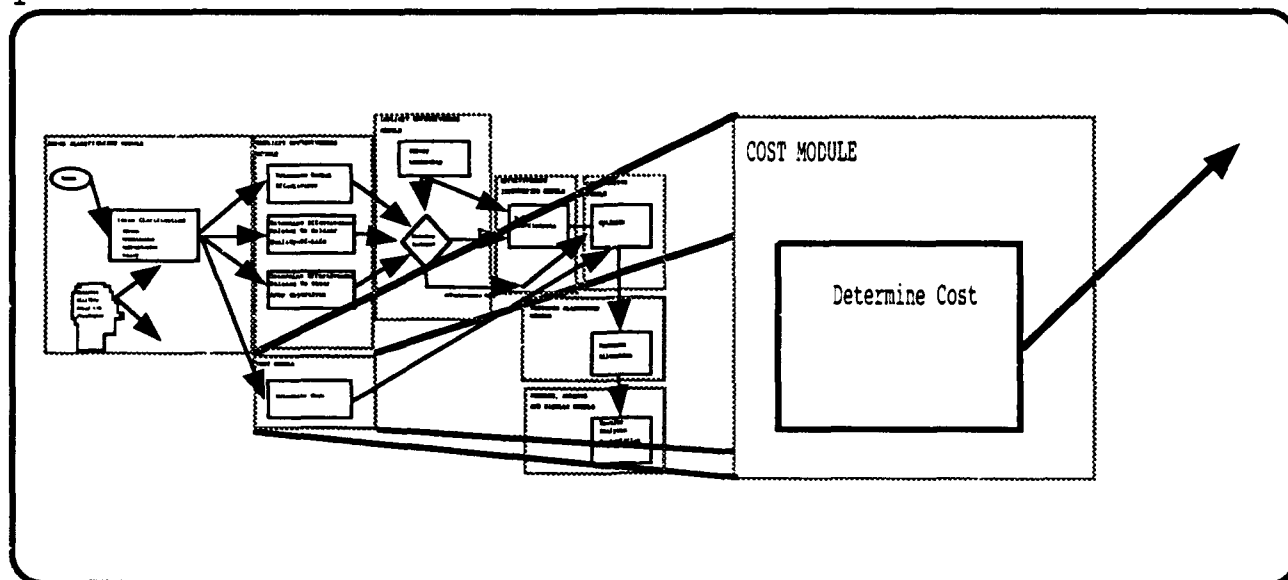


Figure 6-1. VAA Methodology - Costing Overview

c. Figure 6-2 provides a flow chart of the Costing Module.

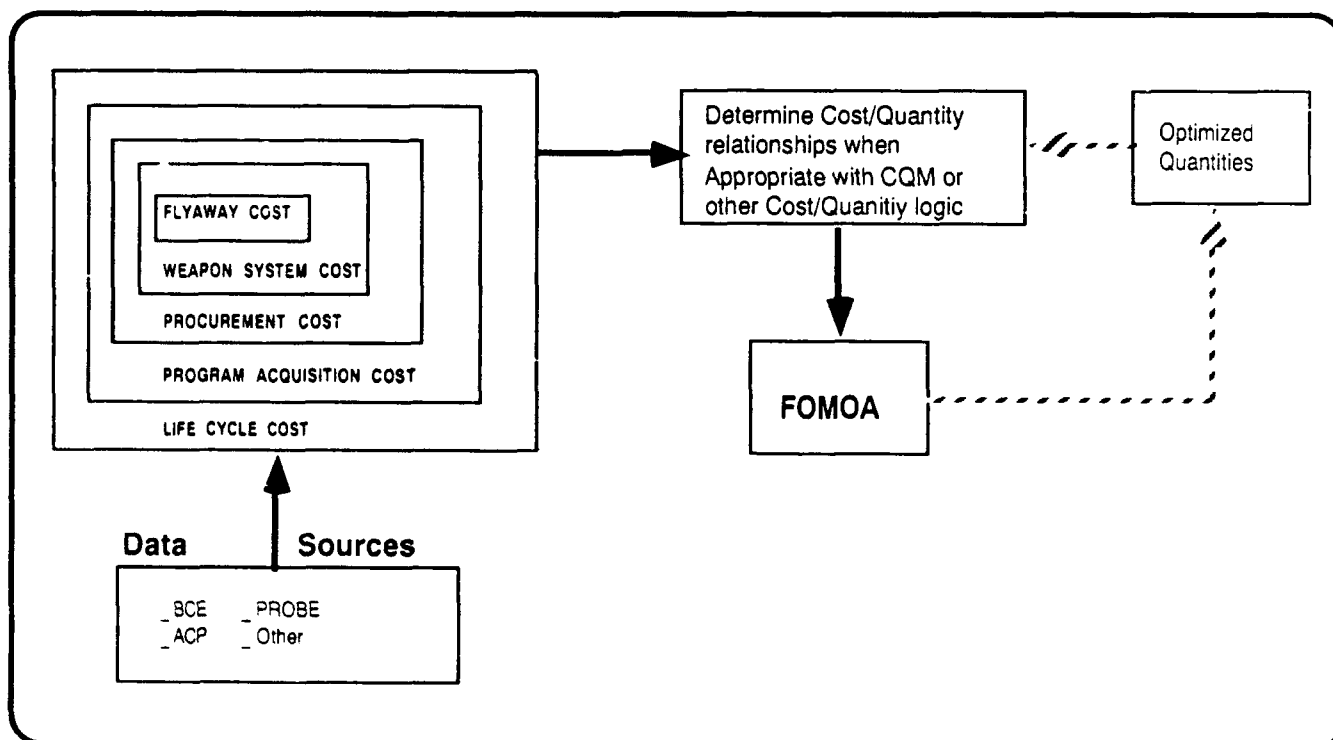


Figure 6-2. Costing Module Flow Chart

6-2. DEVELOPMENT OF THE COSTING CONTEXT

a. Identify Assumptions

(1) Experience curves for weapon systems are computed at the component level. Models rolling up component-level cost and quantity data reside with the program manager of each system. The Value Added Analysis methodology may address several weapon systems simultaneously, making use of component-driven models impractical in a quick reaction environment.

(2) Regression analysis of historical or projected annual weapon system production costs can be used to calculate system first unit costs and experience and production rate curves that generate average annual production cost within an acceptable margin of error.

(3) Similarly, P92 cost codes for the five major cost categories (development, production, military construction, fielding, and sustainment) can be prorated with the impact on the affected appropriation category based on experience/production rate curves and cost factors generated from available data.

b. Identify Cost Policy. Army weapon system costing policy is addressed in Army Regulation (AR) 70-2 (Integration of Weapon Systems Costing Programing and Execution Management Systems, June 1986). CEAC is the proponent for Army weapon system costing. Army inflation guidance is provided every 2 years by the Army Materiel Command (AMC).

c. Determine Lexicon. Definitions for the five categories of weapon system cost were identified as: Fly Away, Procurement, Weapon System, Program Acquisition, and Total Life Cycle Costs. Procurement/production costs were selected as the basis for optimizing system procurement. The P92 cost elements as defined by CEAC in DCA -P92(r) report were used as a point of departure for identifying costs elements for a weapon system. The Army Resource Integration and Management (ARIM) Study addressed the problem of consistent weapon system definition. As part of that effort, the costs for the five major weapon system descriptions were identified. These five major types of weapon system costs are: Fly Away, Weapon System, Procurement, Program Acquisition, and Life Cycle as shown in Figure 6-3 with the respective cost compositions.

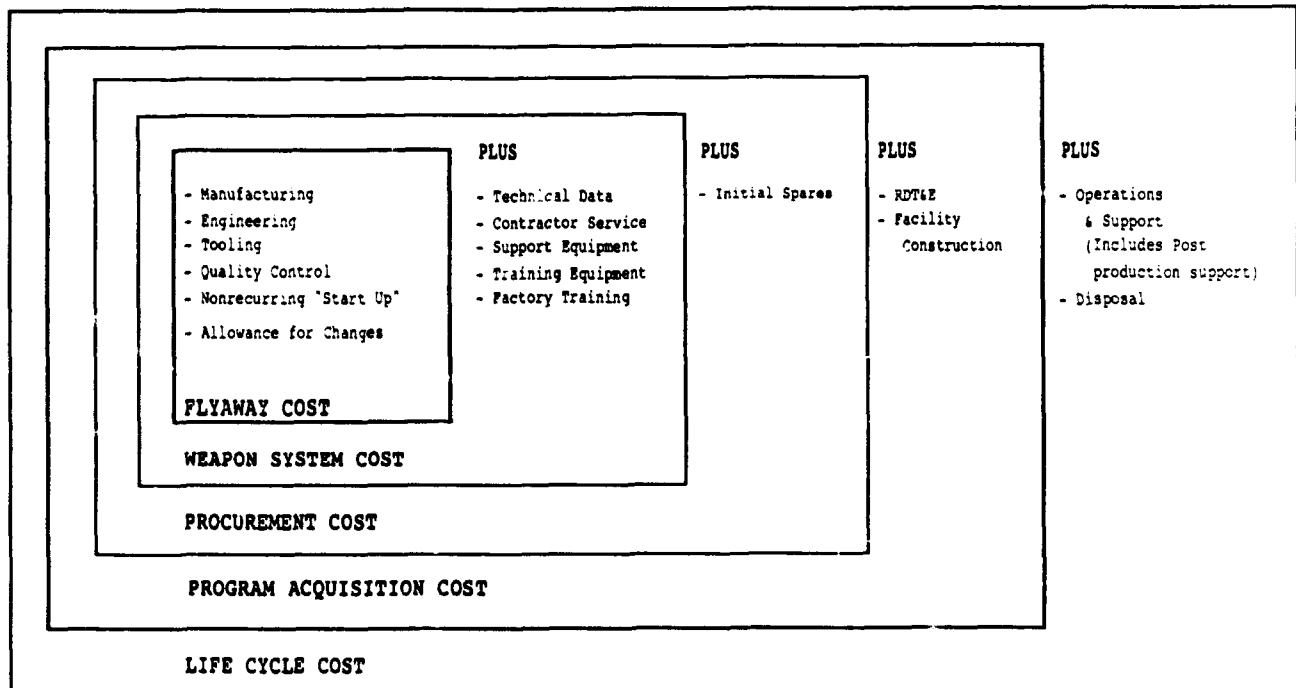


Figure 6-3. Life Cycle Cost Composition

6-3. DETERMINE APPROPRIATE MODELS AND TOOLS

a. Identify Selection Criteria

(1) Models and analytical tools used in the Value Added Analysis methodology for costing were selected based on the following criteria:

(a) The ability to perform quick reaction weapon system cost estimates considering variation in procurement quantities.

(b) The ability to provide consistency among all weapon systems in the computation of cost/quantity relationships.

(c) The ability to estimate broad cost categories and their relationship to Army appropriations that are of interest to budget/programming decisionmakers.

(2) The study team conducted a subjective analysis of the candidate technique using the above criteria. This analysis consisted of:

(a) Determining analytical tools that can provide same day cost estimates.

(b) Determining a consistent cost format for all weapon systems.

(c) Providing the capability to cross-reference between weapon system cost elements and Army appropriations.

b. **Determine Measures of Effectiveness.** The following MOE are relevant for the Value Added Analysis methodology model/tool selection:

(1) **Timeliness.** Costing for the Value Added Analysis methodology requires extremely quick reaction turnaround because the environment in which these types of decisions are conducted is characterized by short timelines.

(2) **Accuracy.** Cost estimates must be accurate within an acceptable margin of error to be of any value in the analysis. A tradeoff exists between the timeliness and accuracy of MOEs. Given the tradeoff with timeliness and the anticipated broad scope of Value Added Analysis applications, selection of models/tools were made with an implicit goal of providing cost estimates with less than a 15 percent margin of error.

c. **Review Alternative Costing Methods**

(1) **Cost Quantity Alternatives**

(a) **Program Manager Level Models.** Production costs of a weapon system are conventionally estimated by aggregating the costs of the individual components. The costs of the components are calculated using learning curves, the required quantities, and the first unit costs of each component. This method requires considerable computation, especially when the number of components is large. Models performing these "component" aggregation cost estimates are complex and usually reside at the program manager level.

(b) **Composite Learning Curves.** An estimation procedure was developed aimed at reducing the computational effort required to aggregate component-level costs while yielding reasonably accurate weapon system costs. This procedure replaces individual component-level learning curves with a composite learning curve. It allowed for the calculation of production costs with simplified computations but with a loss of some accuracy. However, the laborious task of gathering component-level learning curve data exits with this method.

(2) **The CQM Method.** The CQM utilizes experience curve theory to estimate average unit production costs. Base experience curve theory specifies unit cost as a function of the quantity produced. The tenet is that as production of a particular good (weapon system) doubles, production cost decreases at some constant rate. The base experience curve method is an accepted technique to forecast production costs from the known costs of past production. It is specified as follows:

[6.01]

$$Y = AX^b$$

where:

Y = average unit cost
 A = cost of the first unit produced
 X = cumulative quantity of units produced
 b = experience curve slope coefficient.

(a) The CQM employs an altered form of the base experience curve. This is due to the wide recognition that the production rate plays an important role in production costs. In light of this, a production rate variable has been added to the base method. This reveals the following experience curve function, which is utilized by the CQM.¹

[6.02]

$$Y = AQ^b R^c$$

where:

Q = cumulative lot mid-point
 b = cost/lot mid-point slope coefficient
 R = production rate
 c = cost/rate slope coefficient

All other variables are as previously defined.

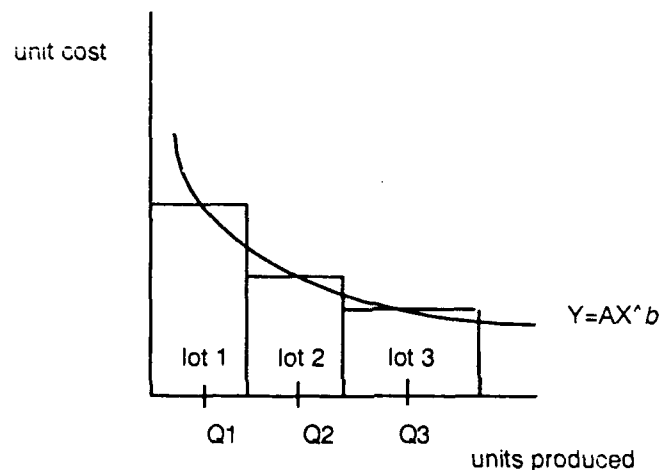
1. In addition to the inclusion of the production rate variable, [6.02] above has been altered in another way. The cumulative quantity variable (X) has been substituted by the cumulative lot mid-point (Q). This is necessary because weapon system(s) program managers generally do not keep cost data on individual units of output. Instead, they maintain cost data on "lots" of output. Since the cost of individual units is unknown, estimation of the experience curve as specified by the base method is impossible.

2. One method to remedy this is use of the cumulative lot mid-point. The lot mid-point is that unit in a given lot of output whose cost is equal to the average cost of all the units in the lot. This can be seen graphically in

¹See Bemis, John C. The Cost Implications of Production Rate. *Concepts*, Spring 1981, Volume 1, Number 2. Pgs 84-94.

Figure 6-4. Unit cost is plotted along the vertical axis, while the number of units produced lies along the horizontal axis. Three separate lots of output are drawn in the figure. The plots marked by Q_1 , Q_2 , and Q_3 represent those units whose cost equals the average cost of the entire lot. In the figure, a curve has been drawn through the respective lot mid-points.

3. This method is helpful because weapon system(s) program managers do maintain data on the number of units produced in a given lot. Coupling this with the cost of that lot allows a cost/quantity relationship to be established. This allows the experience curve to be estimated. The estimator for the cumulative lot mid-point is presented on the next page.²



[6.03]

$$Q = \frac{F + L + 2\sqrt{FL}}{4}$$

Figure 6-4. Lot Mid-Point

where,

Q = approximate cumulative lot mid-point
 F = first unit in the lot
 L = last unit in the lot

Table F-2 in Appendix F lists examples of cumulative lot mid-point calculations.

² Cost Estimating for Engineers. ALM-63-3126-LC. Pgs 210-212.

4. Once all the necessary data is acquired, the experience curve function of equation [6.02] can be estimated. This is done by applying ordinary least squares regression to equation [6.02]. In order to do so, [6.02] must first be made log-linear. Ordinary least squares is then applied to the log-transformed variables of [6.02]. This is all done by the CQM. The only user requirement is entry of the variable data.

5. Output from CQM will include experience curve estimates and descriptive statistics. In cases where the production rate variable is found to be statistically insignificant, CQM allows the user to drop that variable and re-estimate the curve. Included in the output are the experience curve percentages. These reveal the percentage of the first unit cost to which first unit cost decreases when production quantity doubles. Refer to Appendix F for further explanation.

6. Total production costs for a given weapon system are found by finding the area under the experience curve (see Appendix F, paragraph F-6). The average unit cost for the projected production quantity for each affected year is calculated from the estimated first unit cost, experience curve, and production rate curve. This average unit cost for the affected years is then used as input to FOMOA, which computes the optimal procurement quantities. After the new procurement quantities are determined the CQM should be run one more iteration to compute the average unit costs (by year) for the optimal production quantities generated by FOMOA. The use of a constant average unit cost (AUC) for production did not, for this demonstration, create a situation in which a stable solution was unattainable. However, the danger does exist that with repeated iterations convergence to a stable solution may not be obtainable. Further work in regards to dynamic costing within the linear program must be conducted as part of the VAA Phase II study.

(3) BCE Costing Updating

(a) The BCE is a generic term denoting a comprehensive, detailed and fully documented estimate of materiel life cycle costs accomplished by the weapon system project manager. The BCE is a dynamic document, refined and updated throughout the acquisition cycle. The BCE serves, after review and validation, as the principal cost estimate for the system and is used as:

1. The principal institutional source document for cost information related to materiel systems.

2. The basis for projecting funding requirements for acquisition and operation of the materiel system.

3. The benchmark (initial BCE) and source (updated BCEs) for system cost tracking.

4. The basis for cost inputs to such reports as the Selected Acquisition Report (SAR).

(b) It would be impractical to update BCEs to address issues associated with Value Added Analysis applications. Therefore, a suitable strategy to estimate key cost elements comprising total life cycle cost of a weapon system was undertaken.

(4) **The LCCM Method.** Once the optimal procurement quantities and production costs are calculated, the LCCM redistributes production, fielding and sustainment costs. This is accomplished by inputting cost factors generated from the BCE/ACP source data on the first of two LCCM spreadsheets. These prorated cost estimates can be used as input to FOMOA for specific "what if" exercises that require optimization to address issues such as those associated with horseblanket drills.

(a) **Current Method for Prorating Production Costs.** Ideally, variations in production costs would be accompanied by the concurrent changes in the P92 cost categories. This is not possible in the limited timeframe for addressing a Value Added issue. If production quantities are increased or decreased, the CQM is used to determine the total production costs for those quantities. LCCM redistributes total production costs by the percentage of total production costs for each P92 production cost element. These factors are calculated for the BCE/ACP source data in the first spreadsheet. For example, if 2.03 Engineering Changes accounted for 3 percent of total production costs on the BCE/ACP, the second spreadsheet containing the revised production quantities would estimate the P92 cost element 2.03 Engineering Changes to be 3 percent of the new total production costs.

(b) **Methodology for Prorating Fielding and Sustainment Costs.** Again, based on the BCE/ACP source data in the first spreadsheet, per unit/system P92 costs are calculated for each cost element. The second spreadsheet reflects the revised costs for new fielding and sustainment quantities simply by multiplying the new quantities by the per unit costs calculated from the BCE/ACP source data in the first spreadsheet.

(c) **Calculation of Military Construction, Army (MCA and Development Costs).** MCA and development costs are not changed with variations in production quantities. In most applications, this is appropriate, since these costs would not vary significantly with relatively small production quantity changes. In instances where quantities are changed signif-

icantly, MCA and development costs would have to be reevaluated based on the idiosyncrasies associated with the particular system's development and MCA requirement.

6-4. IMPLEMENT ANALYTICAL MODELS AND TOOLS

a. Identify Data Requirements

(1) **Life Cycle Cost Data.** Life cycle cost data are obtained from BCE or Army cost positions (ACP) in order to provide cost quantity data for inclusion in the VAA methodology. BCEs are generated by the weapon system program managers (PMs). The CEAC performs independent cost estimates (ICEs) to validate the BCE. Differences between the BCE and ICE are reconciled in a cost analysis brief (CAB). The CAB results in an ACP used to support the POM. ACP or BCE data are used in VAA depending on which is the most current. Updated BCEs should be available on an annual basis. BCE updates also occur when the approved quantities, operating tempo, or other cost determining factors for a particular weapon system have changed significantly..

(2) **Inflation Indices.** Inflation indices guidance are provided annually from AMC in the form of a memorandum. AMC guidance provides inflation indices for each Army appropriation as well as distinguishing aircraft, missiles, weapons/tracked combat vehicles, and ammunition procurement. The inflation indices or escalation factors are needed to convert constant (e.g., FY 90) dollars to current (i.e., inflated or escalated) dollars. The indices are also used in the conversion of current dollars to constant dollars. The indices are important because VAA requires consistency among the types of costs used in order to make comparisons between alternatives.

(3) **Minimum/Maximum Production Rates.** Rates of production data are required as constraints in the FOMOA (optimization module) Model and can be obtained from Assistant Secretary of the Army for Research, Development, and Acquisition (ASARDA) or the PMs. Systems can only be produced between the parameter of the minimum sustaining rate and the maximum production rate. The minimum sustaining rate (MSR) is defined as a level of production which will keep a production line open while maintaining a responsive vendor and supplier base (i.e., warm production base). The assumption inherent in the MSR is that the plant must operate one shift, 8 hours per shift, 5 days a week. Conversely, the maximum production rate is defined as a level of production which maximizes the capacity of the existing tooling or facilities without requiring an additional investment to increase the production capacity. This definition assumes three shifts of 8 hours per shift, 7 days a week.

b. Obtain Modeling Capability**(1) The Cost Quantity Model (CQM)**

(a) The CQM provides a practical tool to estimate average unit production costs of a given weapons system. It utilizes experience curve theory to make these estimates. CQM allows the user to specify unit production cost as either a function of the quantity produced, or of the quantity produced and production rate. A complete description of experience curve theory and the use of the cost/quantity/rate method is provided in Appendix F.

(b) The CQM Model performs two principal functions. The first is to estimate the experience curve for a given weapons system. This is done through the use of historical production cost, quantity, and rate data. Once the experience curve is estimated, the model yields other needed calculations. This includes the system's first unit cost and the experience curve percentages (see Appendix F for a description of experience curve percentages).

(c) The estimates obtained in the first function of the CQM are inputs to the second. The second function of CQM allows production costs to be computed, given the quantities desired. The model also allows for constrained budgets and other factors that might shift the underlying experience curve (such as technological change, contract competition, etc.). The model produces estimates on the average and cumulative average unit production costs, in both constant and current dollars.

(2) The Life Cycle Cost Model (LCCM)

(a) LCCM is a modified version of the Information System Life Cycle Cost Model developed by CEAC. Modifications and enhancements were made to conform to weapon system life cycle cost data and to provide the capability to redistribute cost elements concurrent with variations in procurement quantities. All formulas and macros were written using Quattro Pro. All computations and final values are workable and accurate in Lotus 1-2-3 spreadsheets with the exception of the macros that realign the columns and provide two graph options. Therefore, it is recommended that Quattro Pro be used when entering data and performing sensitivity analysis on the cost categories and procurement quantities.

(b) LCCM comprises two spreadsheets. The first spreadsheet contains a blank template for the data to be entered based on the general structure and organization of the P92 cost categories developed for BCE and ACP. P92 cost categories are the cost codes established by the Office of the Comptroller of the Army as part of the integration of weapon system costing, programming, and execution of management systems. The second

spreadsheet is linked to the first and recomputes the new major category quantity and cost values of each of the cells by unit cost based on the proportion of the previous entries of the BCE/ACP data. A display of the LCCM spreadsheet with the P92 cost codes utilized is shown in Appendix F, Figure F-1.

(c) A summary of the five major cost categories is computed by year and for the life of the system. Allowance was made for data 13 years beyond the current year set by the user; however, more cells for additional outyears can be added when necessary. A summation of the following appropriations is made for research, development, testing, and evaluation (RDTE), Military Construction Army (MCA), Operations and Maintenance (OMA), Procurement Army (PA), and Military Pay and Allowances (MPA). Costs for associated items of equipment of each system are entered on the first spreadsheet and unit costs for each ASIOE calculated to apply to new production quantities on the second.

(d) The model is time-phased by appropriation, and the life cycle costs of the weapon system are computed in both constant dollars (then year dollars) and current dollars (dollars of the current fiscal year). Based on the current year that the user enters, the prior year and the previous years are computed as is the budget year, the subsequent POM years, and the outyears. Inflation from the US Army Material Command is used.¹ The inflation factors are recorded on the spreadsheet in protected mode and can only be changed by using the disable protection command in Quattro Pro or Lotus 1-2-3.

c. **Experimental Design.** The average unit cost for the projected production quantity for each affected year is calculated from the estimated first unit cost, experience curve, and production rate curve considering the prior quantity produced. The average unit cost for affected years is then used as input to FOMOA, which computes the optimal procurement quantities. CQM is run again to compute the average unit costs for the optimal quantities generated by FOMOA.

d. Use Models and Tools

(1) Illustrative Example

(a) This paragraph provides an illustrative example of the application of CQM and the potential for use of the LCCM Model. The M1A2 Abrams main battle tank from the armor/antiarmor illustrative case study will be used to demonstrate these two models. Table 6-1 displays the CQM inputs for the M1A2 tank.

¹See memorandum, Headquarters, U.S. Army Material Command, Subject: Inflation Guidance. Issued 28 December 1989.

Table 6-1A. CQM Input - M1A2 Tank (\$ FY 90 in \$M)

	Inputs	Curve factors
1st Unit Cost	58.00	A=58.00
Experience Curve (B%)	90.0%	B= -0.15200
Production Rate Curve (C%)	81.0%	C= -0.30401
Previous Quantity	7,786	(1+B) = 0.84800

Table 6-1B. CQM Input by Year - M1A2 Tank (\$ FY 90 in \$M)

Production FY	1991	1992	1993	1994	1995	1996	1997
Proj Shift +/- (%)	20.00	0.00	0.00	0.00	0.00	0.00	0.00
Desired Quantity	261	516	516	516	516	420	181
Constant \$ Budget	1,179.6	1,754.4	1,709.0	1,698.4	1,330.0	1,150.0	635.0
Inflation Factors	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Shift Factor	1.20	1.20	1.20	1.20	1.20	1.20	1.20

(1) The experience curve (B) and the production rate curve (C) were estimated from historical production data for the M1 tank series using the cost/quantity/rate method described in detail in Appendix F, paragraph F-5. The first unit cost was estimated to be \$58M, the cost/quantity curve at 90 percent, and the production rate curve at 81 percent. Prior quantities of M1 tanks produced were 7,786. The desired annual production quantities, with the projected annual budget dollars are input into the model, and the average annual unit production cost (in FY 90 constant dollars for this example) is computed (see Table 6-3). These average annual unit production costs are then used as input to the FOMOA Model which computes the optimal production quantities considering both budget dollars available, combat effectiveness, and competing alternative weapon systems. Once the optimal M1A2 quantities were computed by FOMOA, the average unit production costs for the optimized production quantities were calculated by a second application of the CQM. A 20 percent projected shift factor was included in the first year of production of the M1A2 (1991) to account for the average unit production cost delta for the M1A2 tank over the M1A1 tank.

(2) The LCCM input is extracted from BCE/ACP data and entered into the Life Cycle Cost Model. The input format for the LCCM is shown in Tables 6-2A through 6-2E.

Table 6-2A. LCCM Input Data - Development Costs (\$M)

Category	Cost element	Appn	Total previous years	Prior year 1989	Current year 1990	Budget year 1991	POM yr 1 1992	POM yr 2 1993	Etc.
1.0	Development	RDTE	X	X	X	X	X	X	X
1.01	Dev Eng, Acq	RDTE	X	X	X	X	X	X	X
1.011	Engineering	RDTE	X	X	X	X	X	X	X
1.012	Prod, Eng & Plan	RDTE	X	X	X	X	X	X	X
1.013	Tooling	RDTE	X	X	X	X	X	X	X
1.02	Data	RDTE	X	X	X	X	X	X	X
1.03	System Test	RDTE	X	X	X	X	X	X	X
1.04	System Proj Mgmt	RDTE	X	X	X	X	X	X	X
1.05	Training Service	RDTE	X	X	X	X	X	X	X
1.06	Facilities	RDTE	X	X	X	X	X	X	X
1.07	Other Dev Costs	RDTE	X	X	X	X	X	X	X

Table 6-2B. LCCM Input Data - Production Costs (\$M)

Category	Cost element	Appn	Total previous years	Prior year 1989	Current year 1990	Budget year 1991	POM yr 1 1992	POM Yr 2 1993	Etc.
2.0	Production	PA	X	X	X	X	X	X	X
2.01	Nonrecurring	PA	X	X	X	X	X	X	X
2.011	Initial Prod Fac	PA	X	X	X	X	X	X	X
2.012	Prod Base Spt	PA	X	X	X	X	X	X	X
2.013	DMPE	PA	X	X	X	X	X	X	X
2.014	Other Nonrecurring	PA	X	X	X	X	X	X	X
2.02	Recurring	PA	X	X	X	X	X	X	X
2.021	Manufacturing	PA	X	X	X	X	X	X	X
2.0211	Contract	PA	X	X	X	X	X	X	X
2.0211	In-house	PA	X	X	X	X	X	X	X
2.0213	Warranty	PA	X	X	X	X	X	X	X
2.0214	Other	PA	X	X	X	X	X	X	X
2.022	Rec Engineering	PA	X	X	X	X	X	X	X
2.023	Tooling	PA	X	X	X	X	X	X	X
2.024	Quality Control	PA	X	X	X	X	X	X	X
2.03	ECOs	PA	X	X	X	X	X	X	X
2.04	Data	PA	X	X	X	X	X	X	X
2.05	Sys Test & Eval	PA	X	X	X	X	X	X	X
2.06	Train Serv & Equipment	PA	X	X	X	X	X	X	X
2.07	Intial Spares	PA	X	X	X	X	X	X	X
2.08	Operate/Site	PA	X	X	X	X	X	X	X
2.09	Other Prod Fund	PA	X	X	X	X	X	X	X

Table 6-2C. LCCM Input Data - MCA and Fielding Costs (\$M)

Category	Cost element	Appn	Total previous years	Prior year 1989	Current year 1990	Budget year 1991	POM yr 1 1992	POM yr 2 1993	Etc.
3.0	Military Constr	MCA	X	X	X	X	X	X	X
4.0	Fielding	OMA	X	X	X	X	X	X	X
4.01	System Test	OMA	X	X	X	X	X	X	X
4.02	Training, Serv/Equipment	OMA	X	X	X	X	X	X	X
4.03	Transportation	OMA	X	X	X	X	X	X	X
4.04	Intial Repair Part	OMA	X	X	X	X	X	X	X
4.041	Intial Repair Part	OMA	X	X	X	X	X	X	X
4.0411	OMA Funded	OMA	X	X	X	X	X	X	X
4.0412	Procurement Funded	PA	X	X	X	X	X	X	X
4.042	Init Supplies/Con	OMA	X	X	X	X	X	X	X
4.05	Sys Spec Base	OMA	X	X	X	X	X	X	X
4.051	Civilian	OMA	X	X	X	X	X	X	X
4.052	Military	OMA	X	X	X	X	X	X	X
4.053	Contractor	OMA	X	X	X	X	X	X	X
4.054	Other	OMA	X	X	X	X	X	X	X
4.06	Other Fund Field	OMA	X	X	X	X	X	X	X
4.061	Other OMA Fund	OMA	X	X	X	X	X	X	X
4.062	Other PA Fund	PA	X	X	X	X	X	X	X

Table 6-2D. LCCM Input Data - Sustainment Costs (\$M)

Category	Cost element	Appn	Total previous years	Prior year 1989	Current year 1990	Budget year 1991	POM yr 1 1992	POM yr 2 1993	Etc.
5.0	Sustainment	OMA	X	X	X	X	X	X	X
5.01	Replenishment	OMA	X	X	X	X	X	X	X
5.011	Replenish Repair	OMA	X	X	X	X	X	X	X
5.0111	OMA Funded	OMA	X	X	X	X	X	X	X
5.0112	Procurement Funded	PA	X	X	X	X	X	X	X
5.012	Replenish Spares	OMA	X	X	X	X	X	X	X
5.0121	OMA Funded	OMA	X	X	X	X	X	X	X
5.0122	Procurement Funded	PA	X	X	X	X	X	X	X
5.013	War Reserve Repair	OMA	X	X	X	X	X	X	X
5.014	War Reserve Spares	OMA	X	X	X	X	X	X	X
5.0141	OMA Funded	OMA	X	X	X	X	X	X	X
5.0142	Procurement Funded	PA	X	X	X	X	X	X	X
5.015	War Reserve Repair	OMA	X	X	X	X	X	X	X
5.0151	OMA Funded	OMA	X	X	X	X	X	X	X
5.0152	Procurement Funded	PA	X	X	X	X	X	X	X
5.03	Ammo/Missile	OMA	X	X	X	X	X	X	X
5.031	Train-Ammo / Msl	PA	X	X	X	X	X	X	X
5.032	War Reserve Ammo/Msl	PA	X	X	X	X	X	X	X
5.04	Depot Maint	OMA	X	X	X	X	X	X	X
5.041	Depot Maint Civil	OMA	X	X	X	X	X	X	X
5.0411	Veh OH Civil Lab	OMA	X	X	X	X	X	X	X
5.0412	Veh OH Mat Lab	OMA	X	X	X	X	X	X	X
5.0412	Civilian	OMA	X	X	X	X	X	X	X
5.0412	Military	OMA	X	X	X	X	X	X	X
5.0412	Contract	OMA	X	X	X	X	X	X	X
5.0412	Other	OMA	X	X	X	X	X	X	X
5.042	Depot Maint Mat	OMA	X	X	X	X	X	X	X
5.0421	Military	OMA	X	X	X	X	X	X	X
5.0421	Contract	OMA	X	X	X	X	X	X	X
5.0421	Other	OMA	X	X	X	X	X	X	X
5.0422	Comp OH Mat	OMA	X	X	X	X	X	X	X
5.043	Material (Proc)	PA	X	X	X	X	X	X	X
5.044	Maint Spt Act	OMA	X	X	X	X	X	X	X
5.05	Field Maint Civil	OMA	X	X	X	X	X	X	X
5.06	Transportation	OMA	X	X	X	X	X	X	X
5.07	Repl Training	OMA	X	X	X	X	X	X	X
5.071	Ammo/Msl/Equipment	PA	X	X	X	X	X	X	X
5.072	System/Trng/Srv	OMA	X	X	X	X	X	X	X
5.073	Contract	OMA	X	X	X	X	X	X	X
5.074	Other	OMA	X	X	X	X	X	X	X

Table 6-2D. (continued) LCCM Input Data - Sustainment Costs (\$M)

Category	Cost element	Appn	Total previous years	Prior year 1989	Current year 1990	Budget year 1991	POM yr 1 1992	POM yr 2 1993	Etc.
5.08	MPA	MPA	X	X	X	X	X	X	X
5.09	Sys/Proj Mgmt Civ	PA	X	X	X	X	X	X	X
5.10	Modification Kits	PA	X	X	X	X	X	X	X
5.101	Hardware	PA	X	X	X	X	X	X	X
5.102	Application	PA	X	X	X	X	X	X	X
5.111	Other OMA fund	OMA	X	X	X	X	X	X	X
5.112	Life Cycle Sftwr	PA	X	X	X	X	X	X	X

Table 6-2E. Link Between Appropriation Summary and Major Cost Categories

Category	Appn	Total previous years	Prior year 1989	Current year 1990	Budget year 1991	POM yr 1 1992	POM yr 2 1993	Etc.
Development	RDTE	X	X	X	X	X	X	X
Production	OMA PA	X	X	X	X	X	X	X
Military Construction	MCA	X	X	X	X	X	X	X
Fielding	OMA PA	X	X	X	X	X	X	X
Sustainment	OMA MPA PA	X	X	X	X	X	X	X
NOTES: Constant or Current \$M		X	X	X	X	X	X	X

6-5. ANALYZE RESULTS

a. Introduction. This paragraph provides the CQM inputs and outputs for the M1A2 tank illustrative example. Also included is the incorporation of an application of the LCCM and the results of an ARIM type weapon system definition (using the M1A2 tank illustrative example).

b. CQM Results. Table 6-3 provides the CQM results for the planned procurement quantities presented in the May 1989 M1A2 ACP. Average unit costs declined until the last 2 years when the reduced quantities increased the average unit costs (Table 6-4). The CQM estimates were within 13 percent of the costs generated by the ACP.

Table 6-3. CQM Output M1A2 -\$ FY90/\$M (A3 example)

YEAR	1991	1992	1993	1994	1995	1996	1997
PROPOSED RATE	261	516	516	516	516	420	181
ACTUAL 1ST ITEM	1.00	262.00	778.00	1294.00	1810.00	2326.00	2746.00
ACTUAL LAST ITEM	261.00	777.00	1293.00	1809.00	2325.00	2745.00	2926.00
ACTUAL PROD QTY	261.00	516.00	516.00	516.00	516.00	420.00	181.00
CUMUL ACTUAL QTY	261.00	777.00	1293.00	1809.00	2325.00	2745.00	2926.00
ACT PROD CONSTANT \$	855.00	1364.10	1353.70	1340.00	1329.10	1143.60	633.80
CUMUL CONSTANT \$	855.00	2219.20	3570.80	4910.90	6240.00	7383.60	8017.40
ACTUAL PROD CURR \$	855.00	1364.10	1353.70	1340.00	1329.10	1143.60	633.80
CONSTANT \$ AVG UNIT PROD COST	3.28	2.64	2.62	2.60	2.58	2.72	3.50

Table 6-4. Average Unit Production Costs of Optimized Qtys - M1A2

YEAR	1995	1996	1997	1998	1999	2000
OPTIMIZED QTYS	64	64	64	64	64	64
AVG UNIT PROD COSTS	\$5.03	\$5.03	\$5.02	\$5.01	\$5.01	\$5.00

The CQM provided a useful tool for the quick reaction cost quantity data required by the Value Added Analysis methodology. The Cost Quantity Model has been used successfully in conjunction with FOMOA to optimize acquisition strategies for several modernization plans, including armor systems modernization (ASM) and helicopters. FOMOA cannot currently dynamically account for changes in unit weapon system costs as a result of experience and production rate curves. CQM accounts for this by providing the adjusted unit production costs by year for the optimal quantities computed in an initial FOMOA run (based on an average unit cost FOMOA is then rerun utilizing the adjusted unit costs, considering the experience and production curves. The result is a more accurate optimization of procurement quantities, by year, given constrained annual budgets. The feasibility of incorporation of the CQM or CQM methodology into FOMOA directly may be addressed in the future.

c. The LCCM output provides the same cost elements as the input shown in Tables 6-2A through 6-2E. The cost elements that relate to the five major weapon system type definitions for the M1A2 tank are shown in Table 6-5

Table 6-5. Major Weapon System Cost Definitions - M1A2

MAJOR WEAPON SYSTEM DEFINITION	LCCM COST ELEMENTS
Fly Away Cost	Fly Away Cost
Manufacturing	2.0213 warranty + 2.0214 other
Engineering	2-022 rec engineering
Tooling	2-023 tooling
Quality Control	2-024 quality control
Nonrecurring "Start Up"	2.01 nonrecurring
Allowance for Changes	2.03 engineering changes
	2.05 system test & evaluation
	2.091 system project management
	2.094 other production cost
Weapon System Costs	Weapon System Costs
Fly Away Costs Plus	
Technical Data	2.04 data
Contractor Service	2.0211 contract
Support Equipment	2.09 critical ASIOE
Training Equipment/Factory Training	2.06 training services & equipment
	2.08 operational site activity
Procurement Costs	Procurement Costs
Weapon System Costs Plus	Weapon System Costs Plus
Initial Spares	2.07 initial spares
Other	4.0 fielding (procurement)
Program Acquisition Costs	Program Acquisition Costs
Procurement Costs Plus	Procurement Costs Plus
RJT&E	1.0 development
Facility Construction	3.0 military construction
Life Cycle Costs	Life Cycle Costs
Program Acquisition Costs Plus	Program Acquisition Costs Plus
Operations & Support	5.0 sustainment
Common Support Equipment	2.092 common equip (ASIOE)+ 2.093 OSE
Disposal	NA
	Total life cycle costs

6-6. SUMMARY AND OBSERVATIONS

a. CQM and LCCM are models for use in the Value Added methodology for estimating weapon system costs, given variable budget constraints and system requirements. The two cost models developed are capable of estimating impacts on cost categories and appropriations for a large number of weapon systems in a short timeframe. The ARIM Study clarified the five major definitions of weapons systems which will be incorporated in the Value Added Costing methodology.

b. The LCCM combined with the CQM provides a useful tool for estimating the impact of variations in production quantities on the various life cycle cost elements and affected appropriations. Additional sensitivity analysis using the LCCM and CQM should be conducted. In addition, the LCCM capabilities should be expanded to provide the five major weapon system cost definitions shown in Table 6-5.

c. The CQM and LCCM provide useful tools for the quick reaction cost analysis required in the budget process. CQM is a mechanism for the estimation of cost/quantity and cost/rate relationships. LCCM approximates the impact of variations in procurement quantities on the various subcategories of cost elements and affected appropriations. Both of these models provide cost data that can be incorporated into the optimization model if required.

d. There is an absence of a central data base containing weapon system cost data at either the BCE level of detail or at the summary level of detail. This data is required for Value Added applications as well as numerous other applications throughout the Army. The responsibility for collecting and accessing data is consistent with the missions and functions for CEAC. Currently, this data is forwarded to or generated by CEAC, but there is no mechanism in place for centralizing weapon system data. A recent effort by AMC to install standardized automated BCE formats at the program managers (PMs) should provide impetus for the centralization of BCE data.

¹CHAPTER 7

IMPLICIT MEASURES OF EFFECTIVENESS

7-1. INTRODUCTION

a. The purpose of this chapter is to provide a discussion of the formal analytical framework used to perform quantitative analysis of subjective data which we call implicit measures of effectiveness. This chapter also provides a detailed discussion of how these implicit values will be used in the Value Added Analysis. This chapter is structured as follows:

- (1) Introduction
- (2) SIAM Factors
- (3) Summary

b. Figure 7-1 depicts the Implicit Effectiveness Module and how it relates to the overall VAA methodology. The overview chart indicates that there are two elements within the module, a leadership survey element and a decision element. The leadership survey is conducted to obtain weights for use in the effectiveness integration module and in helping define the secondary factors. The secondary factors decision box is present within the module to indicate that the VAA methodology at this point requires a decision. The analyst may, at this point in the analysis, decide to include or exclude the SIAM factors as part of the single measure of value.

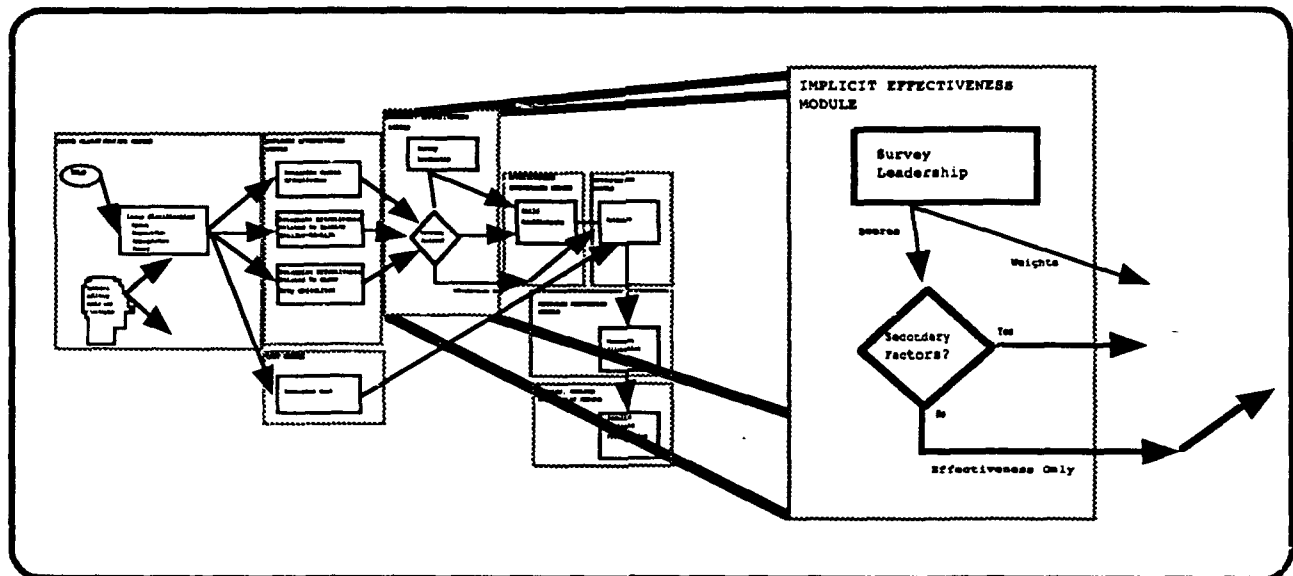


Figure 7-1. VAA Methodology - Implicit Effectiveness Overview

c. The study team decided early in the Value Added Analysis to quantify subjective judgments because of the following¹:

(1) A formal analytical framework supports decision-makers in their attempt to consider relevant information systematically and to examine options and consequences one at a time.

(2) Analysts can break an unmanageable problem into manageable parts and then synthesize information about the parts in a rational fashion.

(3) A formal framework allows sensitivity analysis on alternative judgments, tradeoffs among alternative judgments, study of effects of variations in subjective judgments on outcomes; and it is repeatable.

This group of implicit measures (subjective judgments) are collectively called SIAM factors.

7-2. SIAM FACTORS

a. Development of the Context for SIAM

(1) As indicated in paragraph 2-2, we defined value as being contextual. We have already discussed in Chapter 5 some of the most direct contextual items. These included the

¹Crawford, Gordon and Cindy Williams. The Analysis of Subjective Judgment Matrices, RAND Document R-2572-1-AF, May 1985 (AD-A157 399) (UNCLASSIFIED), page 2.

identification of theaters of interest, doctrine, tactics, weapons systems, and model assumptions. All of these items were used to obtain the explicit measures of effectiveness through combat modeling. However, in analyzing how program decisions are actually made within the Pentagon and the Department of the Army, it became very clear that other factors also influenced the decisions. These factors became known as SIAM factors.

(2) The SIAM factors do reflect context. The manner in which context is achieved is twofold. First, context is created as a function of who decides what is a SIAM factor, i.e., which special interest group, such as the Congress, Office of Management and Budget (OMB), Office of the Secretary of Defense (OSD), CINCs, ARSTAF, or major Army command (MACOM) commanders. Second, these factors provide context through groups weighting each of the factors so that they reflect the group's value judgments. Context in this sense refers to what foreign and domestic issues impact upon the decisionmakers and how they assimilate these issues to make judgments.

b. Terms and Definitions. This paragraph is designed to provide the reader an understanding of the lexicon used in developing the implicit measures of effectiveness.

(1) **Combat Effectiveness.** The contribution to warfighting capability.

(2) **Noncombat Effectiveness.** The contribution to warfighting capabilities other than warfighting. This term includes such factors as nation building, operating facilities to support soldier quality of life and contributions to special programs of national interest such as fighting drugs, environmental protection and energy conservation.

(3) **Secondary Impact Analysis Modifiers.** Key factors which are considered in the decisionmaking process, but are not official Army measures of effectiveness. For example, political risk.

(4) **Blue Force Surviving.** A measure of combat effectiveness obtained from a combat simulation. It is the percentage of the Blue combat power remaining after the end of a Red first echelon attack.

(5) **Correlation of Forces and Means.** A measure of combat effectiveness obtained from a combat simulation. This measure is computed as the ratio of Red and Blue combat power in the strike sector remaining after the end of a Red first echelon attack. It is commonly used to infer the denial of the enemy's tactical objectives.

(6) **Movement of Force Center of Mass.** A measure of combat effectiveness obtained from a combat simulation. When Blue is on the defensive, it is a geographical measure of loss

of territory. Minimum movement is commonly used to infer the accomplishment of a Blue defensive objective. When Blue is on the offensive, success is measured as movement toward the objective.

(7) **Contribution to Industrial Preparedness.** A measure of the impact of a proposed program on the ability of the industrial base of the nation to respond to extraordinary production requirements.

(8) **Political Risk: Public Opinion.** The public opinion measure of political risk is a subjective evaluation of the attitudes of the general public toward a proposed program. It ranges from significant positive support for the program to significant opposition to the program.

(9) **Political Risk: Congressional Opinion.** The Congressional opinion measure of political risk is a subjective evaluation of the attitudes of the Congress toward a proposed program. It ranges from significant positive support for the program to significant opposition to the program.

(10) **Political Risk: Executive Branch Opinion.** The executive branch opinion measure of political risk is a subjective evaluation of the attitudes of the OMB, OSD, and JCS toward a proposed program. It ranges from significant positive support for the program to significant opposition to the program.

(11) **Political Risk: Internal Army Opinion.** The internal Army opinion measure of political risk is a subjective evaluation of the attitudes of special interest groups within the Army toward a proposed program. It ranges from significant positive support for the program to significant opposition to the program.

(12) **Institutional Stability.** A measure of the amount of change which is associated with a program. Change is measured in terms of the impact on the personnel, logistical, and training systems of the Army. Change is subjectively measured on a scale ranging from extreme change to marginal change.

(13) **Program Flexibility.** A measure of the funding flexibility associated with a program. In other words, it measures how much latitude is available to reprogram resources or change decisions with regard to the program. For example, a multiyear contract with a significant penalty clause would have low flexibility.

(14) **Program Feasibility.** A subjective measure of the number of obstacles which might prevent program execution. Programs which are extremely complex or slow to implement have

negative ratings for feasibility, while programs with few bureaucratic hurdles have positive ratings for feasibility.

(15) **Asset Versatility and Deployability.** Asset versatility and deployability measures the applicability of a program to multiple theaters of operation. For example, a program that bought new weapons that could be used in all theaters would have relatively high ratings for asset versatility.

(16) **Operational and Technical Risk.** Operational and technical risk is a subjective measure of the probability associated with a program meeting all of its stated performance criteria. For materiel systems, this factor will roughly correspond to the stage of materiel development for the system. For example, a system in 6.1 will have a higher risk than a system in stage 6.3.

(17) Need as Related to Current Capability.

Program need is a subjective measure of the current status of the mission area or function associated with a program, and the relative fraction of improvement that is expected. For example, programs that only enhance an adequate capability receive a more negative rating for need than those which address an area that has no current capability.

c. Decisionmakers (DMs) and the Pairwise Comparison Approach. Experts in decision theory recognize the Pairwise comparison approach, used in the Analytic Hierarchy Process (AHP) and developed by Thomas L. Saaty in the 1970s, as being particularly effective in eliciting experts' subjective judgments free from the usual negative effects of group pressure. As discussed in Chapter 1, some facets of the problem of developing the most desired POM lack any well-defined, scalar-valued measures of merit and involves a great many interrelated issues such as: combat MOEs, noncombat MOEs, and SIAM MOEs.

(1) An initial decision hierarchy (strawman), which allows the DM to break the complex problem into its constituent elements, is developed using literature reviews, brainstorming, and expert opinion.

(2) A final decision hierarchy is constructed with validated factors only after considerable discussion of the strawman with functional experts, the sponsor and various other DMs. The overall objective is the only element in Level One. Level Two consists of the judgment criteria the DMs consider important to the decision; each criteria can be further subdivided. Level Three contains the attributes (elements) of the previous higher level.

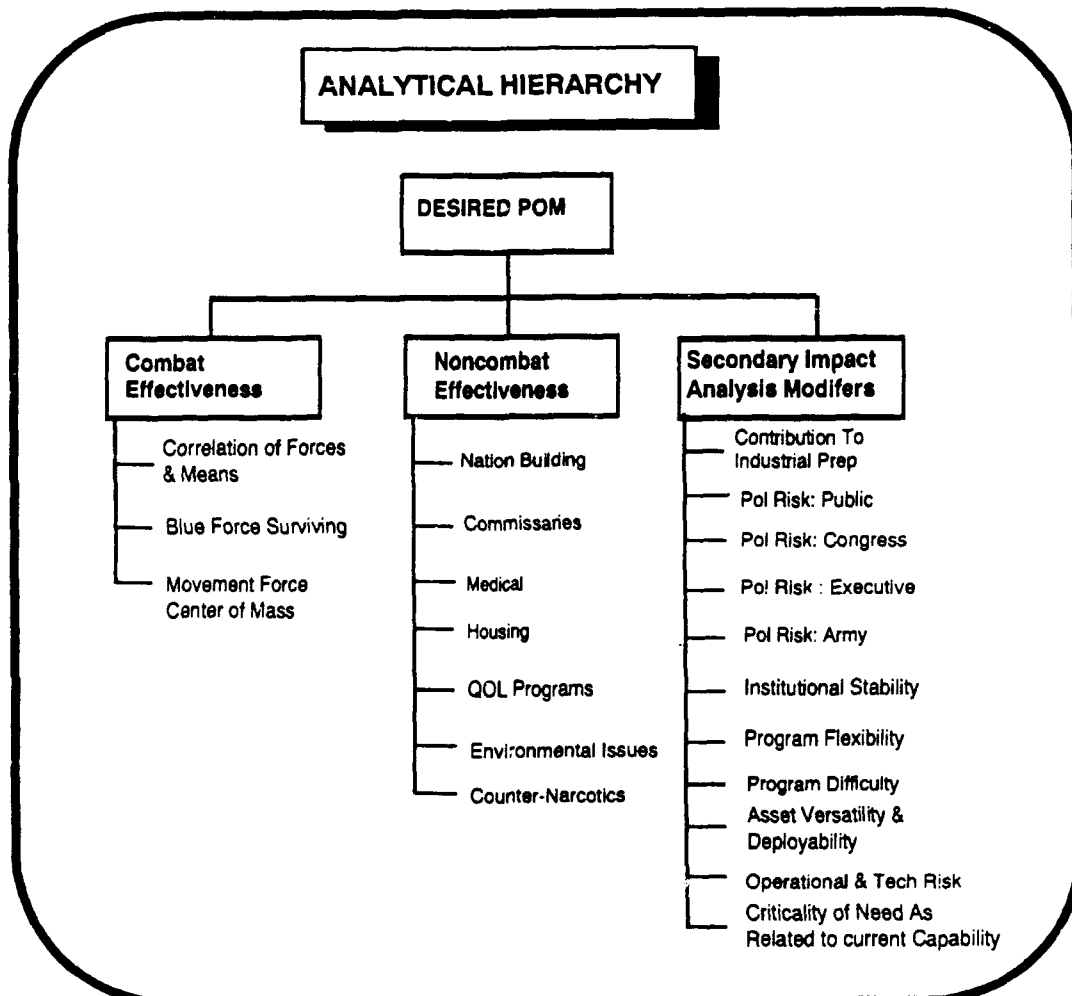


Figure 7-2. VAA Analytical Hierarchy

(3) The solicitation of judgments will be accomplished by means of a deskside briefing on the Value Added Analysis Study, followed by a survey of the attributes. The survey participants should cover a broad range of Department of the Army specialties, all required to make daily decisions relating to the Army program. During this phase of the study, the DM makes his or her preferences known, using a modified version of Saaty's AHP comparison scale (Figure 7-2). All participants should receive the same survey. However, there is no necessity for comparisons to be in the same sequence and in fact should be random if possible as a means of dealing with bias.

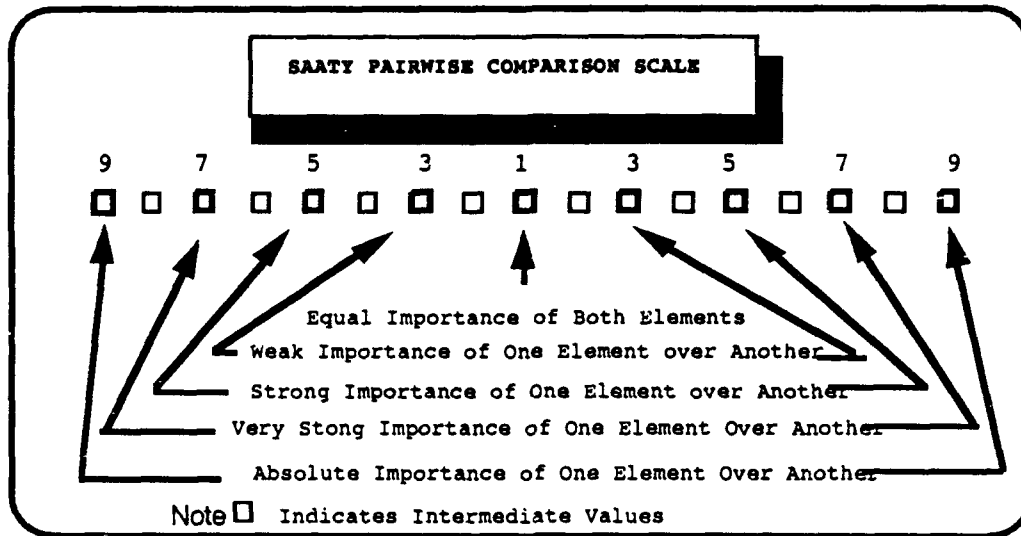


Figure 7-3. SAATY'S Pairwise Comparison Scale

(4) The establishment of priorities is accomplished by making pairwise comparisons, that is "to compare the elements in pairs against a given criterion."¹

(5) A pairwise comparison matrix is developed for each respondent after conducting the confidential interviews to determine the order of attribute priority with relative weights. The study team used a set of survey instruments such as the one depicted in Figure 7-3.

SURVEY INSTRUMENT																	
Contribution to Industrial Preparedness						vs.		Political Risk: Public Opinion									
The contribution to industrial preparedness measures the impact of a proposed program on the ability of the industrial base of the nation to respond to extraordinary production requirements.						The public opinion measure of political risk is a subjective evaluation of the attitudes of the general public toward a proposed program. It ranges from significant positive support for the program to significant opposition to the program.											
Absolute	Very Strong	Strong	Weak	Equal	Weak	Strong	Very Strong	Absolute									
□	□	□	□	□	□	□	□	□									
Check the box which you believe is presently the best measure of the importance of the item on the left as compared to the item on the right.																	

Figure 7-4. Example Survey Instrument

¹ Saaty, T. L. Decision Making for Leaders: The Analytic Hierarchy Process for Decisions in a Complex World. Belmont, CA: LifetimeLearning Publications, 1982 (UNCLASSIFIED) Page 76.

(6) The following is an illustrative example of a pairwise comparison and the calculation of the weights. Figure 7-4 is an example of a tradeoff issue in which the decisionmaker is seeking the most cost effective mix of armor and antiarmor (A3) systems.

Example: Representative Armor/Anti-Armor Systems

Issue: Given limited dollar resources, which mix of A3 Systems should be procured?

Alternatives Characteristics

Basecase Europe Scenario 6.3 with 25 Systems

Alt 1 • M1A2
 • NLOS-AT
 • MLRS SADARM

Alt 2 • M1A2
 • AMS-H
 • BRADLEY BLK III
 • MLRS SADARM

Figure 7-5. Example Tradeoff Issue

Table 7-1 is how one would form a matrix for comparing the issues as outlined in the previous figure. The numeric values show the relative importance to the decisionmaker of the three sample SIAM factors in relation to the mix of A3 systems.

Table 7-1. Example Decision Matrix

	Political Risk Congressional Opinion	Asset Versa- tility and Deployability	Operational and Technical Risk
Political Risk Congressional Opinion	1	1/2	1/5
Asset Versa- tility and Deployability	2	1	1/2
Operational and Technical Risk	5	2	1

(7) Priority weights are computed by the geometric mean method, rather than the more commonly used eigenvector method, because it gives rise to a more meaningful measure of consistency with known statistical properties. The RAND study¹

¹ Crawford, Gordon and Cindy Williams. The Analysis of Subjective

appropriately points out that the geometric mean vector is "rooted in a mathematical approach to estimation," providing an intuitive understanding to the problem as well as means to assess the method's suitability. The geometric mean is computed as follows:

STEP 1: Compute

[7.01]

$$V_i = \left(\prod_{j=1}^n a_{ij} \right)^{1/n} \text{ for } i = 1, 2, \dots, n$$

where:

V_i = Non-normalized weight for attribute "i",

n = total number of attributes,

i = row attribute index,

j = column attribute index,

a_{ij} = value for position ij in decision matrix A ,

V = vector of geometric means.

STEP 2: For V such that

[7.02]

$$V = \begin{bmatrix} V_1 \\ V_2 \\ V_3 \end{bmatrix}$$

[7.03]

$$V = \begin{bmatrix} ((1) (1/2) (1/5))^{1/3} \\ ((2) (1) (1/2))^{1/3} \\ ((5) (2) (1))^{1/3} \end{bmatrix} = \begin{bmatrix} 0.4641589 \\ 1.0000000 \\ 2.1544347 \end{bmatrix}$$

STEP 3: Compute the sum of the elements of V ,

[7.04]

$$\sum_{i=1}^3 V_i = 3.6185936$$

(8) The normalized geometric mean vector, V_n , is computed by dividing each element of the geometric mean vector by the sum of all the elements in the geometric mean vector. The sum of the elements of the normalized geometric mean vector is one.

STEP 4: Compute V_n as

[7.05]

$$\begin{bmatrix} \frac{V_1}{\sum V_i} \\ \frac{V_2}{\sum V_i} \\ \frac{V_3}{\sum V_i} \end{bmatrix} = \begin{bmatrix} V_{1n} \\ V_{2n} \\ V_{3n} \end{bmatrix}$$

[7.06]

$$\begin{bmatrix} 0.4641589 \\ 3.6185936 \\ 1.0000000 \\ 3.6185936 \\ 2.1544347 \\ 3.6185936 \end{bmatrix} = \begin{bmatrix} 0.1282705 \\ 0.2763505 \\ 0.595379 \end{bmatrix}$$

STEP 5: Check the sum of the elements of V_n ,

[7.07]

$$\sum V_{in} = V_{1n} + V_{2n} + V_{3n} = 1$$

$$\sum V_{in} = 0.1282705 + 0.2763505 + 0.595379 = 1$$

(9) Though consistency is not required from the DM when making pairwise comparisons, we must concern ourselves with knowing the degree of his consistency:

"...Consistency ...informs the judges about the adequacy of their knowledge and whether they need to study the matter further in order to obtain greater coherence in their understanding of the problem.¹"

¹Wind, Y. and T. L. Saaty. "Marketing Applications of the

(a) We do not want the decision to be based on judgment with low consistency with results of the survey appearing to be random.¹ Thus, a certain degree of consistency is needed to obtain valid results. Low consistency or high inconsistency may also indicate that: (1) the decisionmaker does not understand the pairwise comparison process, (2) the decisionmaker did not take necessary time to perform the comparisons, or (3) the decisionmaker has internal conflicts or inconsistencies himself. A consistency ratio (CR) measures the overall consistency of judgments and provides an indication that the decisionmaker's values did not change dramatically during the rating process. It is through the proportionality of the preferences that the decisionmaker indirectly provides this measurement.

(b) The CR is calculated as the consistency index (CI) divided by the average random index (RI). It is expressed as:

[7.08]

$$C.R. = \frac{C.I.}{R.I.}$$

A CR of 0.10 or less is considered acceptable; a CR greater than 0.10 makes the judgments appear random and indicates a need to improve the judgments or to restructure the hierarchy.³ When the CR is zero, you have complete consistency. The goal is not to minimize the CR, but to make good sound judgments and decisions. The principle or maximum eigenvalue, λ_{max} , and the number of elements for a given matrix determine the consistency index (closeness to consistency), or inconsistency index as it is sometimes called. This consistency index is represented by the following expression:⁴

[7.09]

$$C.I. = \frac{\lambda_{max} - n}{n - 1}$$

where,

λ_{max} = the maximum eigenvector (sum of the product of the pairwise comparison matrix and the normalized

Analytic Hierarchy Process, "Management Science, 26: 641-658 (July 1980), Page 647.

¹Saaty, T. L. The Analytic Hierarchy Process. New York: McGraw-Hill Book Company, 1980, page 21.

²ibid., Page 21.

³ibid., Page 21.

⁴ibid., Page 21.

geometric mean vector).

n = the order of the pairwise comparison matrix (the number of activities).

(c) Let A equal the pairwise comparison matrix before weighting. To determine the value of λ_{max} in the illustrative example, the pairwise comparison matrix A (3x3) is multiplied by the normalized geometric mean vector (3x1) and the elements of that vector are summed as shown, resulting in a scalar value λ_{max} .

STEP 1: Compute

[7.10]

$$AV_n = V_{nA} = \begin{bmatrix} V_{1nA} \\ V_{2nA} \\ V_{3nA} \end{bmatrix}$$

giving

[7.11]

$$\begin{bmatrix} 1 & 1/2 & 1/5 \\ 2 & 1 & 1/2 \\ 5 & 2 & 1 \end{bmatrix} \times \begin{bmatrix} 0.1282705 \\ 0.2763505 \\ 0.595379 \end{bmatrix} = \begin{bmatrix} 0.3855216 \\ 0.830581 \\ 1.789433 \end{bmatrix}$$

STEP 2: Calculate λ_{max} as follows.

[7.12]

$$\lambda_{max} = V_{1nA} + V_{2nA} + V_{3nA},$$

$$\lambda_{max} = 0.3855216 + 0.830581 + 1.789433 = 3.005536$$

(d) The consistency index is then calculated as

[7.13]

$$C.I. = \frac{(3.005536 - 3)}{2} = 0.002768, \text{ using [7.09].}$$

The denominator of the consistency ratio is the random consistency. That random value is specified by the number of elements or activities for a given matrix according to a random index table. The random index table used in this study to determine the random consistency was generated at the Oak Ridge National Laboratory:¹

Thus,

[7.14]

$$C.R. = \frac{0.002768}{0.58} = 0.0047724$$

NOTE: R.I. = 0.58 (this random index value is obtained from Saaty's text).

The consistency ratio for the A3 mix is less than the 10 percent Saaty uses to rate consistency in the pairwise comparison matrix and indicates the decisionmaker's values did not dramatically change during the pairwise rating process.

d. Subject Matter Experts and Weapon System

Scoring. A second methodology was used to obtain the subjective judgments of subject matter experts (Modernization Program Execution Group [PEG]) on the relative value of 23 weapon systems with respect to the SIAM factors. Experts were asked to rate each of the weapon systems on the rating instruments based on a standard scale from 1 to 9 (see Figure 7-5). The scores given by each expert were then summed to determine the combined score for each of the 23 systems. The results of this analysis confirmed that key air defense and assault helicopter weapon systems were viewed as more versatile, deployable, and more critically needed.

¹ibid., Page 21.

TERMINALLY GUIDED WEAPON (TGW) SCORING									
POLITICAL RISK: CONGRESSIONAL OPINION									
DEFINITION:	The congressional opinion measure of political risk is a subjective evaluation of the attitudes of the congress toward a proposed program. It ranges from significant positive support for the program to significant opposition to the program.								
SCORES:	☐	☐	☐	☐	☐	☐	☐	☐	☐
	1	2	3	4	5	6	7	8	9
	significant opposition (bad)			medium support			positive support (good)		

Figure 7-6. Example Scoring Instrument

(1) An initial scoring instrument was developed using literature reviews, brainstorming, and expert opinion. This example instrument was validated using senior staff officers within the Department of the Army Staff.

(2) A final scoring instrument was constructed using the results of the validation process. The study sponsor assisted the team in selecting a final panel for conducting the weapon system scoring based on their expertise and positions on the Army Staff.

(3) The solicitation of scores from this final panel was conducted in a two-step process. The first step consisted of providing each scorer a complete set of scoring instruments. The experts were asked to use appropriate documents, such as media articles, Congressional reports, technical papers, COEAs, CBRs, and Modernization plans etc., to develop a knowledge base for each of the systems (to be used during the scoring process). The second step consisted of a deskside briefing to ensure the respondents understood and felt comfortable with the Value Added methodology and approach.

(4) The following is an illustrative example of how the scoring would be completed. Table 7-2 is an example of a tradeoff issue in which the decisionmaker is seeking the most cost effective mix of armor and antiarmor systems.

Table 7-2. Example Scoring Matrix

	PRCO*	AV/D**	OTR***
WEIGHTS	0.1282705	0.2763505	0.595378
BASE CASE	31	19	36

ALT 1	29	36	27
ALT 2	16	24	17

* - Political Risk: Congressional Opinion

** - Asset Versatility and Deployability

*** - Operational and Technical Risk

Figure 7-6 summarizes the scoring for five subject matter experts as calculated using the following steps:

STEP 1: Collect the raw data and organize into a matrix.

Case	SIAM factors	Subject matter experts				
		S1	S2	S3	S4	S5
BC	PRCO	6	5	7	8	5
	AV/D	3	5	4	4	3
	OTR	8	7	6	8	7
Alt 1		S1	S2	S3	S4	S5
	PRCO	6	5	6	7	5
	AV/D	8	6	7	8	7
Alt 2	OTR	5	6	5	4	7
		S1	S2	S3	S4	S5
	PRCO	4	2	5	3	2
	AV/D	4	6	5	5	4
	OTR	2	3	5	3	4

Figure 7-6. Illustrative Example of SME Scoring

STEP 2: Compute the individual SIAM factor score for each case, where

$$[7.15]$$

$$\sum_{n=1}^5 SIAM_{jn} \text{ for } i = 1, 2, 3 \text{ and } j = 1, 2, 3$$

Resulting in summed scores for each SIAM factor (see Figure 7-7)

	BC	Alt 1	Alt 2
PRCO	31	29	16
AV/D	19	36	24
OTR	36	27	17

Figure 7-7. Illustrative Example of Summary Scores

e. **Analysis.** The results of the analysis associated with this portion of the method are contained in Appendix E. The study team wanted to keep the main body of the report unclassified.

(1) The methodology used in this study to help the decisionmaker determine the most desirable RDA portion of the POM to meet the program year's requirements can be used in other areas as well. It can be used for any decision with multiple criteria to evaluate the relative strength of the variables. The methodology can be used to compare alternative weapon systems, deployment options, training devices, etc. Consequently, the methodology can aid the decisionmaker in ensuring that a force is properly resourced. The flexibility and simplicity of the Analytic Hierarchy Process allow the decisionmaker to better understand complex systems of interrelated components, such as resources, desired outcomes, or objectives.

(2) The analysis shows the decisionmakers believe that, of the major criteria, the combat objective holds the most relative importance; the most relatively important combat sub-objective is correlation of forces and means; while the four most relatively important SIAM subobjectives are asset versatility and deployability, criticality of need as related to current capability, political risk with respect to Congressional opinion, and operational and technical risk. Judgments were not taken on the noncombat subobjectives. As a result of feedback received from the senior leadership during the conduct of the survey, this area was expanded and will be more thoroughly evaluated during Value Added Phase II.

7-3. SUMMARY. The development of the Value Added methodology specifically included two components (explicit and implicit) to the valuation portion of VAA. The implicit effectiveness component was specifically designed to measure the subjective element of value. This measurement of the subjective element of decisionmaking was included in the VAA methodology based on the findings of previous work done in this area for both the Army and others. One of the key findings of our literature review stressed the importance of including the secondary factors which impact upon decisions. The methodology, as currently envisioned, uses an approach that is based on the Analytical Hierarchy Process and appears to be very useful in helping decisionmakers focus their attitudes and identify the factors which impact upon PPBES programming decisions. The results of this module are passed to the Effectiveness Integration Module in order to combine their effects with those of the Explicit Effectiveness Module.

CHAPTER 8

EFFECTIVENESS INTEGRATION

8-1. INTRODUCTION

a. The purpose of this chapter is to provide a discussion of the integration of multiple measures of effectiveness into a single measure. This chapter also discusses the implementation of a Value Added Analysis tool for this function

- (1) Introduction
- (2) Develop Context for Effectiveness Integration
- (3) Select and Develop Appropriate Models and Tools
- (4) Implement Models and Tools
- (5) Summary

b. Figure 8-1 depicts the Effectiveness Integration Module and how it relates to the overall VAA methodology. The Effectiveness Integration Module is the section of the VAA methodology which produces the single measure of value associated with VAA and is used to conduct a cost effectiveness evaluation. The output of this module consists of program value coefficients for each of the alternatives being investigated.

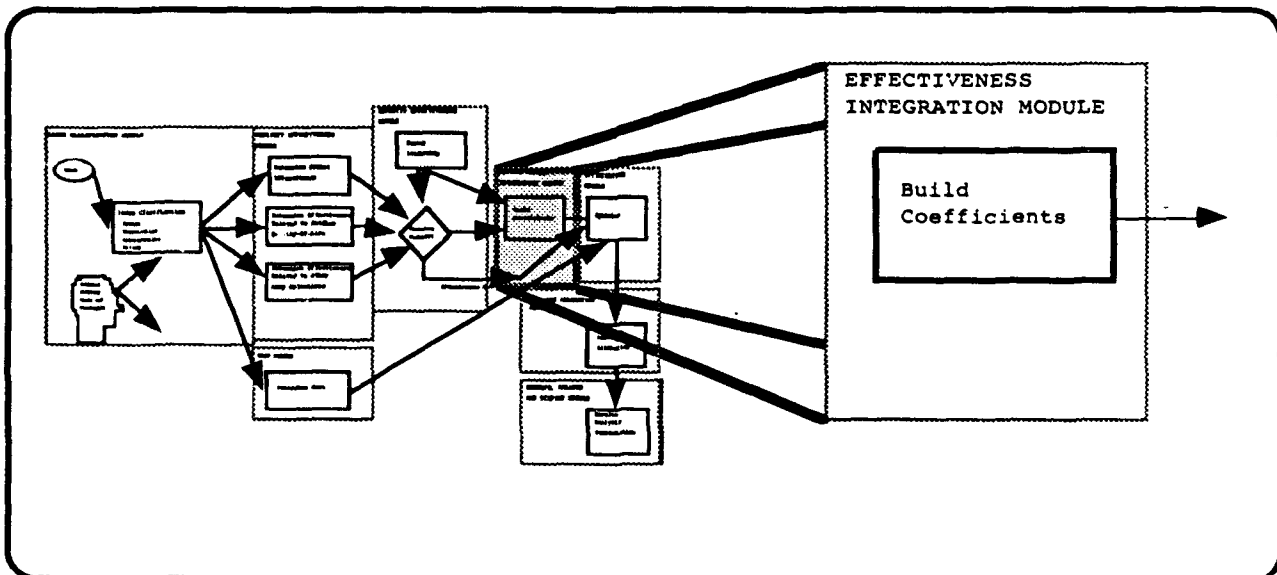


Figure 8-1. VAA Methodology - Effectiveness Integration Overview

c. The Value Added methodology recognizes both the advantages and limitations of combining multiple measures of effectiveness, and consequently allows decision analysis either in an integrated mode or in a mode which only displays the measures of effectiveness in tabular form. Thus, this chapter can be viewed as a discussion of an optional part of the methodology. In practice, however, because of the insights gained from integrated measures of effectiveness, and because of the input requirements of "downstream" tools such as FOMOA, integration has almost always been performed. In fact, the outputs of the tool discussed in this chapter provide a meaningful analysis product in their own right for comparing alternatives.

d. The analytic tool selected for measure of effectiveness integration is the Technique for Order Preference by Similarity to an Ideal Solution, better known by its acronym, TOPSIS. This technique was developed by Ching-Lai Hwang¹ and Kwangsun Yoon at Kansas State University and has been widely used by the Army and taught in operations research classes at the Army Logistics Management Center. It is based upon the concept of choosing alternatives which lie in an n-dimensional (see Figure 8-2) Euclidean space closest to a theoretically ideal position and farthest from a theoretically worst position.

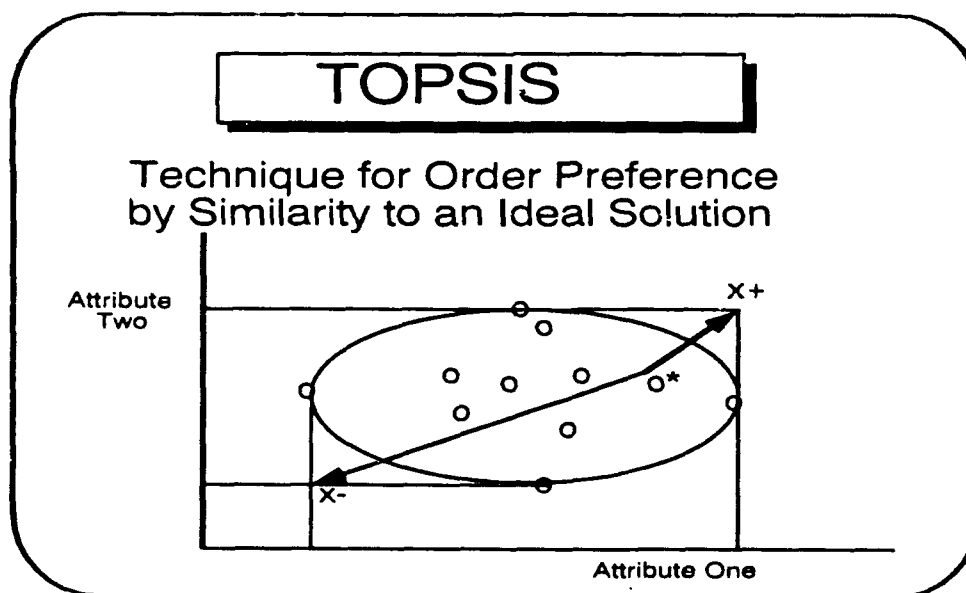


Figure 8-2. TOPSIS Technique

e. Computer software to implement TOPSIS was the first tool designed and implemented to operate in the capsule environment

¹Hwang, Ching-Lai and Yoon, Kwangsun, Multiple Attribute Decision Making, Methods and Applications, Springer-Verlag, Berlin, 1981.

of the data base computer chosen for the Value Added prototype. While software to compute TOPSIS coefficients was available previously, the Value Added team designed and wrote a TOPSIS tool from scratch in order to ensure wide applicability of the methodology and to overcome inherent problem size limitations of the existing software. The TOPSIS software described was written in ANSI standard C language and has been successfully compiled and used on MS-DOS and Macintosh microcomputers and UNIX workstations. Because TOPSIS is useful in its own right, a standalone version has been implemented and extensively tested as part of this study. A brief set of instructions for use of the stand alone TOPSIS software in the MS-DOS environment is provided in Appendix G. Instructions for use of TOPSIS and other Value Added Analysis tools in the METAPHOR environment will be provided as part of Phase II of the Value Added project.

8-2. DEVELOP CONTEXT FOR EFFECTIVENESS INTEGRATION

a. Nature of the Problem. Techniques for integration of multiple decision criteria, such as TOPSIS, are well suited to the type of management decision problem typified by Value Added Analysis. These problem characteristics include:

- (1) A requirement to build a rank-ordered preference list of candidate systems from among a relatively constrained set of initial alternatives.
- (2) A requirement to be able to compare the relative strength of preference (cardinal rank) among the candidates.
- (3) A set of quantifiable criteria related to attributes associated with each alternative.
- (4) A set of weights which express the relative measure of importance the decision authority attaches to each criteria.
- (5) A modicum of confidence in the statistical independence and reliability of the measures associated with the different criteria. This confidence may be "subjective" based upon the decision authority's judgment.
- (6) A requirement for sensitivity measures associated with variance in input values or decision authority tolerance to error.

b. Operational Considerations. Operational constraints require the use of a measure of effectiveness integration tool. Interviews with sponsors and review of decision science literature substantiated the following operational characteristics:

- (1) Real-world problems contain too many alternatives ($n > 50$) and too many decision criteria ($n > 10$) for human

comprehension in tabular form. Some simplification procedure is required.

(2) Available optimization techniques (e.g., linear and dynamic programming) require objectively quantified and integrated measures of effectiveness. In particular, even techniques which deal with multiple measures of effectiveness (e.g., goal programming) always contain either an explicit or implicit combining function.

(3) Even when mathematically precise measures of effectiveness are not available or integration of available measures appears infeasible, operational estimates must be made with sufficient precision to allow meaningful analysis to proceed.

c. **Problem Domain.** The problem domain (prioritized allocation of resources in construction of the Army POM) is suited to the use of a measure of effectiveness integration tool. Important characteristics include:

(1) A hierarchical schema for relating measures of effectiveness has been defined (see Chapter 7).

(2) Integration tools of this type (including TOPSIS itself) have been previously and are currently being used with varying degrees of success in this domain. In particular, TRADOC has extensive experience in using the TOPSIS methodology to construct the Field Long-Range Research and Development Plan.

(3) Key decision authorities are knowledgeable concerning the underlying assumptions, capabilities and limitations of this approach in this problem domain.

8-3. SELECT AND DEVELOP APPROPRIATE ANALYTICAL MODELS AND TOOLS

a. **Criteria.** The following criteria led to the selection of the TOPSIS tool:

(1) The chosen integration technique must be known and accepted within the decision science literature.

(2) The chosen integration technique must be capable of being implemented and used within the time constraints available.

(3) The chosen integration technique must not have data requirements that exceed the collection capability of the analysis effort.

(4) The chosen integration technique must produce outputs compatible with other Value Added Analysis tools, especially the Force Modernization Analyzer.

b. **Review and Evaluate Alternatives.** Several alternatives were extensively considered for use in lieu of TOPSIS. They were found to be unsuitable for the following reasons:

(1) Multiple attribute utility functions were not accepted because of the lack of consensus on the definition of the output measure ("utils"). Utility measures (based on consumer preference theory) have the most extensive theoretical literature background, but they are also much more difficult to develop, implement, and document.

(2) Probability-based decision trees were not chosen because of the difficulty of collecting data related to the attributes and probabilities required for such an analysis. An extensive case study related to multiple theaters of conflict and multiple levels of conflict intensity was prepared, and showed potential because it made a direct link to the Army strategic planning process. However, as the methodology developed, the decision tree approach was later abandoned because of an inability to properly define all of the decision paths and alternatives. A by-product of this effort was that Value Added Analysis became much more focused toward weapon system acquisition, wherein alternatives are more clearly defined.

(3) Other methods of combination (e.g., count of advantages and disadvantages) were considered but rejected because they either did not produce the desired cardinal preference weight or because they were relatively unknown to the decision authorities.

8-4. IMPLEMENT ANALYTICAL MODELS AND TOOLS

a. **Notation.** The following notation is used in the TOPSIS methodology.

A_i = the i^{th} alternative considered,
 x_{ij} = the numerical outcome of the i^{th} alternative with respect to the j^{th} criterion,
 R = normalized decision matrix,
 r_{ij} = an element of the normalized decision matrix with respect to,
 the i^{th} alternative and j^{th} criterion,
 m = total number of alternatives,
 n = total number of attributes,
 w_j = weight associated with the j^{th} criterion,
 V = weighted normalized decision matrix,
 A^+ = ideal artificial alternative (most preferable alternative),
 A^- = negative-ideal artificial alternative (least preferable alternative),
 v_{ij} = an element of the weighted normalized decision matrix with respect to,
 the i^{th} alternative and j^{th} criterion,
 $J = \{j \in \{1, 2, \dots, n\} \mid j \text{ associated with benefit}\},$
 $J' = \{j \in \{1, 2, \dots, n\} \mid j \text{ associated with cost}\},$
 S_i^+ = separation of the i^{th} alternative from A^+ ,
 S_i^- = separation of the i^{th} alternative from A^- ,
 C_i^+ = relative closeness of A_i with respect to A^+ .

b. The Algorithm. The algorithm is from Hwang and Yoon,¹ cited previously. A description is provided below:

STEP 1: Construct a normalized decision matrix, R ;

[8.01]

where

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^m x_{ij}^2}}$$

¹Hwang, Ching-Lai and Yoon, Kwangsun, Multiple Attribute Decision Making, Methods and Applications, Springer-Verlag, Berlin, 1981. Pages 128 through 140. The algorithms and formula listed here were obtained directly from the above referenced pages of Hwang and Yoon's text.

STEP 2: Construct the weighted normalized decision matrix, V ; such that

[8.02]

$$V = \begin{bmatrix} v_{11} & v_{12} & v_{1n} \\ v_{i1} & v_{i2} & v_{in} \\ v_{m1} & v_{m2} & v_{mn} \end{bmatrix} = \begin{bmatrix} w_1 r_{11} & w_2 r_{11} & w_n r_{1n} \\ w_1 r_{i1} & w_2 r_{i1} & w_n r_{in} \\ w_1 r_{m1} & w_2 r_{i1} & w_n r_{mn} \end{bmatrix}$$

STEP 3: Determine ideal and negative-ideal solutions; Let the two artificial alternatives A^+ and A^- be defined as:

[8.03]

$$A^+ = \left\{ (\max_j v_{ij} | j \in J), (\min_j v_{ij} | j \in J) | i = 1, 2, \dots, m \right\} = \{v_1^+, v_2^+, \dots, v_n^+\}$$

$$A^- = \left\{ (\min_j v_{ij} | j \in J), (\max_j v_{ij} | j \in J) | i = 1, 2, \dots, m \right\} = \{v_1^-, v_2^-, \dots, v_n^-\}$$

STEP 4: Calculate the separation measure. The separation between each alternative can be measured by the n -dimensional Euclidean distance. The separation of each alternative from the ideal alternative is given by:

[8.04]

$$S_i^+ = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^+)^2}, \quad i = 1, 2, \dots, m$$

Similarly, the separation from the negative-ideal alternative is given by:

[8.05]

$$S_i^- = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^-)^2}, \quad i = 1, 2, \dots, m$$

STEP 5: Calculate the relative closeness to the ideal solution.

[8.06]

$$C_i = \frac{S_i^-}{(S_i^+ + S_i^-)}, \quad 0 < C_i < 1, \quad i = 1, 2, \dots, m$$

STEP 6: Rank the preference order.

STEP 7: Perform sensitivity analysis and graphically portray results.

c. **The Implementation.** A C language computer software program was designed and written to support the Value Added Analysis effort. This program has the following modules:

(1) **General Purpose Math Support Routine Module.** This module contains memory allocation routines and numeric conversion routines that are broadly applicable to all of the Value Added Analysis support software. The support routines are based upon similar routines contained in Numerical Recipes in C by Press, Flannery, Teukolsky, and Vettering¹.

(2) **TOPSIS Matrix Input-Output Routine Module.** This module contains special purpose routines to read in the TOPSIS input file and allocate memory for the TOPSIS matrix. Of special importance are the procedures which determine the number of rows and columns in the matrix. The software is constructed so that the size of the TOPSIS matrix is not predetermined and works with large sizes limited only by available memory. On a Macintosh microcomputer, matrices of sizes up to 120 rows and columns have been tested. Considering that each floating point number takes 8 bytes, matrices with hundreds of thousands of cells are possible. Appendix G contains example inputs and outputs using the A3 illustrative example.

(3) **TOPSIS Calculation Routine Module.** This module actually encodes the TOPSIS algorithm as described by Hwang and Yoon. All TOPSIS specific calculation is performed in this module.

(4) **Main Program Module.** This module contains the top level routine ("main") and calls all other modules. Its primary purpose is to parse the command line interface arguments and open the appropriate input and output files.

8-4. **SUMMARY.** The closeness value becomes the program value coefficient and is the single measure of benefit used in the follow-on modules. This value is used in the optimization module as a means of calculating the VAA cost effectiveness. The closeness value can also be used to rank order alternatives based solely on the criterion used in the TOPSIS calculations. This capability provides us with a flexibility to stop the analysis at this juncture or continue based on the needs of the decisionmaker.

¹ Press; Flannery; Teukolsky; and Vettering, Numerical Recipes in C, Oxford University Press, 1988.

CHAPTER 9

COST EFFECTIVENESS ANALYSIS

9-1. INTRODUCTION

a. The purpose of this chapter is to provide a discussion of the optimization tool used to produce an acquisition strategy given costs and relative measures of benefit. This chapter also discusses the implementation of a Value Added Analysis tool for this function.

- (1) Introduction
- (2) Develop Context for Acquisition Strategy
- (3) Select and Develop Appropriate Models & Tools
- (4) Implement Models and Tools
- (5) Summary

b. Figure 9-1 depicts the Optimization Module and how it relates to the overall VAA methodology. The Optimization Module is the section of the VAA methodology that is used to conduct the cost effectiveness evaluation. The module allows us to simultaneously trade off alternatives based on their cost and effectiveness and also to schedule the alternatives acquisition. The output of this module consists of a funding and acquisition stream very similar to the streams found in the Army POM.

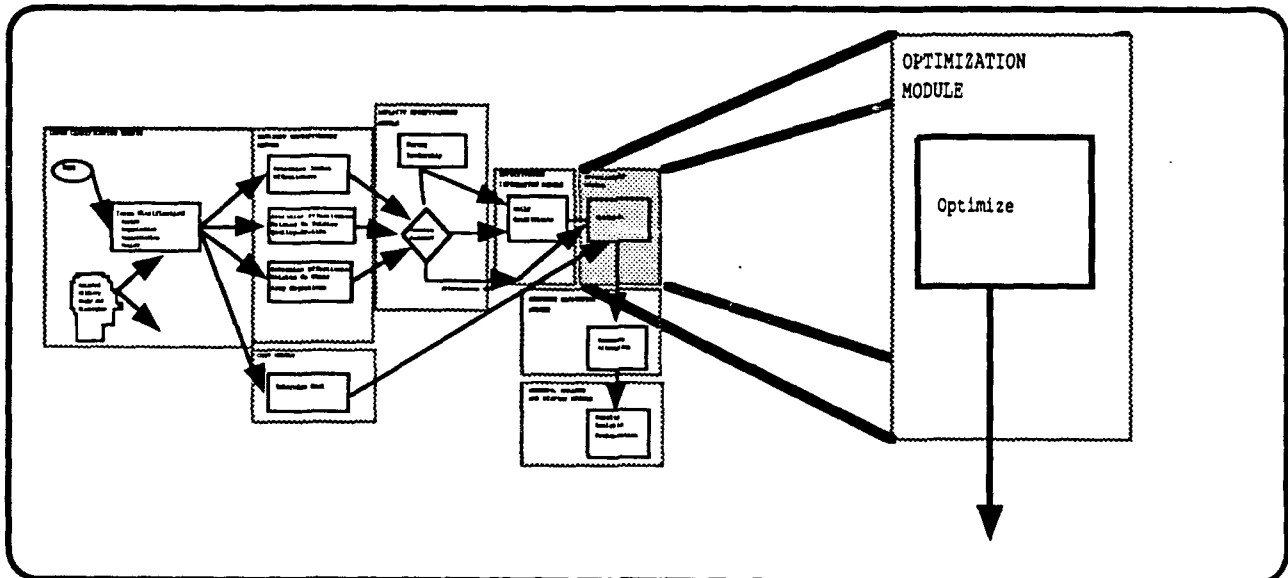


Figure 9-1. VAA Methodology - Cost Effectiveness Overview

(1) The Value Added methodology does not require the production of a procurement strategy. However, the optimization tool does provide the integration of costs and benefits into a comprehensive cost-benefit analysis. Thus, this chapter can be viewed as a discussion of an optional part of the methodology, but in practice, an acquisition strategy and cost benefit analysis has almost always been performed.

(2) The analytic tool selected for development of the acquisition strategy was the Force Modernization Analyzer, better known by its acronym, FOMOA. This technique was developed by Robert Schwabauer¹ at the US Army Concepts Analysis Agency and has been widely used by the Army for the production of weapon system modernization plans. It is based upon the concept of linear programming and econometric modeling of cost-quantity relationships. The Value Added FOMOA formulation considers production, total obligation authority (TOA), and force structure constraints in conjunction with cost and benefit data in order to determine an optimal mix of weapon system procurements by year.

(3) Computer software to implement FOMOA for Value Added Analysis differs from that described by Schwabauer. For Value Added Analysis, a tool was designed and implemented to operate in the capsule environment of the data base computer chosen for the Value Added prototype. The more traditional FOMOA operates using commercially procured software only in the environment of an Apple Macintosh microcomputer spreadsheet. As such, the design of the FOMOA software reflects the "icon-and-arrow" data base technology discussed by Cunningham,² et al. The FOMOA software described was written in ANSI standard C language and has been successfully compiled and used on MS-DOS and Macintosh microcomputers and UNIX workstations. For the Value Added Analysis Project, Dr. Schwabauer prepared an original algebraic formulation of the weapon systems acquisition strategy problem, which was independent of the specific weapon system costs and parameters involved. A total separation of problem formulation and data was thereby achieved. Because FOMOA is useful in its own right, a standalone version has been implemented and extensively tested as part of this study. A brief set of instructions for use of the standalone FOMOA software in the Macintosh environment is provided at the end of this chapter. Instructions for use of FOMOA and other Value Added Analysis tools in the environment of the data base machine will be provided as part of Phase II of the Value Added project.

¹ Schwabauer, Robert. "User's Manual for Force Modernization Analyzer (FOMOA) Level 1," US Army Concepts Analysis Agency Report CAA-D-89-3, Bethesda, MD, November 1989.

² Cunningham, Van; Koury, Robert; and Richmann, James, "Less Expensive. More Powerful Database Analysis," Database 90 Conference, US Navy Automation Systems Command, San Diego CA, June 1990.

9-2. DEVELOP CONTEXT FOR ACQUISITION STRATEGY DEVELOPMENT

a. **Nature of the Problem.** Techniques for development of acquisition strategies such as FOMOA are well suited to the type of management decision problem typified by Value Added Analysis. These problem characteristics include:

(1) A requirement to project procurements by dollars and quantities for candidate systems by year.

(2) A requirement to be able to consider the effects of changing production and TOA constraints on the weapon mix. Changes to constraints will be made frequently and results must be obtained on a time sensitive basis. Responsiveness is more important than precision for this requirement.

(3) A set of quantifiable attributes that can be associated with each candidate system including cost, an integrated measure of benefit, production constraints, and force structure requirements.

(4) A requirement to determine sensitivity measures associated with variance in input values or decision authority tolerance to error.

b. **Operational Considerations.** Operational constraints require the use of an acquisition strategy tool. Interviews with sponsor management and review of decision science literature substantiated the following operational characteristics:

(1) Value Added acquisition strategy problems contain multiple alternatives ($n > 50$) and multiple types of constraints ($n > 10$). Some simplification procedure is required. Also, the preferred solution is usually a mix of systems rather than the selection of only one system for procurement.

(2) All optimization techniques (e.g., linear and dynamic programming) require extensive analysis during the formulation stage in order to tailor the algebraic specification to the problem at hand. Typically, this formulation is provided as data coefficients which form the input to the mathematical optimization tool. This approach usually requires long time periods to collect, validate, and prepare data inputs. An ability to generalize the formulation so that data can be obtained automatically from a data base query would reduce errors in transcription and formulation.

(3) Even when mathematically precise cost and effectiveness data are not available or optimization of the acquisition strategy appears infeasible, operational estimates and preliminary plans must be made with sufficient precision to allow programming and budgeting to proceed.

(4) All programming and budgeting tradeoffs must accommodate multiple and sometimes conflicting goals. The acquisition strategy tool must be able to optimize the mix of systems while considering these multiple goals. The FOMOA formulation developed during Phase I of Value Added Analysis does not adequately address multiple goals simultaneously. In order to consider multiple goals, separate formulations must be constructed and run.

9-3. SELECT AND DEVELOP APPROPRIATE ANALYTICAL MODELS AND TOOLS

a. **Criteria.** The following criteria led to the selection of the FOMOA tool:

(1) The chosen optimization technique must be known and accepted within the decision science literature.

(2) The chosen optimization technique must be capable of being implemented and used within the time constraints available.

(3) The chosen optimization technique must not have data requirements that exceed the collection capability of the analysis effort.

(4) The chosen optimization technique must address essential constraints (e.g., production limits by year and force structure requirement maximums by year). Without these constraints, no acquisition strategy would be considered valid.

(5) The chosen optimization technique must be capable of being used by personnel with a wide variety of backgrounds and educational experiences. This objective was only partially achieved during Phase I of Value Added Analysis and is a priority requirement for Phase II.

(6) The chosen optimization technique must produce outputs required by the study sponsor. In particular, the tool must produce a time-phased acquisition plan in a format recognizable as input to the Army POM.

b. **Review and Evaluate Alternatives.** Several alternatives were extensively considered for use in lieu of FOMOA. None were selected for the following reasons:

(1) The use of a Leontif¹ Input-Output Model as described in the Army Dollar Resource Study² was not accepted because leadership viewed the technique as a "black box," too complex for management understanding of the effects of changing inputs. Also, the model developed for the Army Dollar Resource Study was memoryless in that previous decisions were easily changed during subsequent analysis. Management considered it important that decisions made in the past, and in the process of implementation, should not be revisited. Stability is an important criterion.

(2) The use of a capital budgeting technique as described by Michael Anderson,³ which uses vectors of cost-benefit swapped in and out of a proposed solution set based upon TOA and relative cost-benefit comparisons was not used because the technique was relatively inflexible in accounting for multiple measures of benefit. In particular, the technique did not adequately address subjective measures of value.

(3) The use of simple rank order preference was considered but not used because it did not analytically integrate all appropriate information in arriving at an acquisition strategy. It should be noted that simple rank order preference is the technique currently used to construct the Army POM. It was the strong opinion of the study sponsor that the existing method was not sufficiently analytic and resulted in competition among proponents based upon suboptimal decision criteria.

9-4. IMPLEMENT ANALYTICAL MODELS AND TOOLS

a. **Formulation.** The formulation of the optimization problem solved in this module can be summarized as follows.

(1) **Objective.** The objective is to maximize the total value added by the systems in the force over the planning horizon. The objective coefficients are the value added coefficients computed in TOPSIS. These coefficients are given as a function of time period and equipment system.

(2) **Constraints.** There are three classes of constraints. The first class consists of funding constraints which limit expenditures for procurement to be no greater than the total obligation authority for those systems. The second set of constraints deals with force structure. A minimum and maximum number of each system, based on force structure

¹ Leontif, Wassily W. "The World Economy of the Year 2000," Scientific American, September 1980.

² Army Dollar Resource Allocation II Study, US Army Concepts Analysis Agency, 1978.

³ Anderson, Michael, "Capital Budgeting White Paper," US Army Training and Doctrine Command, unpublished paper, 1989.

requirements, is specified, constraining the number of system of each type in the force. The final class of constraints deals with production limitations. A minimum production quantity might be specified to ensure an economic quantity is produced. The maximum production capacity is addressed by constraining the total number of systems of each type that can be produced.

(3) **Decision Variables.** The answer to the optimization problem consists of the number of each type of system produced during each time period. For the purpose of Value Added Analysis, these time periods will be fiscal years that are included in the POM and EPA.

(4) **Notation.** The following notation is defined for the Value Added version of the FOMOA Model. This formulation and notation were based on the original work developed at CAA (see Appendix H, paragraph H-2).

a_{ij} = value added coefficient for system i in time period j ,
 x_{ij} = number of system i produced in time period j ,
 $\hat{x}_{ij}$ = number of systems i produced in time period j
 without considering production line status,
 M_j = total obligation authority in time period j ,
 s_i = inherited assets of system i available in year 1,
 f_{ik} = programed fielding in year k for system i where,
 $k = 1$ denotes 2 years before planning period,
 and $k = 2$ denotes 1 year before planning period,
 y_{ij} = number of systems retired in time period j ,
 e_{ij} = number of systems on-hand in time period j ,
 c_{pij} = procurement cost of system i in time period j ,
 c_{oij} = O&S cost of system i in time period j ,
 e_{lij} = lower limit on number of system i required in time period j ,
 e_{uij} = upper limit on number of system i required in time period j ,
 x_{bij} = lower production limit on number of system i in time period j ,
 x_{tij} = upper production limit on number of system i in time period j ,
 p_{ij} = production line status in time period j for system i ,
 where $p_{ij} = 1$ if line is open, and 0 otherwise,
 I = set of all systems,
 J = set of all time periods.

(5) Dependent Relationships Among Variables. The following relation is defined for determining the number of systems onhand during each time period.

[9.01]

$$\begin{aligned}
e_{i1} &= s_i + f_{ij} - y_{i1}, \quad \forall i \in I, \\
e_{i2} &= s_i + f_{ij} - y_{i2}, \quad \forall i \in I, \\
e_{ij} &= e_{i(j-1)} + x_{i(j-2)} - y_{ij}, \quad \forall i \in I, \quad \forall j > 2.
\end{aligned}$$

Note here that in order to take into consideration the status of the production lines, we must perform the following preprocessing step.

[9.02]

$$x_{ij} = p_{ij} \hat{x}_{ij} = \begin{cases} \hat{x}_{ij} & \text{if } p_{ij} = 1, \\ 0 & \text{otherwise.} \end{cases}$$

Thus, x_{ij} is constrained to be zero when the production line is not open in particular time period j for system i .

(6) **Objective Function.** The following objective function maximizes the total "Value Added" by the procured systems over the entire planning horizon.

[9.03]

$$Z = \sum_{i=1}^{|I|} \sum_{j=1}^{|J|} a_{ij} e_{ij}$$

(7) **Constraints.** As discussed above, there are three classes of constraints. The first class involves funding constraints.

[9.04]

$$\sum_{i=1}^{|I|} c_{pij} x_{ij} \leq M_j, \quad \forall j \in J.$$

Notice that we consider only procurement costs here. O&S costs are used in the prototype for accounting purposes only. Notice also that cost values used here constitute average unit costs. Costs are actually a function of the quantity produced (see chapter 6). No provision was made in this formulation to take into account this functional relationship.

Therefore the possibility exists that using average unit costs as an approximation could result in a violation of the budget constraint when the true cost is considered. Another possible result is suboptimality in the solution. Unfortunately, this problem has plagued analysts for years, and its solution was beyond the scope of this study. This problem should be addressed in future Value Added Analysis applications.

The next set of constraints deals with force structure, and it specifies the range of acceptable values of items onhand to support established requirements.

[9.05]

$$e_{lij} \leq e_{ij} \leq e_{uij}, \quad \forall i \in I, \forall j \in J.$$

The final set of constraints expresses both the limits on production capacity and the minimum allowable procurement quantities for each system.

[9.06]

$$x_{lij} \leq x_{ij} \leq x_{uij}, \quad \forall i \in I, \forall j \in J.$$

We observe that the force structure and production constraints can be expressed either as explicit constraints, or as bounds. In the prototype version of this optimization, they were expressed as bounds.

b. Implementation. A C language computer software program was designed and written to support the Value Added Analysis effort. This program has the following modules:

(1) **General Purpose Math Support Routine Module.** This module contains memory allocation routines and numeric conversion routines that are broadly applicable to all of the Value Added Analysis support software. The support routines are based upon similar routines contained in Numerical Recipes in C by Press, Flannery, Teukolsky, and Vetterling.¹ This module is identical to that used for TOPSIS as described in paragraph 9-7.

(2) **FOMOA Matrix Input-Output Routine Module.** This module contains special purpose routines to read in the FOMOA input data files and allocate memory for the FOMOA linear programming formulation. Of special importance are the procedures which determine the number of rows and columns in each input matrix. The software is constructed so that the size of the FOMOA linear programming formulation is not predetermined and works with large sizes limited only by available memory. On

¹ Press, Flannery, Teukolsky, and Vetterling, Numerical Recipes in C, Oxford University Press, 1988.

a Macintosh microcomputer optimization problems with up to 120 decision variables and 1000 constraints with an average nonzero density (i.e., sparse matrices) of 10 percent have been tested. Appendix H contains example inputs and outputs using the A3 illustrative example.

(3) **FOMOA Formulation Input Module.** This module reads and decodes the FOMOA formulation in the algebraic language specified by Schwabauer. The formulation language is a special purpose notation designed for the specification of linear programming problems. Its syntax is a limited subset of commercially available specification languages such as GAMS and LINGO. This module is actually a series of subprograms which lexically analyze, parse, and interpret the FOMOA language and produce an LP problem matrix for use by the LP Solver Module. The FOMOA language interpreter was written using UNIX parser generating software ("lex" and "yacc") and has a compact grammar specification which conforms to standard UNIX conventions.

(4) **Linear Programming Solver Module.** This module contains the linear programming engine which solves the problem generated by the FOMOA Formulation Input Module. This solver uses a revised product form simplex algorithm with compact storage of sparse input matrices.

(5) **Main Program Module.** This module contains the top level routine ("main") and calls all other modules. It primarily serves to parse the command line interface arguments and open the appropriate input and output files.

9-5. SUMMARY. The linear program formulation used for the prototype VAA case study was a simplification of the work developed at CAA for use in creating modernization plans for the Office of the Chief Staff for Operations and Plans. We have included the more generalized form of the formulation in Appendix H. Also included in this appendix is a set of instructions for users of the software developed for this module. The software currently is based on Mac Lingo, an off-the-shelf product, but could be exported to other commercial solvers. This algebraic approach using commercial products we feel provides a great degree of flexibility and exportability.

CHAPTER 10

SUMMARY AND FINDINGS

10-1. INTRODUCTION. The purpose of this chapter is to provide the summary and findings for the Value Added Analysis Study. Chapter 10 is structured as follows:

- (1) Introduction
- (2) Summary
- (3) Observations and Findings
- (4) Future Development

10-2. SUMMARY. The purpose of the Army Program Value Added Analysis was to create an analytical methodology and decision support system for the development of a balanced and effective Army Program. We have been successful in creating a flexible and rational methodology to support the POM process and Army program development. Although we were not able to completely automate the decision support system, this study does provide a solid foundation for finishing this aspect of the study. The team has found that a linear combination of value components creating a single measure of an issue's marginal value is effective in ranking alternatives and conducting tradeoff analyses. We were successful in capturing the subjective elements used by decisionmakers in conducting tradeoffs between alternatives through the use of judgment weights. This study also provided some important insights into the POM decision process which suggest areas to be explored further, such as the use of aggregated effectiveness models, new costing approaches, and issue clarification techniques.

10-3. OBSERVATIONS AND FINDINGS

a. EEA Observations and Findings. The observations and findings contained in this section of the chapter are keyed to the EEA as listed in the study directive.

(1) **EEA 1:** What measures of effectiveness (MOE) are appropriate for judging relative value among all MDEPs in the program?

(a) Two generalized categories of measures were discovered to be important in judging relative value. The first (called explicit effectiveness) consists of three subdivided elements (combat effectiveness, soldier quality of life, and other Army goals and objectives) and includes those measures which can be directly quantified. These measures include such MOE as fractional exchange ratios (FER), correlation of forces and means (COFM), day care days, energy Btus saved, etc. These

MOE are selected for their ability to appropriately measure the issue in its own context. The second set of MOE is called implicit and includes those measures which are qualitative; political risk, institutional stability, and importance of need are examples of implicit measures. These MOE are selected because they express subjective values which are best measured through expert judgment.

(b) Viewing system effectiveness as an integrated piece of force effectiveness, instead of measuring pure weapon system performance, yields a more rational view of weapon system contribution across systems and mission areas. Traditional weapon system-on-weapon system performance used by the combat developments community does not yield the insights required by the PPBES programming community. We believe that the total force effectiveness perspective yields a more useful measure for programming decisions. A weapon system's "Value Added" changes, depending on the force mix with which the system interacts, and is not normally captured using the traditional approach.

(c) Implicit effectiveness factors (SIAM factors) beyond explicit (pure combat) effectiveness are a significant component of the DA decision process, and a management survey can yield important inputs into this process.

(d) No one single measure of combat effectiveness is adequate to measure the contribution of weapon systems. More work on combat effectiveness MOE is required.

(e) Establishing a hierarchy of MOE was found to be an effective way to use results from different models. The use of different levels of MOE in conjunction with sufficiency criteria allows the analyst to compare results from different functional models and use those results as if the models were equivalent.

(2) EEA 2: Should a linear combination of value components be used to arrive at a single measure of value added? If so, what system of judgment weights should be used?

(a) A linear combination of value components appears to be useful in creating a single measure of an issue's marginal value.

(b) VAA uses a system of judgment weights which measures the value of an issue in a dual context. The methodology seeks two sets of estimates. The first set of estimates is created by surveying the Army leadership to determine both the set of judgmental factors and their weights in accordance with the group's value set and world view. The second set of estimates is created by scoring individual systems using subject matter experts and the judgmental factors developed by surveying the leadership. Both sets of surveys appear to yield consistent

and informative values. These approaches are successful in capturing the multiple attributes used by the decisionmakers in the PPBES programming decision process.

(c) TOPSIS as a method of integrating multiple measures of effectiveness into a single measure of value is useful and effective; however, it may have several analytical weaknesses including scale compression, inadequate treatment of equivalence classes and sensitivity to probabilistic inputs. However, none of these potential problems have been manifested in this prototype proof of concept.

(3) EEA 3: What decision analysis framework should be used?

(a) The VAA methodology as demonstrated in Phase I holds promise as the decision analysis framework that should be used for conducting Army program tradeoff analyses. Further work in the areas of quick turn-around combat modeling, dynamic costing, and data collection need to be conducted. Although some limitations in the methodology exist, it has been shown that this methodology is viable for the conduct of these analyses, and will provide senior Army leaders with a good and feasible starting point for decision making, and a way to further analyze the appropriateness of various alternatives.

(b) We believe that VAA is a decision analysis framework that can be used to give decisionmakers the capability to group decisions by stakeholder (interest group) and by the appropriate context for the issue. For example, the CINCs may be one stakeholder group which would like to look at their issues in a context of combat operations based on their scenarios and OPLANs. Congress could be another group whose context is both the Illustrative Planning Scenario (IPS) and constrained federal budgets.

(c) The theory of cost-benefit analysis as detailed in the Value Added methodology is fundamentally sound. The systematic specification of costs and benefits within a consistent framework understood by both analyst and decisionmaker is an extremely positive feature of the methodology. The possibility of apparently anomalous results exists, however. An example of such a case that arose in this study concerned TGW. This system was determined to be the number one VAA priority. Combat simulation results and the explicit measures for the TGW system were found to be totally consistent with those of TRADOC, the program manager, and RAND Corporation analyses. However, a large percentage of the senior Army leadership expressed concern about achieving the level of results reported. As a result, the decision was made to fund only the RDTE portion of the program. The positive aspect of this type of occurrence is that a serious issue was brought to the attention of both analysts and decisionmakers. Clearly, additional work was needed to show, one way or another, what could reasonably be expected with regard to

the performance of this system. Identification and illumination of these issues is an extremely important function of analysis, and VAA seems to be very useful in this area.

(d) The ability to modularize (plug in, pull out) components of the Value Added methodology is critical to a successful implementation. The analysis framework must be standardized, and yet sufficiently flexible to accommodate a variety of input data and a wide range of PPBES issues. The output of each module provides significant analytical results in its own right. These intermediate results will prove useful to a variety of decisionmakers at different levels.

(e) It is clear that sufficient information is not always present during the construction of the POM to provide detailed acquisition strategies and distribution plans. Therefore, the VAA methodology must be capable of using information at various levels of detail while still providing meaningful results.

(3) EEA 4: Does a highly aggregated combat model provide useful insights for answering program-wide tradeoff questions? If so, can such a model be calibrated to a more detailed model if necessary?

(a) A highly aggregated combat model can provide useful insights for answering macro level program tradeoff questions. To a more limited degree, such a model is also capable of providing specific program guidance. However, decisionmakers require sufficient detail to understand the reasons for combat outcomes to assist them in specific program decisions. For example, it was important during the sponsor requested presentations to senior decisionmakers that explanations be given regarding an apparent anomalous result in the procurement of AH-64 over the LHX.

(b) In order for aggregated combat models to be useful, they must be calibrated. In order to calibrate them, one must be able to establish some landmark values or calibration points using data or output from accepted and "known" sources. These points do not necessarily need to be developed from other models of higher resolution. Calibration can be done using other models, empirical data, or historical data. Calibrating one model with results from another has been a commonly used procedure in hierarchical analysis.

(4) EEA 5: What Blueprint (of the battlefield) options provide the most useful framework for the analysis of change to the Army's materiel, force structure, etc? TRADOC's Blueprint of the Battlefield, which this EAA was directed towards, appears not to be useful within the context of VAA. The blueprint concept is oriented by its very nature toward a requirements perspective and does not necessary address the

issues of affordability or duplication of capability. The AHP process appears to hold the greatest possibilities in this regard.

b. Other Observations and Findings. The observations and findings contained in this paragraph of the chapter are not necessarily keyed to the original questions proposed in the study directive but are insights obtained as a result of the work completed in this study.

(1) The Value Added methodology is data intensive. Accuracy and timeliness of input data, especially production data, is of crucial importance in making the value added process operational.

(2) The initial goal of value added was to be quick turnaround for all components. What was found was that an extensive front-end process (especially combat modeling and costing) was required which consumed large amounts of time. Once this front end work was completed, then quick-response excursions were possible.

(3) The Value Added methodology will "buy" the most cost effective systems subject to constraints.

(4) The study developed a modular "living" methodology with extreme flexibility that can be used with a variety of techniques and models.

(5) The methodology provides a standardized quick reaction approach that uses ORSA techniques. It evaluates program tradeoff issues by functional area experts and decisionmakers. ORSA expertise is required during the preparatory analysis, consisting of the combat modeling, costing, and surveying. The functional analysis which would take place during the POM building and defense, consisting of the actual tradeoffs, do not require extensive ORSA expertise when using the VAA methodology.

(6) Issue clarification is difficult, and it appears that senior decisionmakers have difficulty focusing issues. Therefore, issue clarification is key to the success of the follow-on modules and analysis.

(7) The technique used to survey the Army leadership allows decisionmaking attitudes and behaviors to be accurately modeled. Administration of the management survey under tightly structured and controlled conditions yielded statistically reliable results.

10-4. VAA FUTURE DEVELOPMENT

a. **Methodology.** The study team believes the following methodological improvements or research should be conducted to enhance the VAA capability

(1) The issue clarification module requires better definition to include appropriate models and algorithms.

(2) Research is needed into the use of response curves or some other emulation method for developing a quick turnaround combat modeling capability.

(3) The analytical hierarchy portion of the implicit effectiveness module must be completed. It must include the level 3 elements of the soldier quality of life and other Army goals and objectives.

(4) The ability to provide a "supervalue" for a particular SIAM factor needs to be incorporated into the methodology. For example, a particular issue or piece of equipment may have high operational risk associated with it. This risk may be so important that it overshadows all other factors, to include the explicit measures of value. The methodology should identify these types of issues during the process.

(5) The methodology should be capable of handling uncertainty associated with the scores SMEs give to an issue or piece of equipment. The process may include some kind of parametric sensitivity mechanism to accommodate the imprecision of the values provided.

(6) Research into the potential TOPSIS weaknesses of scale compression, inadequate treatment of equivalence classes and sensitivity to probabilistic inputs must be performed.

(7) A more complete and detailed formulation of the optimization LP must be determined in order to better address decisionmakers' concerns. The LP should include dynamic costing for procurement costs.

(8) An effective methodology for presenting VAA results must be developed to more clearly convey information to the decisionmakers.

b. **Implementation.** The study team believes the following implementation questions should be addressed in follow-on work.

(1) A VAA desk top for the METAPHOR architecture to include associated icons and capsules must be developed and implemented.

(2) Software to implement the issue clarification models and algorithms must be developed. ARIM, as part of this effort for both issue clarification and costing, must be fully implemented.

(3) The CQM and LCCM models in the METAPHOR environment must be implemented.

(4) A family of combat effectiveness models to include an additional force level model and appropriate functional area models must be developed.

(5) The implementation of expert systems to assist in capturing the experience of SMEs and decisionmakers should be explored.

(6) An automated or networked collection system may be helpful in collecting the data needed to build weights and scores.

c. Management. The study team believes the following management issues should be considered in the future.

(1) The survey technique needs to be institutionalized within the Department of the Army to include groups to be surveyed, timing in relation to the PPBES cycle, documentation of the survey process, and development of criteria for selecting survey teams.

(2) A default standardized Value Added Analysis approach should be institutionalized.

(3) The scope of value added analysis needs to be expanded beyond the RDA appropriations since these contain only about 22 percent of the Army program dollars.

APPENDIX A
STUDY CONTRIBUTORS

1. STUDY TEAM

a. Study Director

LTC James A. Richmann, Force Systems Directorate

b. Team Members

MAJ George A. Broadnax, Surveys/Data Collection
Mr. Daniel A. Citrenbaum, Costing
Mr. Karsten G. Engelmann, CORBAN Modeling
Mr. Joe Gordon, Costing
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CORBAN Modeling/Editor
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Dr. Robert J. Schwabauer, Linear Programming
LTC Rodney K. Stuart, CORBAN Team Chief
CPT Patrick M. Williams, CORBAN Modeling

2. PRODUCT REVIEW BOARD

Mr. Ronald Iekel, Chairman
Ms. Patricia A. Murphy
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3. EXTERNAL CONTRIBUTORS

LTC Robert R. Koury, HQDA, DACS-DPZ
MAJ George A. Broadnax, HQDA, DACS-DPZ
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APPENDIX B

STUDY DIRECTIVE



DEPARTMENT OF THE ARMY
OFFICE OF THE CHIEF OF STAFF
WASHINGTON, D.C. 20310-0200



DACS-DPZ

MEMORANDUM FOR DIRECTOR, CONCEPTS ANALYSIS AGENCY
DEPUTY CHIEF OF STAFF FOR COMBAT DEVELOPMENTS, TRADOC

SUBJECT: Army Program Value Added Analysis (Value Added Analysis 90-97)

1. PURPOSE OF STUDY DIRECTIVE: This memorandum tasks:

a. The U.S. Army Concepts Analysis Agency (CAA) in coordination with the PAED Modeling Cell and the ODCSOPS Technical Advisor to develop a program trade-off analysis methodology that fits within the Value Added concept as developed by PAED for building the POM (see enclosure 1).

b. U.S. Army Training and Doctrine Command (TRADOC), in particular TRADOC Analysis Command (TRAC), to provide Corps level force on force analysis support. Efforts in support of the Army Requirements and Capabilities Studies (ARCPS) will be incorporated wherever possible to take advantage of useful methods, data, and methodologies; and provide consistency between ARCPS and the Value Added Analysis.

2. STUDY TITLE: Army Program Value Added Analysis (Short title: Value Added Analysis 90-97)

3. BACKGROUND: HQDA needs analysis to support the development of a balanced and effective Army Program within Department of Defense resource guidance. Traditionally this has been accomplished during the POM building process with functional area panels. The processes that have evolved do not include adequate means of integrating and balancing the functional programs into the total Army Program.

a. Early in the process TOA is provided to each panel and, within the panel, a prioritization is conducted. The methods used vary from panel to panel and subjective judgement is often used.

b. Virtually all analysis currently performed in program evaluation focuses on defining individual Management Decision Package (MDEP) issues. When MDEP analysis is conducted the senior Army leadership lacks the analysis necessary to help identify the marginal value of resources within a MDEP or across MDEPs.

c. Analysis of the total Army Program requires an understanding of how individual MDEP contribute to the Army mission and strategy so as to determine which MDEPs and resource levels have the greatest return on investment and to assess affordability. One approach to this problem is to

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estimate the value added by individual MDEPs, or groups of MDEPs (expressed as program enhancement packages) to the Army as measured by their contribution to the warfighting capability of the Army.

d. The Value Added Analysis concept developed by PAED uses a hierarchical assessment framework for assessing how resource changes relate to battlefield capability. This assessment framework is used to portray existing capability and measures shortfalls against a postulated objective requirement. The contribution of program alternatives (enhancement packages) will be evaluated within the hierarchical framework. The methodology is based on using combat simulations and models to identify how alternatives impact relevant MOEs. These relationships in conjunction with the funding resources, will form the input values which will be used in a decision analysis framework.

4. STUDY SPONSORS:

a. The Director Program Analysis and Evaluation (DPAE), Office of the Chief of Staff Army, is a co-sponsor. DPAE is responsible for the Army Program and for building the Program Objective Memorandum (POM).

b. The Technical Advisor to the Deputy Chief of Staff for Operations and Plans is a co-sponsor. The Technical Advisor is responsible for providing advice and assistance on analytical issues to the DCSOPS.

c. The Study Sponsor's Representative is MAJ Robert R. Koury, PAED (DACS-DPZ).

5. STUDY AGENCIES: CAA is the lead study agency.

a. CAA will identify, and where necessary develop, models and quantitative techniques to assist in the refinement and implementation of analytic methods for estimating the marginal value to the Army of competing MDEPs.

b. TRAC will assist CAA as required.

c. The U.S. Army Materiel Command (AMC), the US Army Cost and Economic Analysis Center (CEAC), and other agencies will assist as required.

6. OBJECTIVES:

a. Formulate an analytic method for estimating the marginal value of competing MDEPs to the Army. The methodology will provide a common understandable basis for the analysis of affordability issues.

b. Identify or develop prototype models that support the Value Added Analysis Methodology and provide management tools for the analytic method developed in a, above.

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c. Establish within PAED an in-house capability to conduct program issues trade-offs.

d. Conduct a proof of concept analysis during the building of the 92-97 POM.

7. TERMS OF REFERENCE:

- a. Use Amended Budget FY90/91 and Program Force (FY94) As Baseline
- b. Scenario Conditions: NATO Central Europe, IPS Scenario
TRADOC approved scenario(s)
Scenario variations necessary for sensitivity analysis.
- c. Conflict Duration: TBD
- d. Conflict Type: Conventional
- e. Measures of Effectiveness: (For Example)
 - * Independent Measures (Note 1)
 - Blue Force: Surviving
 - Correlation of Forces and Means
 - * Dependent Measures (Note 2)
 - Air Defense - Time Air Space Denied
 - CSS - Short Tons/ Day
 - Close Combat - Force Exchange Ratio

Note 1: Establish an overall force effectiveness.

Note 2: Establish effectiveness values for specific battlefield functional areas.

8. LIMITS:

a. Time for developing the prototype analysis will not exceed 1 August 1989.

b. Since this initial effort will be a proof of concept validation, the analysis will exam only the RDA appropriations. However, the final methodology must eventually be capable of examining trade-offs across the full range of program issues. The analysis will expand to the other appropriations as the methodology matures.

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c. President Reagan's Budget position will be used for both PROBE and RDAISA databases.

d. Software must operate in an IBM PC compatible environment.

9. ASSUMPTIONS AND THEIR SIGNIFICANCE: The study's major assumptions are listed below. Scenario-based assumptions will be described in the final study report annex dealing with the warfight scenarios:

a. Any set of value added models to be used in the POM building process must be quick turn-around and IBM PC compatible based. Because the Value Added Analysis models must execute in a quick turn-around environment, the inherent combat models must process aggregated data and may need to be calibrated to higher fidelity models as a means of increasing their credibility.

SIGNIFICANCE: This assumption drives us to a low-resolution model which captures the effects and interactions of the warfight; NOT necessarily the process of the warfight itself.

b. The Program Value Added Analysis must accommodate the manner in which the senior Army leadership makes decisions.

SIGNIFICANCE: The decision framework and models developed must be acceptable to the senior Army leadership.

c. The Program Value Added Analysis must allow for prioritizing between dissimilar MDEPs, i.e., Weapon system procurement, logistical improvements, force structure changes, etc.

SIGNIFICANCE: In order to provide a means to trade-off between different MDEPs, the analysis must be capable of relating the MDEPs contribution to the Army warfight capability.

d. Input data will come from a wide variety of sources and may prove to be difficult to obtain at times.

SIGNIFICANCE: This lack of data will be handled, most likely, by parametric analysis for those data elements which cannot be obtained.

10. ESSENTIAL ELEMENTS OF THE ANALYSIS:

a. What dependent measures of effectiveness (MOEs) are the most appropriate means of judging relative value added?

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- b. What system of judgement weights should be used?
- c. What decision analysis framework should be used?
- d. Does a highly aggregated macro level analytical methodology provide useful insights for answering total Army program trade-off questions?
- e. What Blueprint options provide the most useful framework for the analysis of change to the Army's materiel, force structure, etc.?

11. RESPONSIBILITIES:

- a. D,PAE will:
 - (1) Provide the study sponsor representative and study guidance.
 - (2) Provide a study team member.
- b. Technical Advisor to the DCSOPS will:
 - (1) Provide study guidance to the study sponsor's representative.
 - (2) Provide a study team member.
 - (3) Coordinate the input of ARCPS data to the study.
- c. CAA will:
 - (1) Designate a study director and provide the study team.
 - (2) Coordinate/communicate with the PAED, ODCSOPS, TRAC, CEAC, and AMC for data and information to accomplish the study.
 - (3) Provide periodic in-process reviews (IPRs) as requested by the study sponsors and provide the study products as listed in paragraph 12 of this tasker.
 - (4) Assist PAED in establishing an in-house capability for linking the prototype models and analytical tools into a coherent analytical approach.
 - (5) Assist PAED in conducting a proof of concept analysis using the prototype models on specific program issues which will be identified prior to the building of the 92-97 POM (1 July 89).

DACS-DPZ

SUBJECT: Army Program Value Added Analysis (Value Added Analysis 90-97)

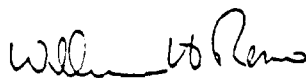
12. STUDY PRODUCTS: CAA will produce, in coordination with TRAC and the PAED Modeling Cell:

- a. A final study report which will thoroughly documents the Value Added Methodology.
- b. A working Value Added Methodology to include the underlying analytical concepts, software and hardware linkages.
- c. Briefings as required.

13. ADMINISTRATIVE:

- a. Support.
 - (1) Funds for travel/per diem will be provided by the parent organization of each study participant.
 - (2) Clerical support will be provided by CAA and/or TRAC as required.
 - (3) ADPE support will be provided by CAA and by TRAC as required.
- b. Milestone Schedule. The proposed schedule is at enclosure 2
- c. Control Procedure. The study sponsor's representative will provide guidance within the HQDA staff and between the ARSTAFF and the study agencies.
- d. Coordination. This directive has been coordinated with CAA and TRAC.

2 Encl



WILLIAM H. RENO
Major General, GS
Director, Program Analysis
and Evaluation.



JOHN A. RIENTE
Technical Advisor to the
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Operations and Plans

APPENDIX C

BIBLIOGRAPHY

DEPARTMENT OF THE AIR FORCE

US Air Force Institute of Technology

Broadnax, George A. A Multiple Attribute Decision Analysis of High-to-Medium-Altitude Air Defense Command and Control Systems. Masters Degree Thesis, AFIT/GST/ENS/88M-1. School of Engineering, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, March 1988 (AD-A191-061) (UNCLASSIFIED)

Graney, R. E. An Optimization Methodology for Multicriteria Comparison Using Response Surface Methods and Mathematical Programming. Masters Degree Thesis, AFIT/GST//OS/84M-11. School of Engineering, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, March 1984 (AD-A141 169) (UNCLASSIFIED)

DEPARTMENT OF THE ARMY

US Army Combined Arms Combat Development Activity

Wade, B., D. Hillis, and others. Maneuver and Fire Support Study. Ft. Leavenworth, KS: Combat Operations Analysis Directorate, CACDA, December 1978 (AD C017350) (CONFIDENTIAL)

US Army Concepts Analysis Agency

Army Dollar Resource Allocation II Study, Bethesda MD: , CAA, 1978 (UNCLASSIFIED)

Schwabauer, Robert. User's Manual For Force Modernization Analyzer (FOMOA)(Level 1), Bethesda MD: Force Systems Directorate, CAA, November 1989 (CAA-D-89-3) (UNCLASSIFIED)

US Army Logistics Management Center

Cost Estimating for Engineers, Ft. Lee, VA: ALM 63-3126-LC (UNCLASSIFIED)

US Army TRADOC Analysis Command

Anderson Michael R. White Paper - Combined Hierarchical Assessment and Capital Budgeting Framework, Ft. Leavenworth, KS: Systems Analysis Directorate, TRAC-FLVN, November 1988 (UNCLASSIFIED)

MISCELLANEOUS

- Bemis, John C.. "The Cost Implications of Production Rate". Concepts, (Spring 1981 Volume 4 Number 2) (UNCLASSIFIED)
- Buede D. M. and others. Applications of Decision Analysis to the U.S. Army Affordability Study. McLean, VA: Decisions & Designs, Inc., December 1978 (AD A064442) (UNCLASSIFIED)
- Bunn, Derek W. Applied Decision Analysis. New York: McGraw-Hill Book Company, 1984 (UNCLASSIFIED)
- Carlsson, Christer and Yevgeny Kochetkov. Theory and Practice of Multiple Criteria Decision Making. New York: North-Holland Publishing Company, 1983 (UNCLASSIFIED)
- Coutinho, John de S. Advanced Systems Development Management. New York: John Wiley & Sons, Inc., 1977 (UNCLASSIFIED)
- Crawford, Gordon and Cindy Williams. The Analysis of Subjective Judgment Matrices, RAND Document R-2572-1-AF, May 1985 (AD-A157 399) (UNCLASSIFIED)
- Flannery, Teukolsky, and Vetterling. Numerical Recipes In C, Oxford University Press, 1988 (UNCLASSIFIED)
- Fowler, Theodore C. Value Analysis in Design, New York, Van Nostrand Reinhold, 1990 (UNCLASSIFIED)
- Hwang, Ching-Lai and Yoon, Kwangusn,. Multiple Attribute Decilslion Making, Methods and Applications, Berlin, Springer-Verlag, 1981 (UNCLASSIFIED)
- Keeney, Ralph L. and Howard Raiffa. Decisions with Multiple Objectives: Preferences and Value Trade-offs. New York: John Wiley & Sons, Inc., 1976 (UNCLASSIFIED)
- Kmenta, Jan. Elements of Econometric". New York: Macmillan Publishing Co., 1986 (UNCLASSIFIED)
- Little, Arthur D. Inc Applications Survey for Remote Photovoltaic Power Systems. 1989 (UNCLASSIFIED)
- Leontif, Wassily W. "The World Economy of the Year 2000". Scientific American, (September 1980) (UNCLASSIFIED)
- Meridian Corporation, Photovoltaics for Military Applications. 1989 (UNCLASSIFIED)
- Porter, Michael E. Competitive Advantage Creating and Sustaining Superior Performance. New York: The Free Press 1985 (UNCLASSIFIED)

Quade, E. S. and W. I. Boucher. Systems Analysis and Policy Planning: Applications in Defense R-439-PR (Abridged). Santa Monica, CA: RAND Corp., June 1968 (UNCLASSIFIED)

Robinson, M. and Jeffrey Grotte. The Analytic Hierarchy Process: Critical Assumptions and Critical Literature (Bibliographies) (UNCLASSIFIED)

Report to the 58th MORSS. Alexandria, VA: Institute for Defense Analyses, June 1990 (UNCLASSIFIED)

Roman, Daniel E. Science, Technology, and Innovation: A Systems Approach. Columbus, Ohio: Grid Publishing, Inc., 1980 (UNCLASSIFIED)

Saaty, T. L. The Analytic Hierarchy Process. New York: McGraw-Hill Book Company, 1980 (UNCLASSIFIED)

Saaty, T. L. and J. M. Alexander. Thinking with Models: Mathematical Models in the Physical, Biological, and Social Sciences. New York: Pergamon Press, 1981 (UNCLASSIFIED)

Saaty, T. L. Decision Making for Leaders: The Analytic Hierarchy Process for Decisions in a Complex World. Belmont, CA: Lifetime Learning Publications, 1982 (UNCLASSIFIED)

Saaty, T. L. "Priority Setting in Complex Problems," IEEE Transactions on Engineering Management, EM-30: 140-158 (August 1983) (UNCLASSIFIED)

Souder, Williams E. Management Decision Methods. New York: Van Nostrand Reinhold Co., 1980 (UNCLASSIFIED)

Smith, Jason "Learning Curve for Cost Control," Institute of Industrial Engineers (1989) (UNCLASSIFIED)

Vargas, L. and J. Dougherty III. "The Analytic Hierarchy Process and Multicriterion Decision Making." American Journal of Mathematical and Management Sciences, 2: 59-92 (1982) (UNCLASSIFIED)

Wind, Y. and T. L. Saaty. "Marketing Applications of the Analytic Hierarchy Process," Management Science. 26: 641-658 (July 1980) (UNCLASSIFIED)

Zahedi, F. "The Analytic Hierarchy Process, A Survey of the Method and its Application," Interfaces, 16: 96-108 (July-August 1986) (UNCLASSIFIED)

Zeleny, Milan. Multiple Criteria Decision Making. New York: McGraw-Hill Book Co., 1982 (UNCLASSIFIED)

APPENDIX D

VAA MODULE MATRIX (PROCESSESS, TECHNIQUES AND PRODUCTS)

G-1. INTRODUCTION. The VAA module matrix was developed to provide, in a single document, an outline of the methodology and the processes associated with the VAA concept. The matrix is divided into two parts. Each section represents a module of the methodology and is labeled with the module name. The first part outlines the processes, techniques and products associated with each module. The second part is organized to relate the input data, sources of data and assumptions back to each process and module.

G-2. MATRIX ORGANIZATION. This section will briefly outline each of the matrices:

a. **Annex 1 Matrix 1.** There are eight sections to this matrix covering seven of the eight modules. No discussion of the results and display module is provided because it is yet to be determined and will be defined as part of VAA Phase II. Processes are located in the second column of the matrix and are linked to subsections of the modules. The intent of this matrix was to show the relationship within and between modules and how processes are related to analytical techniques.

b. **Annex 2 Matrix 2.** There are also eight sections to matrix 2 covering seven of the eight modules. Processes are located in the second column of the matrix in a short hand style and are linked to subsections of the modules. The intent of this matrix was to show the relationship of input data to the modules and processes of the VAA Methodology..

APPENDIX D
Annex 1
VAA Module Matrix (Processes, Techniques and Products)

VAA PHASE 1 MATRIX 1

MODULE OR EVENT	PROCESS	TECHNIQUE	PRODUCT
D-1 ISSUE CLARIFICATION	1. Obtain broad guidance. 2. Describe issue relationships as characterized by , system, org, policy, and appropriation 3. Determine referential integrity of proposed issues. 4. Determine the degree or extent to which this application of the methodology will use default processes and techniques.	1. Ad Hoc 2. Interviews 3. Literature review (solar)	Memo
D-2 EXPLICIT EFFECTIVENESS (COMBAT)			
A. Develop Combat Context (Establish Environment)	1. Identify assumptions (a priori knowledge). 2. Force structure. 3. Doctrine. 4. Identify resources (material assets) to be investigated and their characteristics. 5. Scenarios. 6. Determine lexicon	- A-2 a. TA96/Program force. - A-3 Build Force Structure Spreadsheet - A-4 a. Approved TRADOC Scenarios. - A-4 a. Interview with sponsor. b. TRADOC weapons characteristics files. c. Interview with FD FISOs. - A-5 Approved TRADOC Scenarios.	Spreadsheets LOTUS 123
B. Select or develop appropriate analytical models and tools.	1. Identify criteria for selection. 2. Determine lexicon 3. Establish required outputs (MOE). 4. Review and Evaluate alternatives. 5. Select or Develop model or tool.	- B-1 a. Subject matter experts. b. Formal inventory of existing models. - B-3 a. Discussions with proponents. b. Workshop (July 89). c. Literature review. - B-4 a. Workshop (July 89). b. Literature review. - B-5 Selected CORBAN	CORBAN output files
C. Implement Analytical Models and Tools	1. Identify data requirements and authoritative sources. 2. Determine lexicon 3. Establish analytical capability. 4. Develop experimental design. 5. Use Models and Tools. 6. Analyze results (e.g. Validate and Verify). 7. Pass output data.	- C-1 a. CORBAN class b. Model Documentation. c. OJT d. One on one Tutorials. e. Sponsor involvement. - C-3 a. CORBAN class b. Model Documentation. c. OJT d. One on one Tutorials. e. Sponsor involvement. - C-4 a. CORBAN class b. CORBAN class c. Run matrix - C-5 a. Multiple sites for simultaneous runs b. Run matrix c. Battleshow for quick turnaround of runs d. Sponsor involvement (feedback). - C-6 a. Class on use of graphical techniques for experimental design. b. Statistical analysis. c. Graphical plots d. Subject Matter Expert (SME). e. Compare with high resolution model (VIC).	CORBAN output files

MODULE OR EVENT		PROCESS		TECHNIQUE		PRODUCT
D-3 EXPLICIT EFFECTIVENESS (NONCOMBAT)						
A. Identify Army Goals and Objectives		1. Identify assumptions (a priori knowledge). 2. Extract goals & objectives from TAP & DG 3. Identify other quantifiable army goals & objectives. 4. Develop a hierarchy of goals & objectives. 5. Determine lexicon		- A-2 a. Review TAP for specific statements related to the prototype case studies (e.g. energy/environmental, JQOL studies-Chaplaincy, retirement, & Education). - A-3 a. Establish JQOL Advisory Committee. (1) looked at potential candidates. (2) selected 3 cases to determine feasibility of developing quantifiable MOE. b. Reviewed and Used Army Energy Plan (e.g. for energy/environmental). - A-4 Subject Matter Expert (SME) - B-1 a. Subject Matter Expert (SME) b. Advisory Committee established criteria. - B-3 a. Subject Matter Expert (SME). b. Army Energy Plan c. To be determined through case study approach - review literature interview experts. - B-4 Review determined done were available. - B-5 Developed an analytical technique for energy/environmental		
B. Select or Develop appropriate analytical models and tools.		1. Identify criteria for selection. 2. Determine lexicon. 3. Establish required outputs (MOE). 4. Review and Evaluate alternatives. 5. Select or Develop model or tool.				
C. Implement Analytical Models and Tools		1. Identify data requirements and authoritative sources. 2. Determine lexicon 3. Establish analytical capability. 4. Develop experimental design. 5. Use Models and Tools. 6. Analyze results (Validate and Verify). 7. Pass output data.		- C-1 a. Extracted from Army Energy Plan b. Subject Matter Expert (SME). c. Based on analytical technique developed in submodule B-3. - C-3 Economic Analysis Technique. - C-4 Not done (only one issue) - C-5 a. Subject Matter Expert (SME). b. Comparison with outside sources. (1) Economic goals - in public law. (2) Energy goals - Army Energy Plan. - C-6 Not done		Issue Papers
D-4 COSTING						
A. Develop Costing Context		1. Identify assumptions (a priori knowledge). 2. Identify Cost Policy (requirements, decisions, guidance) 3. Establish Costing Lexicon (terms of reference and scope)		- A-1 a. Personal Interview. b. Review of key documents for other models. c. Advisory committee. - A-2 a. Literature review. b. Guidance from proponent. c. Visit with experts (CEAC, SRA, Calibre). - A-3 a. Literature review. b. Courses/training c. Hard knocks.		
B. Select or Develop appropriate analytical models and tools.		1. Identify criteria for selection. 2. Determine lexicon. 3. Establish required outputs (MOE). 4. Review and Evaluate alternatives. 5. Select or Develop model or tool.		- B-1 Personal expertise. - B-2 a. Guidance from proponent. b. Personal expertise. - B-3 Hard knocks. - B-4 a. Management guidance. b. Reviewed other models (e.g. IMA [Reserve Col.], Life Cycle, & Cost Quantity). c. Incremental improvement. - B-5 a. Selected two models. b. Enhanced both models.		

MODULE OR EVENT	PROCESS	TECHNIQUE	PRODUCT
C. Implement Analytical Models and Tools	1. Identify data requirements and authoritative sources. 2. Determine lexicon 3. Establish analytical capability. 4. Develop experimental design. 5. Use Models and Tools. 6. Analyze results (Validate and Verify). 7. Pass output data.	- C-1 a. Model documentation b. Policy and sponsor guidance. - C-2 Hard knocks (experience - trial & error) - C-3 a. Built spreadsheets. b. Wrote basic computer program. - C-4 Not done. - C-5 Used spreadsheets. - C-6 a. Model aggregated quantities and dollars compared to program aggregated quantities & cost. b. Compared to CEAC cost quantity curves. - C-7 Hand-carried spreadsheets and diskettes.	Procurement Cost and O&S Costs. Models LCOM COM
D-5 IMPLICIT EFFECTIVENESS A. Develop Context for SIAM factors.	1. Identify assumptions (a priori knowledge). 2. Identify policy. 3. Determine degree or extent to which secondary factors will be included.	- A-1 a. Subject matter expert (SME). b. Literature search. - A-3 a. Interview sponsor to determine guidance. b. Team decisionmaking process (brainstorming). - B-1 Subject matter expert (SME). - B-2 Brainstorming. - B-3 Brainstorming. - B-4 a. Brainstorming. b. July 89 Workshop. c. Surveys. - B-5 Selected Saaty's pairwise comparison technique.	Survey Instruments
B. Select or Develop appropriate analytical models and tools.	1. Identify criteria for selection. 2. Determine lexicon. 3. Establish required outputs (Identify tentative list of SIAM factors [MOE not included in YAP or Combat or MCE areas.]). 4. Review and Evaluate alternatives.(Verify SIAM factors [eliminate duplicates, ensure completeness, and independence between factors]) 5. Select or Develop model or too..	- C-1 a. Literature search. b. Brainstorming. - C-2 Created initial survey. - C-3 a. Test Cases. b. Two man interview teams. - C-4 Test Cases. - C-5 Use spreadsheets. - C-6 a. Spreadsheets. b. 3D Graphics. c. Spreadsheet graphics. - C-7 a. Created floppy disks. b. Hard copy output.	Spreadsheet of Survey Results Lotus 1-2-3
C. Implement Analytical Models and Tools	1. Identify data requirements and authoritative sources. 2. Determine lexicon 3. Establish analytical capability.(A. Design survey instrument, validate survey instrument, identify target population and conduct survey for weighting. B. Design survey instrument, validate survey instrument, identify target population and conduct survey for scoring. C. Conduct statistical and data analysis of both survey and scoring results.) 4. Develop experimental design. 5. Use Models and Tools. 6. Analyze results (Validate and Verify). 7. Pass output data to effectiveness integration module..	- A-1 a. Interview with sponsor b. Literature review. - A-2 a. Interviews. b. Guidance from study agency management. - B-1 Subject Matter Expert (SME). - B-2 Extraction of acquisition strategy model dat input requirements. - B-3 a. Subject Matter Expert (SME). b. Review of model output. - B-4 Selected TOPSIS.	Model selection. TOPSIS
D-6 EFFECTIVENESS INTEGRATION A. Develop Context for effectiveness integration.	1. Identify assumptions (a priori knowledge). 2. Determine degree or extent to which effectiveness will be integrated.		
B. Select or Develop appropriate analytical models and tools.	1. Identify criteria for selection. 2. Determine lexicon. 3. Establish required outputs (MOE). 4. Review and Evaluate alternatives. 5. Select or Develop model or tool.		

MODULE OR EVENT	PROCESS	TECHNIQUE	PRODUCT
C. Implement Analytical Models and Tools	1. Identify data requirements and authoritative sources. 2. Determine lexicon 3. Establish analytical capability. 4. Develop experimental design. 5. Use Models and Tools. 6. Analyze results (Validate and Verify). 7. Pass output data.	C-1 Model documentation. C-2 Model documentation. C-3 Wrote "C" program to implement TOPSIS algorithm. C-4 Used analytical hierarchy process to form groupings of decision factors for decision support graphics. C-5 Used Macintosh to simulate METAPHOR. C-6 Passed data to acquisition module manually.	Spreadsheet of Coefficients. LOTUS 123
D-7 OPTIMIZATION MODULE			
A. Develop Context for Acquisition Strategy	1. Identify appropriate policies (e.g. long term vs short term) 2. Determine Lexicon	A-1 a. Personal interviews. b. Review of other agencies strategies. A-2 Literature review.	
B. Select or Develop appropriate analytical models and tools.	1. Identify criteria for selection. 2. Determine lexicon. 3. Establish required outputs (MOE). 4. Review and Evaluate alternatives. 5. Select or Develop model or tool.	B-1 a. Literature review. b. July 89 Workshop. B-2 Literature review. B-3 None B-4 a. Literature review. b. July 89 Workshop. B-5 a. Selected and modified FOMOA (FOMOA Clone - A. Personal experience and review of literature to design logical model(Dr. Schwebeur's work), B. Preparation of C language software, C. Test and validation of "C" language software on other computers. b. METAPHOR selected as platform.	FOMOA Clone
C. Implement Analytical Models and Tools	1. Identify data requirements and authoritative sources. 2. Determine lexicon 3. Establish analytical capability. 4. Develop experimental design. 5. Use models and tools. 6. Analyze results (validate and verify). 7. Pass output data.	C-1 Model documentation. C-2 Model documentation. C-3 Wrote "C" program to implement FOMOA algorithm. C-4 Used Macintosh to simulate METAPHOR. C-7 Passed data out for presentation.	
D-8 RESOURCE ALLOCATION			
A. Develop Context for Distribution Strategy	1. Identify criteria for selection. 2. Determine lexicon. 3. Establish required outputs (MOE). 4. Review and evaluate alternatives. 5. Select or develop model or tool. 1. Identify policy (priorities)		
B. Select or develop appropriate analytical models and tools.	1. Identify data requirements and authoritative sources. 2. Determine lexicon 3. Establish analytical capability. 4. Develop experimental design. 5. Use models and tools. 6. Analyze results (validate and verify). 7. Pass output data.		
C. Implement Analytical Models and Tools			

APPENDIX D
Annex 2

VAA Module Matrix (Processes, Input data, Sources, and Assumptions)

VAA PHASE 1 MATRIX 2

MODULE OR EVENT	PROCESS	INPUT DATA What	Sources	Assumptions
B-9 ISSUE CLARIFICATION	1.	1. Queuing 2. Equipment List (Trade-offs) 3. Mission area Trade-offs	PAS	
	2.			
	3.			
B-10 EXPLICIT EXPECTIVNESS (COMBAT) A. Develop Combat Context (Establish Environment)	1. Assumptions. 2. Force Structure 3. Doctrine 4. Resources 5. Scenarios 6. Lexicon	1-1 Timeframe/Theaters (99/2004) 1-2 Use program force 2-1 VII CORPS Structure 2-2 Task Organisation 3-1 Battle Dynamics 3-2 ALB Doctrine 3-3 Logistics & C2 4-1 Asset Description 5-1 THADOC Scenario	1a. Sponsor b. Sponsor 2a. TAA-96 & Force Packages b. THADOC doctrine & FMs 3a. Scenarios b. THADOC c. THADOC 4. THADOC 5. THADOC	a. 2 years after end of POM or EPA is when equipment will arrive in units. b. Current M-10 force will be used in both 1999 & 2004.
	B. Select or develop appropriate analytical models and tools.	1-1 Manageability/availability of data 1-2 Resource requirements. 1-3 Acceptability of model. 1-4 Speed of turn-around. 1-5 Support by TRAC. 1-6 Can be implemented. 1-7 Applicability. 2-1 Acronyms 2-2 Terms of reference (define) 3-1 COFM values 3-2 Blue force surviving 3-3 Force Movement Ctr Mass 3-4 FTR 4-1 Model parameters 4-2 Model documentation. 5-1 CORBAN	1a. Model document b. A3 Team c. TRAC 2. Model documentation 3. DCSITV COFM paper 4a. THADOC b. BDM c. A3 Team 5. A3 Team.	a. COFM- Measure of red force commander perception of success. b. BFG-blue force commanders ability to prosecute his plan. c. FMCN-Measure of success/failure to achieve objectives. d. FTR-CAA director's guidance.

MODULE OR EVENT	PROCESS	INPUT DATA	Sources	Assumptions
C. Implement Analytical Models and Tools	1. ID data reqmt. 2. ID lexicon 3. Capability 4. Experimental Design 5. Use model 6. Analyze results 7. Pass output	1-1 Data Syntax 1-2 Scenario & Plans 1-3 Task Organization 1-4 5 Paragraph Field Order. 1-5 TOSB 1-6 SOP for operations. 1-7 Asset characteristics. 1-8 Terrain. 1-9 Search Patterns. 1-10 Sensor Classes. 2-1 Model Documentation. 2-2 Professional expertise 3-1 CORBAN Class. 3-2 OUT 4-1 Run Matrix. 5-1 Run Streams 6-1 Data Plots 6-2 Killer Victim Tables. 6-3 PLOT traces. 6-4 Unit traces.	1a. CORBAN Users Manual 1b. TRADOC & P&S tapes c. BDM d. OCSOPS (FD) e. AJ Team. 2. BDM 3a. BDM b. AJ Team 4. CAA CORBAN Modeling Team 5. CAA CORBAN Modeling Team 6. Model	Comparative Static -- Assume quantities modeled are similar to quantities to be bought such that new effectiveness simulations do not need to be run.
D-11 EXPLICIT EFFECTIVENESS (NONCOMBAT) A. Identify Army Goals and Objectives	1. ID assumptions 2. Extract goals 3. ID other Q goals 4. Lexicon	1-1 None 2-1 Energy goals & objectives 3-1 Retirement 3-2 Education. 3-3 Religion 4-1 Not done (QOL) 4-2 Energy objectives and renewable energy objectives 5-1 Acronyms. 5-2 Jargon	1a. None 2a. Army Energy Plan 3a. Proponents 4a. Army Energy Plan 5a. Assorted documents b. Steve Siegel.	MCE initially combined, after survey we decided to split into QOL and other.
B. Select or develop appropriate analytical models and tools.	1. ID criteria 2. ID lexicon 3. MOE 4. Review 5. Select	1-1 Manageability/availability of data 1-2 Resource requirements. 1-3 Acceptability of model. 1-4 Speed of turn-around. 1-5 Can be implemented. 1-6 Applicability. 2-1 Acronyms 2-2 Terms of reference (define) objectives. 3-1 Contribution to energy goals & objectives. 3-2 Cost/Effectiveness 3-3 QOL (criteria). 4-1 None 5-1 None	1a. Proponents b. Assorted docs 2a. Proponents b. Assorted docs 3a. Proponents b. Assorted docs 4. None. 5. None.	
C. Implement Analytical Models and Tools	1. ID data reqmt. 2. ID lexicon 3. Capability 4. Experimental Design 5. Use model 6. Analyze results 7. Pass output	1-1 Photovoltaic performance characteristics 1-2 Conventional energy characteristics. 1-3 Cost PV & conventional energy. 3-1 Nothing 4-1 None 5-1 None.	1a. Proponents b. Assorted docs	
D-12 COSTING A. Develop Costing Context.	1. ID assumptions 2. ID cost policy 3. Lexicon	1-1 Inflation factors 1-2 Economic life. 1-3 Period of analysis	1a. AMC. b. PMs/PEOs/CC c. Study sponsor.	
B. Select or develop appropriate analytical models and tools.	1. ID criteria 2. ID lexicon 3. MOE 4. Review 5. Select	1-1 P92 definitions 2-1 P92 definitions 3-1 List of Acq Strategy Model Inputs. 4-1 Pros & Cons of each alt. 5-1 Cost Quantity model selected 5-2 LCC Model	1a. CSAC Memo 2a. CSAC Memo 3a. CAA Memos 4a. User manuals.	a. Blank entry = 0\$ or inclusion in another stub. b. P92 stubs defines all life cycle costs. c. Cost quantity relationships exist as defined.

MODULE OR EVENT	PROCESS	INPUT DATA What	Sources	Assumptions
C. Implement Analytical Models and Tools	1.ID data reqmt. 2.ID lexicon 3.Capability 4.Experimental Design 5.Use model 6.Analyze results 7.Pass output	1-1 Cost SAR info, BCE ACP 2-1 LCC - economic life, inflation index, p92 stub entries, period of analysis.	1a.AMC 2a.DOD,SAR Doc,PAs/PBOs,Army Commodity Cade, & CBAC	
D-13 SIAM FACTORS	1.ID assumptions 2.Determine degree	1-1 None 2-1 Decision to survey 2-2 Decision to look at separate hierarchical levels and survey within the levels.	2a.Sponsor b.Sponsor	Assume that the objective function for the factors are representative of decision function. (e.g. Program flexibility max is good)
B. Select or develop appropriate analytical models and tools.	1.ID criteria 2.ID lexicon 3.MOR 4.Review 5.Select	1-1 Manageability/availability of data 1-2 Resource requirements. 1-3 Acceptability of model. 1-4 Speed of turn-around. 1-5 Support by TRAC. 1-6 Can be implemented. 1-7 Applicability. 2-1 Acronyms 2-2 Terms of reference (define) 3-1 SIAM factors. 4-1 Model documentation 5-1 Select Saaty pairwise comparison technique.	1a.Literature search b.VAA Team. 2a.Literature search 3a.VAA Team b.Survey 4a.Dr. Anderson's White Paper. b.Literature search. 5a.VAA Team	For each factor that the objective function is correct.
C. Implement Analytical Models and Tools	1.ID data reqmt. 2.ID lexicon 3.Capability 4.Experimental Design 5.Use model 6.Analyze results 7.Pass output	1-1 Factors and definitions. 2-1 Factors and definitions. 3-1 Saaty pairwise comparisons. 4-1 Issues and factors. 5-1 Fill in survey instruments. 6-1 Fill and run spreadsheets. 6-2 SIAM weights and scores. 7-1 Hand carry spreadsheet	1a VAA Team 2a VAA Team 3a.Survey spreadsheets & instruments. 4a.Factors. 5a Survey instruments 6a.Spreadsheets. 7a.Spreadsheets.	
D-14 EFFECTIVENESS INTEGRATION	1.ID assumptions 2.Determine degree	1-1 None 2-1 Decision to fully integrate 2-2 Decision to look at separate hierarchical levels.	1a.None 2a.VAA Team b.VAA Team	
B. Select or develop appropriate analytical models and tools.	1.ID criteria 2.ID lexicon 3.MOR 4.Review 5.Select	1-1 Manageability/availability of data 1-2 Resource requirements. 1-3 Acceptability of model. 1-4 Speed of turn-around. 1-5 Support by TRAC. 1-6 Can be implemented. 1-7 Applicability. 2-1 Acronyms 2-2 Terms of reference (define) 3-1 VAA Coefficients 4-1 Model documentation 5-1 TOPSIS/AHP	2a.Model 3a.ALMC	

MODULE OR EVENT	PROCESS	INPUT DATA What	Sources	Assumptions
C. Implement Analytical Models and Tools	1. ID data reqmt. 2. ID lexicon 3. Capability 4. Experimental Design 5. Use model 6. Analyse results 7. Pass output	1-1 MOE 1-2 SIAM weights and scores. 2-1 None 3-1 TOPSIS algorithm. 4-1 None. 5-1 Batch files and METAPHOR capsule.	1a. Models. b. Previous VAA steps 3a. Original sources.	
D-15 ACQUISITION STRATEGY A. Develop Context for Acquisition Strategy.	1. ID assumptions 2. Determine lexicon	1-1 Period of acquisition 1-2 Period of life cycle cost 1-3 Applicability of cost quantity relationships for production data and no other. 1-4 Unconstrained by force structure. 1-5 Constrained by min/max production data and no other production data. 2-1 Terms and model component definitions. 1-1 Manageability/availability of data 1-2 Resource requirements. 1-3 Acceptability of model. 1-4 Speed of turn-around. 1-5 Support by TRAC. 1-6 Can be implemented. 1-7 Applicability. 2-1 Acronyms 2-2 Terms of reference (define) 3-1 Program \$/yr by system 3-2 quantity/yr/system 4-1 Documentation 4-2 Pros & Cons of model 5-1 POMOA Clone on METAPHOR	1a. VAA Team 2a. POMOA document. 3a. Force structure 4a. Model document 5a. VAA Team	1a. Expert opinion e. Use surrogate production constraint 2a. POMOA documentation
B. Select or develop appropriate analytical models and tools.	1. ID criteria 2. ID lexicon 3. MOE 4. Review 5. Select	1-1 VAA coefficients 1-2 TOA targets. 1-3 Cost/system 1-4 Program \$/system 1-5 Production Max/Min 2-1 Documentation 3-1 POMOA algorithm. 4-1 None. 5-1 Batch files and METAPHOR capsule.	1a. Integration module b. Adding current program \$ for mission area systems. c. Costing module d. Array POM (PAIS) e. ASARDA/analogous reasoning. 2a. Documentation 3a. Documentation 4a. None 5a. METAPHOR machine and documentation.	
C. Implement Analytical Models and Tools	1. ID data reqmt. 2. ID lexicon 3. Capability 4. Experimental Design 5. Use model 6. Analyse results 7. Pass output	1-1 VAA coefficients 1-2 TOA targets. 1-3 Cost/system 1-4 Program \$/system 1-5 Production Max/Min 2-1 Documentation 3-1 POMOA algorithm. 4-1 None. 5-1 Batch files and METAPHOR capsule.	1a. Integration module b. Adding current program \$ for mission area systems. c. Costing module d. Array POM (PAIS) e. ASARDA/analogous reasoning. 2a. Documentation 3a. Documentation 4a. None 5a. METAPHOR machine and documentation.	
D-16 RESOURCE ALLOCATION A. Develop Context for Distribution Strategy	1. Identify criteria for selection. 2. Determine lexicon. 3. Establish required outputs (MOE). 4. Review and Evaluate alternatives. 5. Select or Develop model or tool.			
B. Select or Develop appropriate analytical models and tools.	1. Identify policy (priorities)			

MODULE OR EVENT	PROCESS	INPUT DATA What	Sources	Assumptions
C. Implement Analytical Models and Tools	1. Identify data requirements and authoritative sources. 2. Determine lexicon 3. Establish analytical capability. 4. Develop experimental design. 5. Use Models and Tools. 6. Analyze results (Validate and Verify). 7. Pass output data.			

APPENDIX E
STUDY CLASSIFIED RESULTS

VAA Phase I Classified Results are Published Under Separate Cover

APPENDIX F**COST LEARNING CURVES****F-1. INTRODUCTION**

a. Experience curves have been a tool historically employed by government and industry to forecast production costs. Their origins lie chiefly in the aircraft industry of the 1930s and World War II. Relying on data from previous production experience, these curves map out a relationship between the costs of producing a particular good and the quantity of that good made. The costs can be measured in various forms, such as labor input per unit or dollars per unit. Although they were originally utilized in the production of aircraft, they are easily applied to other products (such as tanks, trucks, etc.).

b. When speaking of experience curves, one is referring to the general case. There are many factors involved in the production of a good. The two most common are capital and labor. Each factor of production has its own underlying experience curve. For example, the curve for labor is often referred to as the "learning curve." Thus, the term "experience" can be used with labor, machinery, management, etc. It is a general concept that applies to all the factors of production.

F-2. EXPERIENCE CURVE THEORY

a. Experience curve theory simply states that as production of a particular good doubles, the production cost decreases at some constant rate.¹ This is due to the "experience" aspect of performing tasks repetitively. As an example, consider the case of labor. As workers perform tasks again and again, they become more efficient in executing a given task. Since worker efficiency rises, less labor input is required in the production of additional units. This reduces production costs.

b. In general, experience curve theory appears in two forms. One refers to the incremental unit costs of production. This form states that as production doubles, the *per* unit cost of a good at a given quantity will decrease at a constant rate. The other form is similar and deals with the average costs of production. Here, the theory states that as production doubles, the *average* costs of production up to a given quantity will decrease at a constant rate. For simplicity, the following discussion will refer to experience

¹Cost Estimating for Engineers Correspondence Text (CEE), ALM-63-3126-LC(C). Page. 201.

curves on the incremental cost basis. Any conclusions can be easily extended to the average cost basis.

c. There is a whole host of factors that contribute to the decrease in production costs as output rises.² Some of these include learning on the behalf of management, machinery improvements, technological change, etc. All of these factors will have a substantial impact on production costs. Despite this, it is viewed by some that worker learning through repetition is the dominant factor in experience curve theory.³ This notion of the dominant role of labor is not universally accepted.⁴

F-3. BASE EXPERIENCE CURVE

a. The experience curve is traditionally represented by the following function:

$$1) \quad Y = AX^b$$

where:

Y = unit cost

A = cost of the first unit

X = the unit number

b = experience curve slope coefficient.

The slope coefficient (b) is usually constrained to lie between zero and negative one. That is,

$$2) \quad -1 \leq b \leq 0.$$

The slope coefficient (b) can be viewed as the marginal change in the unit cost (Y) that would occur if one more unit of output (X) were produced. Given (2), it can easily be verified from (1) that as (b) approaches zero, the experience curve effect diminishes. In fact, should (b) take the value zero, then unit cost (Y) would be equal to the first unit cost (A).⁵ This implies that increases in the number of units produced has no impact upon unit cost. That is, there is no experience effect. This would be termed a 100 percent experience curve.

² See CEE ALM-63-3126-LC(C), Page 201, and Smith, Jason. 1989. *Learning Curve for Cost Control*. Institute of Industrial Engineers. Pages 14 and 15.

³ This will be more true for those industries that are labor-intensive.

⁴ See Smith, Jason. 1989. *Learning Curve for Cost Control*. Institute of Industrial Engineers. Pages 13-17, 20.

⁵ Let (b) equal zero. This implies $X^b=0$ will always equal one. From (1), this reveals: $Y=A$. In a graph with the horizontal axis the number of units and the vertical axis being unit cost, there would be a horizontal line at $Y=A$.

b. The exact opposite occurs as (b) approaches (-1). Here, the experience effect becomes large. Should (b) equal (-1), then a doubling of the number of units produced would lead to a 50 percent reduction in unit cost. This outcome would be called a 50 percent experience curve.

F-4. ESTIMATING THE BASE EXPERIENCE CURVE

a. The most precise method of estimating the experience curve is through the use of ordinary least squares regression (OLSQ). To do this, equation (1) must first be put in linear form. From above,

$$1.a) \quad Y = AX^{-b}.$$

Note that the learning curve exponent (b) is negative. This is due to the constraint placed by (2). Taking the logarithm of (1.a) yields,

$$3) \quad \ln(Y) = \ln(A) - b \ln(X).$$

Since equation (3) is now log-linear, it can be estimated by OLSQ. The resultant regression coefficients will be $\ln(A)$ and (b). To determine the first unit cost (A), the anti-log of $\ln(A)$ must be taken. The experience curve slope (b) is found directly from its estimated coefficient.

b. The experience curve percentage can be determined in the following manner.⁶ Allow (%) to represent the fraction to which unit cost decreases as production doubles. Then,

$$4) \quad \% = \frac{Y_{2x}}{Y_x}$$

where:

Y = unit cost

Y_x = the unit cost of the xth unit

Y_{2x} = the unit cost of twice the xth unit.

Substitution from (1) above gives

$$5) \quad \% = \frac{Y_{2x}}{Y_x} = \frac{A(2x)^b}{Ax^b} = 2^b.$$

This can be rewritten as

⁶RAND Corporation, *The Learning Curve*, RM-6103-SA. Pages 96-97.

$$6) \ln(\%) = b \ln(2).$$

From (6), the experience curve percentage can be determined.

c. Consider the following example. Unit cost and quantity data for a certain weapons system is presented in Table F-1. These variables will be represented by (Y) and (X), respectively. Also listed in the table are the logarithm values of each variable. To estimate the experience curve for this system, equation (3) must first be estimated. This is done by utilizing OLSQ regression. From the data in Table F-1, the following OLSQ results were found:

$$3.a) \ln(\hat{Y}) = 2.002 - 0.118 \ln(X).$$

Table F-1. Cost & Quantity Data for a Given Weapon System (cost data in millions of dollars)				
Fiscal year	Unit cost (Y)	$\ln(Y)$	# Units (X)	$\ln(X)$
1996	4.995	1.608	29.15	3.372
1997	3.869	1.353	234.23	5.456
1998	3.451	1.239	657.84	6.489
1999	3.225	1.171	1168.18	7.063
2000	3.072	1.122	1672.19	7.422
2001	2.980	1.091	2174.34	7.684
2002	2.923	1.073	2675.68	7.892
2003	2.892	1.062	3137.04	8.051

The "hat" above the unit cost variable (Y) denotes it as the predicted, or fitted value of (Y).

d. From (3.a) the slope coefficient (b) can be taken directly. Here, (b) is equal to (-0.118). The first unit cost value (A) is not as simply determined. From (3) above, it can be seen that the OLSQ regression of (3.a) gives the log value of (A). Since we are not interested in the logarithmic value of (A), but (A) itself, the anti-log of (A)

must be taken.⁷ Doing so reveals that (A) is equal to 7.406.⁸

a. The experience curve percentage can be found by applying equation (6):

$$\begin{aligned} 6.a) \quad \ln(\%) &= b \ln(2) \\ &= (-0.118)(0.693) \\ \ln(\%) &= -0.081774. \end{aligned}$$

Note that we are interested in (%), not its logarithm. Thus, the anti-log of [$\ln(\%)$] must be found. Doing so reveals,

$$\% = 0.92 \quad \text{or } 92 \text{ percent.}$$

Below is a summary of the estimated experience curve from the data in table F-1:

$$\begin{aligned} \text{Estimated Equation: } Y &= 7.406X^{-0.118} \\ \text{Slope of cost/quantity line} &= 0.92 \end{aligned}$$

F-5. COST/QUANTITY/RATE METHOD

a. It is widely recognized that the rate of production plays an important role in unit production costs. One method of accounting for this effect has been proposed by Bemis.⁹ He has altered the traditional experience curve in two ways. First, the functional form of the experience curve has been changed to:

$$7) \quad Y = AQ^{-b}R^{-c}$$

where

Y = average unit cost
Q = cumulative lot mid-point
R = production rate
b = cost/quantity slope coefficient
c = cost/rate slope coefficient.

⁷This can easily be done on a hand-held calculator. Simply take the log value in question, and press the (inverse) and (ln) keys (in that order).

⁸ The regression found $\ln(A)=2.002$ (the constant term). The anti-log of this value is equal to 7.406. See footnote (7).

⁹ Bemis, John C. The Cost Implications of Production Rate. *Concepts*, Spring 1981, Volume 4, Number 2. Pgs. 84-94.

In this revised form, unit cost is a function of both the cumulative lot mid-point (a measure relating unit cost and quantity produced) and the production rate.

b. The variable cumulative lot mid-point is the second alteration. It serves as a measure relating unit cost to the total quantity produced. This is necessary because manufacturers generally do not keep cost data on individual units of production. Instead, they maintain cost data based on "lots" of output. The number of units in a given lot will also be known. To determine the experience curve, the unit number and its associated cost is needed. The cumulative lot mid-point is a method to adjust the lot data so the experience curve can be estimated.

c. The mid-point of any given lot can be estimated by the algebraic lot mid-point (ALM). The algebraic lot mid-point is the unit in a given lot whose cost is equal to the average cost of all the units in the lot. It can be found using the following estimator:

$$8) \quad \hat{ALM} = \frac{F + L + 2\sqrt{FL}}{4}$$

where

$$\begin{aligned} \hat{ALM} &= \text{approximate algebraic lot mid-point} \\ F &= \text{first unit in the lot} \\ L &= \text{last unit in the lot.} \end{aligned}$$

Note that the variable (Q) appears in equation (7). This signifies that the production lot data should be converted as in (8). Equation (8) must be applied in the appropriate manner.

d. Calculating the cumulative lot mid-point (Q) can most easily be shown by an example. Consider the average unit cost (Y) and production rate (R) data in table F-2. For FY96, (Q) is found in the following manner:

$$\begin{aligned} Q_{FY96} &= \frac{F + L + 2\sqrt{FL}}{4} \\ &= \frac{1 + 96 + 2\sqrt{(1)(96)}}{4} \\ &= \left(\frac{116.6}{4} \right) \end{aligned}$$

$$Q_{FY96} = 29.15.$$

Table F-2. Cost, Quantity, and Rate Data for a Given Weapon System (cost data in millions of dollars)			
Fiscal year	Unit cost (Y)	Production rate (R)	Lot mid- point (Q)
1996	4.995	96	29.15
1997	3.869	335	234.23
1998	3.451	500	657.84
1999	3.225	500	1168.18
2000	3.072	500	1672.19
2001	2.980	500	2174.34
2002	2.923	500	2675.68
2003	2.892	418	3137.04

For FY 97, the cumulative lot mid-point is:

$$Q_{FY97} = \frac{F + L + 2\sqrt{FL}}{4}$$

$$= \frac{97 + 431 + 2\sqrt{(97)(431)}}{4}$$

$$Q_{FY97} = 234.23.$$

The remaining entries in Table F-2 can be found in a like fashion.

e. Estimation of the cost/quantity/rate equation is similar to the base experience curve. OLSQ regression is performed on the log transformed variables of (7). The dependent variable is average unit cost (Y), and the explanatory variables are the cumulative lot mid-point (Q) and production rate (R). The cost/quantity/rate equation to be estimated is,

$$9) \quad \ln(Y) = \ln(A) - b\ln(Q) - c\ln(R). \quad [D.12]$$

From the regression results of (9) the slope coefficients can be taken directly.

f. The data in Table F-2 can serve as an example of the cost/quantity/rate method. Estimating (9) with this data by OLSQ reveals:

$$10) \quad \ln(Y) = 2.04 - 0.114\ln(Q) - 0.012\ln(R).$$

Following the techniques previously presented, the following was determined:

Estimated Equation: $Y = 7.7Q^{-0.114}R^{-0.012}$

Slope of the cost/quantity curve = 0.92

Slope of the cost/rate curve = 0.99

Multiple Regression Coefficient (R^2) = 0.99

g. It should be noted that the multiple regression coefficient (R^2) is usually presented. R^2 is a measure of the "goodness of fit" of a given regression line. It simply describes the proportion of variance in the dependent variable that can be attributed to the explanatory variable(s). Since it is a proportion, it is bounded to lie between (0) and (1). At the extremes, a R^2 value equal to zero would imply that none of the variation in the dependant variable can be described by the regression line. When R^2 equals (1), this means that all of the variation in the dependant variable is captured by the regression line. Thus, as the value of R^2 becomes larger, more of the variation in the dependent variable is explained by the regression line. The general rule is the larger the value of R^2 , the better the estimating equation.¹⁰

F-6. CQM COST QUANTITY MODEL

a. Ideally, military procurement personnel would like to deal in a world of unlimited financial resources. There, they could purchase every piece of equipment or system desired. Analysts would only have to compile a "shopping list" of goods and set about acquiring them. But in the real world, equipment procurement is not so simple. The Army functions in an environment of limited resources (which will probably shrink in future years). The quantity and types of equipment and systems obtained are largely restricted by the funding decisions of the Executive Branch and Congress.

b. Given this environment of budgetary constraints, analysts need tools to assist them in deciding how much equipment or how many systems to purchase. That is, to determine the optimal quantity given a certain budgetary constraint. One method of doing this was developed by the US Army's Cost and Economic Analysis Center. CEAC developed a model that was constructed in the form of a Lotus 1-2-3 spreadsheet. In application, this model proved difficult to work with due to a "circular reference" in the spreadsheets programming. This circular reference resulted in an endless loop, which made the model nearly impossible to copy.

¹⁰ A good discussion on R^2 can be found in Kmenta, Jan, *Elements of Econometrics*. Macmillan Publishing Company, New York, 1986. Pages 237-243.

c. Because of this difficulty, the CEAC model was modified into the CQM presented below. The CQM is designed to provide equipment production and cost estimates based on experience curve theory. Estimates are provided in terms of both constant and current dollars. In cases where there are budget constraints, the model will compute how many items may be procured with the constrained funds. While still retaining USACEAC's original outline, CQM also provides the following:

- (1) Experience curve parameter estimation.
- (2) Current and constant dollar estimates.
- (3) A method of providing for programmed and unprogrammed changes in costs through shifts to the experience curve.

d. The CQM model is based on the cost/quantity/rate experience curve method of (7) above. That is,

$$7.3) \quad Y = AQ^{-b}R^{-c}$$

where all variables are as previously defined. The CQM model produces estimates of the experience curve parameters. It also produces the experience curve percentages and other descriptive statistics. There is an option to drop the production rate (R) variable if it is found to be statistically insignificant. If that should be the case, CQM can estimate the experience curve without this variable.

e. Total production costs are found by examining the area under the experience curve. The total production cost is determined by the following:¹¹

$$11) \quad TC = \int_{1-0.5}^{L+0.5} AQ^b R^c dx$$

where:

- TC = total production cost
- F = unit number of the first item produced
- L = unit number of the last item produced.

Equation (11) can be modified to determine the total cost of any given lot. This is done below.

¹¹ CEC, ALM-63-3126-LC. Page 214.

$$11.a) \quad TC_g = \int_{F-0.5}^{L+0.5} AQ^b R^c dx$$

where

TC_g - total production cost of a given lot
 F - unit number of the first item produced
 L - unit number of the last item produced.

f. Table F-3 provides a listing of sample data used to construct and test the results of the CQM. This table consists of 8 years of production cost data. A total of 3,349 units are to be purchased at a budgeted cost of \$10,810 million. Average unit cost is found by dividing lot cost by lot size. The cumulative lot mid-point is computed by equation (8) as presented above.

g. Equation (7.a) is estimated in the usual manner, by applying

Table F-3.			
Cost, Quantity, and Rate Data for a Given Weapons System (cost data in millions of dollars)			
Fiscal year	Unit cost (Y)	Lot mid- point (Q)	Production rate (R)
1996	4.995	29.15	96
1997	3.869	234.23	335
1998	3.451	657.84	500
1999	3.225	1,168.18	500
2000	3.072	1,672.19	500
2001	2.980	2,174.34	500
2002	2.923	2,675.68	500
2003	2.892	3,137.04	418

OLSQ to the log-transformed variables. The average unit cost variable (Y) is the dependent variable, and the explanatory variables are the cumulative lot mid-point (Q) and production rate (R). Table F-4 displays the regression results from the data of Table F-3. Also included are the results as they are presented by the CQM.

h. The experience curve coefficient estimates are then utilized to determine the total cost (TC). This result can be seen in Table F-5.

Table F-4.	
Estimated Experience Curve Parameters (based on data from Table F-3)	
Regression output:	CQM Model output:
	First Unit Cost = 7.743
Constant = 2.04677426	QTY Slope (b) = -0.11404
b = -0.114044	Cost/Qty slope = 0.9240
c = -0.0118126	Rate Slope (c) = -0.01181
R squared = 0.999	Cost/Rate slope = 0.9918

As can be verified, the CQM estimates the total cost of this particular system to be \$10,792.5 million. Presented also in Table F-5 are the projected total costs of the system. The projected total cost amounts to \$10,810 million. Comparison of the model's estimate to the projected total costs reveals that the model forecast projected total costs quite well.

i. The portion of the CQM devoted to computing production costs given desired quantities and possible budget constraints is divided into three sections. The first is the input section, which requires the user to enter certain key data. This data includes:

(1) First Unit Cost (A). It should be noted that this variable must be based on an annual production rate.¹²

(2) Quantity slope (b)

(3) Rate slope (c)

(4) Production rate (R) by fiscal year.

¹² This portion of CQM does not perform the regression estimates of equation (7a). This must be done in another portion of the model, and then manually entered.

Table F-5. Estimate of Total Cost and Lot Costs (based on data from Table F-3)			
Fiscal	Production	Projected	Model est.
year	rate (R)	lot cost*	lot cost*
1996	96	480	470.1
1997	335	1,296	1,295.0
1998	500	1,726	1,714.5
1999	500	1,613	1,607.0
2000	500	1,536	1,542.9
2001	500	1,490	1,497.4
2002	500	1,462	1,462.5
2003	418	1,209	1,203.2
TOTAL	3,349	10,810	10,792.5

*In millions of dollars.

- (4) Previous quantity produced.
- (5) First fiscal year of procurement
- (6) Projected shifts of first unit cost, by fiscal year. These can be positive or negative.
- (7) Desired quantities, by fiscal year.
- (8) Budget constraints, by fiscal year. These should be entered in terms of current dollars.
- (9) Inflation factors, by fiscal year.

The second section is the Desired Production at Maximum Rate Section. This section computes the constant dollars needed to produce the desired amount of items. Also calculated by this section are the number of items that can be produced given the budget constraints, budgeted funds against estimated production costs, and whether there is a surplus or shortage of budgeted funds.

The final section is the Actual Production at Maximum Rate Section. This section will compute the total number of items that can be produced given the budget constraints. These items will be presented based on the assumption that they can be produced at a rate equal to the originally desired annual rate. In the case of a severe budget constraint, this would be analogous to a manufacturer producing at top capacity for the first few months of the fiscal year and then halting production for the remainder of the fiscal year.

F-7. SPREADSHEET VERSION OF CQM

a. The three sections discussed above also appear in a spreadsheet version of the CQM. The model depends upon the user entering string and formula data into the spreadsheet. This projects production and budget information for two fiscal years. Information on subsequent fiscal years is found by copying the formulas.

b. The spreadsheet version of CQM is operated in the following manner:

(1) **Template Expansion.** The model's template only provides data for 2 fiscal years. But it can easily be extended to account for additional years. This is done by copying the spreadsheet's fourth column to the n th column, where n is the number of additional fiscal years to be considered.

(2) **Data Entry.** The input variables discussed in paragraph F-6i above are entered.

c. The model can be modified to account for inflation. The model assumes that future budget estimates are made in terms of then year dollars. If appropriate inflation factors are entered, then a constant dollar baseline can be obtained. It should be mentioned that when a baseline is chosen, the first unit cost (A) should be expressed in terms of the baseline dollars.

d. The CQM also has the ability to account for significant changes to recurring production costs. This is accomplished by shifting the experience curve.

e. The CQM provides the capability to develop production estimates based on budgetary constraints. Through the use of shifts in the unit cost curve, the model provides the capability to quickly assess the effects of significant changes to recurring production costs.

F-8. LIFE CYCLE COST MODEL (LCCM)

a. The purpose of the LCCM is to examine the baseline cost estimate and ACP of a weapon system by the P92 subcategories within each of the Big Five cost categories. The values input into the BCE are derived from the cost histories of weapon system programs. Systems include the following: aircraft, missiles, air defense combat support, and fire support, among others.

b. The LCCM is a large spreadsheet-based model that is intended to recompute new values, e.g., due to sensitivity analysis on specific quantities and cost levels, current

proposed budget ceilings or revised contractual agreements. The recalculated results are based on the ratios of the historical production quantities that are listed in the BCE to the updated/revised production quantity entries.

c. For example, given a production rate of 516 M1A2 tanks in the fifth year at a total cost of \$1.825 billion, if a revised budget proposal or new production rate schedule provides for a revised quantity of 400 vehicles, the CQM would calculate the proportional production cost reduction (i.e., 400 M1A2s * \$2.8 million allocated to producing a tank). The LCCM addresses all proportional changes to the respective production subcategories based on the revised quantities and production costs. All associated and procurement-funded cost subcategories would change in a similar manner.

d. An example of a production cost used in the LCCM is cost element 2.02, recurring investment cost. This cost is comprised of the following subcategories: manufacturing cost, recurring engineering cost, sustaining tooling cost, and quality control cost. The LCCM is set up so that when the data is input at the lowest level cost element (if available), it automatically calculates the next highest cost element.

F-9. LCCM OUPUT

a. Several types of information that can be derived from the LCCM. It is assumed that entries are provided in either current or constant base year dollars from either the BCE or ACP.

b. A sample from the BCE data subcategories using the M1A2 tank for a current year within the 2.0 category (without subcategories such as 2.091 System Project Management) is illustrated in Table F-6.

Table F-6. Production Phase Breakdown

Life Cycle Cost Model -- Production Phase Illustration M1A2 Tank			
Category	Cost Element	Appropriation	FY 90 (\$000)
2.0	Production Total		33,189.4
		OMA	1,770.5
		PA	31,418.9
2.01	Nonrecurring	PA	2,820.5
2.02	Recurring	PA	25,716.0
2.03	ECOs	PA	98.9
2.04	Data	PA	177.0
2.05	Sys Test & Eval	PA	234.5

2.06	Train Serv & Equipment	PA	519.7
2.07	Intial Spares	OMA	1,770.5
2.08	Operate/Site	PA	
2.09	Other Prod Fund	PA	1,852.3

c. A sample of the output format showing the rolled up costs for the Big 5 cost categories over is illustrated below in Table F-7. Total life cycle costs for the weapon system are also calculated.

Table F-7. Sample Output for Big 5 Categories

Category	POM 1 1992	POM 2 1993	POM 3 1994	POM 4 1995	POM 5 1996	POM 6 1997	Total POM	Total Outyears	Total Life Cycle
Dev	X	X	X	X	X	X	X	X	X
Prod	X	X	X	X	X	X	X	X	X
MCA	X	X	X	X	X	X	X	X	X
Fldg	X	X	X	X	X	X	X	X	X
Sustain	X	X	X	X	X	X	X	X	X

d. Another form of output is designed to provide a breakdown of all costs by appropriation: OMA, MPA, MCA, and PA. Moreover, another depiction is provided by procurement funded costs (total fly away cost, total weapon systems cost, total procurement cost, and total program acquisition cost) in both constant and current dollars for a given base year.

e. The basic spreadsheet template was developed using a PC-based application, Quattro Pro. The file is initially set up in protected mode so the formulas cannot be overwritten; however, an option is available for overwriting the formulas by changing the default to unprotected mode when input data is provided at a higher level, e.g., 2.011 instead of 2.01. The step is for the analyst to copy the template to another spreadsheet file (one which has substantive meaning such as MLRS.WQ1 or BFVS.WQ1) so that the basic formulas and layout maintain a standard format.

f. The output of the LCCM provides several rollups, in both current and constant dollars, with an indexed base year which is contingent on the budget year for the given system. Output formats include total requirements by appropriation category, Big 5 category, procurement funded cost as well as a listing of the systems' associated items of equipment (ASIOE). Timeframes of interest include previous years through the current year, budget year, POM years, total outyears, and total life cycle cost.

g. Bar graphs can easily be called up and viewed within each weapon system spreadsheet. A sample illustration of the

total life cycle cost (FY 91 current dollars) of the single channel ground and radio airborne system (SINCGARS) by each applicable appropriation is illustrated in Figure F-1.

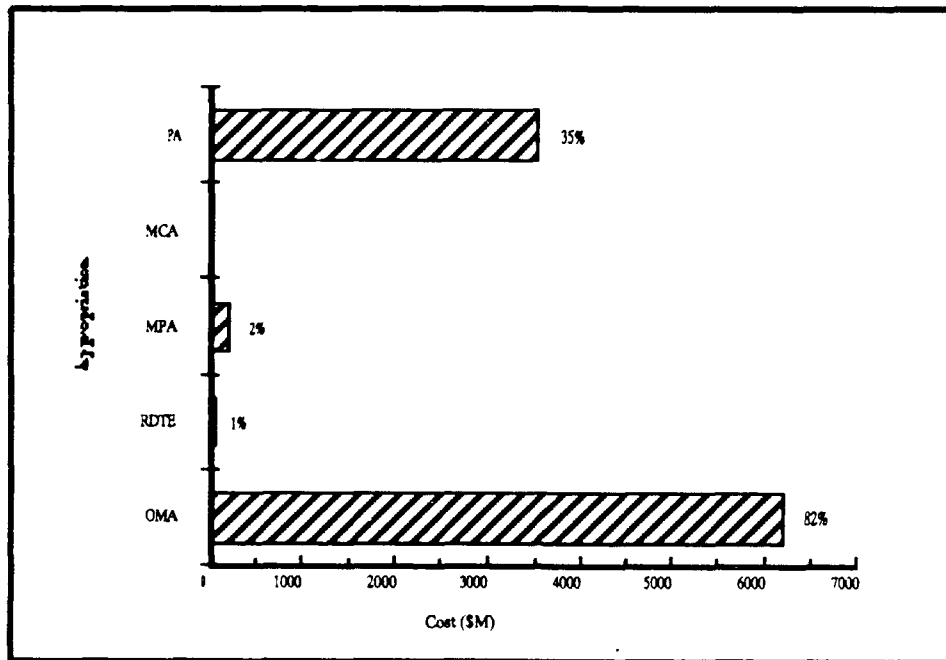


Figure F-1. SINCGARS Appropriation Summary

h. In conclusion, the LCCM provides a useful tool to perform life cycle costing for a given weapon system. The input is based on the BCE; however, other data can be used if desired. Assuming all the input values are converted to fit into the structure of the spreadsheet template, costs in many modes of display are calculated. (Note: in order to successfully use the model, a 286-based machine running at 12MZ is recommended as a minimum standard with available expanded memory of at least 1MB.)

APPENDIX G

TOPSIS USER NOTES

G-1. INTRODUCTION. The analytic tool selected for measure of effectiveness integration was the "Technique for Order Preference by Similarity to an Ideal Solution, better known by its acronym, TOPSIS. This technique was developed by Ching-Lai Hwang¹ and Kwangsun Yoon at Kansas State University and has been widely used by the Army and taught in operations research classes at the Army Logistics Management Center.

G-2. USER'S INSTRUCTIONS FOR MS-DOS. To execute the TOPSIS software independent from the capsule environment, the following steps should be taken:

a. Preparation of Input. An ASCII text file forms the input for the TOPSIS calculation engine. The text file is used to mimic the relational tables found in the data base environment. Because of this "table" structure, the input has a particular structure, but is relatively free format otherwise. You never have to count columns or use numeric format codes. The text file may be prepared using a normal text editor, but is most commonly prepared with a microcomputer spreadsheet program such as Microsoft Excel. Since all spreadsheets support the display of multiple rows and columns of data, they are particularly advantageous as a user interface. When the spreadsheet containing the inputs is finished, it is only necessary to save the output as "text," an option supported by all known spreadsheet products.

b. File Format. The format for the input file is as follows:

(1) The first three lines of the file are "header" lines which label the decision attributes associated with each alternative. These three lines all begin with a TAB character (or a sequence of spaces) to distinguish them as header lines.

(2) The first line of the file contains the names of the decision attributes. Each name can have any number of characters, but must not contain any blanks, tabs, carriage returns, or commas, as these characters are used as field separators.

(3) The second line of the file contains either a plus sign ("+") or a minus sign ("-") indicating that the attribute

¹Hwang, Ching-Lai and Yoon, Kwangsun, Multiple Attribute Decision Making, Methods and Applications, Springer-Verlag, Berlin, 1981.

in this column is either a benefit or a cost measure respectively.

(4) The third line of the file contains the weight associated with the attribute. This is a number between 0 and 1, and is computed using the methods described in Chapter 7.

(5) All subsequent lines after the third line contain rows of the decision matrix with the scores associated with each alternative. Each row begins with an alternative name (which again can contain no blanks or tab characters), followed by the scores associated with that alternative for each attribute.

c. Command Line Invocation. To use the engine, simply type the command TOPSIS followed by the data file name of the file containing the input data. (On the Macintosh, double click on the application icon. You will be prompted for the input file name.) This input file must end with the extension ".dat" in order to be found correctly. After TOPSIS has computed its results, a file with the same name, but with extension ".out", will automatically be generated. If there are no errors, TOPSIS will operate silently, producing no further output to the command interface.

d. Output File. The output file contains a mirror image of the input data with two new columns in the matrix. The first new column is the TOPSIS coefficient, and the second column is the relative rank among the listed alternatives.

e. Example Input. The following is a small input file (named "example.dat") formatted properly for use with the standalone version of TOPSIS.

Table G-1. Example Input

	Political Risk Congressional Opinion	Asset Versatility and Deployability	Operational and Technical Risk
	+	+	+
WEIGHTS	0.1282705	0.2763505	0.595378
BASE CASE	31	19	36
ALT 1	29	36	27
ALT 2	16	24	17

f. Example Command Line: To run TOPSIS on the above data, the following command line invocation is used:

```
C:> topsis example
```

g. Example Output. The following is the output file generated by the above input.

Table G-2. Example Output

				EXAMPLE_coef	EXAMPLE_rank
BASE CASE	31	19	36	0.327866	2
ALT 1	29	36	27	0.895215	1
ALT 2	16	24	17	0.255277	3

h. **Possible Errors.** The following are typical errors, and the recommended corrective action:

(1) "Could not open <filename> for input."

This error is usually the result of misspelling the input file name, or not having the appropriate extension (.dat) on the input file name. Also common when the input file is in another directory besides the current directory. Provide either the complete path and directory name or "cd" to the appropriate directory before running TOPSIS.

(2) "Could not allocate r."

This error is usually the result of trying to run TOPSIS on a machine with insufficient memory. MS-DOS machines have the most restricted memory. There is little you can do. Try using a Macintosh, which can handle much larger problems. If the problem persists on the Macintosh, turn multifinder off.

(3) "Invalid vector length" <Next line shows defective vector>

This error is usually the result of having too many or too few attribute scores in a particular row. Count them again. Also, look for blanks in the name of the alternative.

APPENDIX H
FOMOA USER NOTES

H-1. INTRODUCTION

a. The analytic tool selected for development of the acquisition strategy was the Force Modernization Analyzer, better known by its acronym, FOMOA.. It has been widely used by the Army for the production of weapon system modernization plans. It is based upon the concept of linear programming and econometric modeling of cost-quantity relationships. The Value Added FOMOA formulation considers production, TOA, and force structure constraints in conjunction with cost and benefit data in order to determine an optimal mix of weapon system procurements by year.

H-2. GENERAL FORM OF THE OPTIMIZATION MODEL

a. **The Formulation.** Documentation for the general formulation of the Value Added FOMOA is provided within this paragraph of the appendix.

b. **Key Words.** The model formulation contains the following key words: SETS, ENDSETS, MODEL, DATA, ENDDATA, and END. The formulation begins following the SETS section. The data files are listed near the end of the program after the key word DATA. Figure H-1 shows the relative arrangement of the major sections of the formulation file. The formulation file name ends with the extension "<filename>.mod".



Figure H-1. FOMOA Formulation Sections

The general form for each of the sets listed in the subsequent paragraphs of this appendix is: set name, elements of the set, and finally attribute(s) for the elements. For example:

T /1..12/ : TOA;

T = Set Name
/1..12/ = Elements
:TOA = Attribute.

c. **Comments, Etc.** Anything between an exclamation mark (!) and a semicolon (;) is a comment. FOMOA does not distinguish between lower and upper case. Index variables (I,J,K,L below) could be typed in lower case, but in the output, they would be in upper case. Value Added FOMOA, except for comments, is written entirely in upper case.

d. **Time.** The first lines of the SETS section contain the following statement:

T/1..12/: TOA;

(1) The elements 1, 2, ...12 of the set T are indicated between the two slash (/) delimiters. In terms of mnemonics, T is, of course, time. (In this formulation, Value Added FOMOA is currently executed using only 12 planning years. In the event of a larger implementation, only two lines of code need be changed--this set line and the line in the DATA section accessing a 12-year data file.)

(2) After the colon (:), attributes of the elements are listed. (The semicolon (;) indicates the end of the statement.) Attributes pertain either to input data or program variables. The values for data attributes appear in an input data file associated with each attribute and named "<attribute name>.dat". The TOA attribute data would be in a file called "TOA.dat" and the attribute has the following definition:

TOA(I) Funding level for procurement for year I.

e. **Time and Mission.** The next two statements define the set M of vehicle missions/roles/force packages which vary with time. It should be noted that while the formulation explicitly accounts for missions/roles/force packages, in Phase I of Value Added Analysis, we considered only one mission per system.

M /TK, IN, AT, EN, AR, AM/ : ;

TM(T,M) : EQM, WM, RM, LM, UM;

(1) The variable attributes of TM are:

EQM(I,J) The size in terms of number of vehicles in year I of mission J (of all types K--see below).

WM(I,J) The total modernization weight of the vehicles in year I in mission J (see definition of the modernization weight W of vehicle types of the Time, Mission, and Equipment paragraph below).

(2) The data attributes of TM are:

RM(I,J) Minimum fraction modernization required in year I in mission J (weight divided by size--see mission constraints section below).

LM(I,J) Lower limit on number of vehicles in year I in mission J (i.e., total number of required vehicles in year I in mission J).

UM(I,J) Upper limit on number of vehicles in year I in mission J.

f. Mission and Equipment. The next several lines associate each equipment type with a mission and give attributes of equipment that do not vary with time. (They involve planning years 1 or 2.)

E / @file(equip.dat) / ;

ME (M,E) / @file(mission.dat) / : ST, FE1, FE2;

(1) ME is a subset of the direct product of M and E. The definition of ME is given by the parenthetical expression (M,E) and a list of specified elements of between the slash (/) delimiters.

(2) The attributes of ME are all of the data category. They are:

ST(J,K) Inherited assets available for year 1 (starting year) in mission J of type K.

FE1(J,K) Programmed fielding in year 1 (programmed buys 2 years before planning period) for vehicles in mission J of type K.

FE2(J,K) Programmed fielding in year 2 (programmed buys 1 year before planning period) for vehicles in mission J of type K.

g. Time, Mission, and Equipment. The next line of the code defines the set TME and is the capstone of what has gone before. It gives the equipment attributes that can vary with time.

TME (T,ME) : X,Y,EQ, CP,CO,W,LX,UX,UE;

(1) The variable attributes of TME are:

X(I,J,K) Number of vehicles purchased in year I in mission J of type K.

Y(I,J,K) Number of vehicles retired in year I in mission J of type K.

EQ(I,J,K) The number of vehicles in year I in mission J of type K (force composition).

(2) The data attributes are:

CP(I,J,K) Purchase cost of a vehicle in year I in mission J of type K.

CO(I,J,K) O&S cost of a vehicle in year I in mission J of type K.

W(I,J,K) Modernization weight of a vehicle in year I in mission J of type K. This weight is a user input value between 0 and 1. Fully modernized vehicles have weight 1, completely obsolete vehicles have weight 0.

LX(I,J,K) Lower limit on number of vehicles procured in year I in mission J of type K.

UX(I,J,K) Upper limit on number of vehicles procured in year I in mission J of type K.

UE(I,J,K) Upper limit on number of vehicles in year I in mission J of type K. (Used only in minimum cost runs to remove old systems with low operation and support costs.)

h. Production Lines. The next several lines name the production lines, specify the equipment type each produces, and give the line attributes, all of which can vary with time. It should be noted that while the formulation explicitly accounts for multiple production lines per system, in Phase I of Value Added Analysis, only one production line per system was considered.

P. /@file(lines.dat)/ : ;
PME (P,M,E) / @file(PME.dat)/;
TP (T,P) : XP,LP,UP,Z;

The variable attribute of TP is:

XP(I,L) Total number of vehicles produced in time I on line L.

The data attributes of TP are:

LP(I,L) Lower annual production limit in year I for line L.

$UP(I,L)$ Upper annual production limit in year I for line L.

$Z(I,L)$ Open/close production line status in year I for production line L. If the line is open, the status value is 1; 0, otherwise.

i. Dependent and Decision Variable

(1) The variables EQM and WM of set TM are both defined in term of the variable EQ of set TME as follows:

[H.01]

$$EQM(I,J) = \sum_{K | (I,J,K) \in ME} EQ(I,J,K) \text{ for } I \in T, J \in M.$$

[H.02]

$$WM(I,J) = \sum_{K | (I,J,K) \in ME} EQ(I,J,K) * W(I,J,K) \text{ for } I \in T, J \in M.$$

(2) The variable EQ is in turn defined in term of the more basic variables X and Y of TME as follows:

For $(J,K) \in ME$ and $I > 2$

$$\begin{aligned} EQ(1,J,K) &= ST(J,K) + FE1(J,K) - Y(1,J,K) \\ EQ(2,J,K) &= EQ(1,J,K) + FE2(J,K) - Y(2,J,K) \\ EQ(I,J,K) &= EQ(I-1,J,K) + X(I-2,J,K) - Y(I,J,K) \end{aligned}$$

Note that vehicles procured in year I-2 are fielded in year I because of a 2-year lag between the purchase year and the operational year.

(3) The variable XP is defined in terms of the variable X as follows:

[H.03]

$$XP(I,L) = \sum_{(I,J,K) \in PME} Z(I,L) * X(I,J,K) \text{ for } I \in T$$

(4) The variables EQM, WM, EQ, and XP can be considered as functions of the decision variables X and Y. There is one other decision variable, **TMSTAR**. It can be thought of as a technical maximizer. It occurs in the maximization objective function and in a set of six constraints. These constraints

maximize the minimum of the six ratios EQM(5,J) to LM(5,J) involving the target (5th) planning year and the six missions J.

j. Objective Function

(1) **Objective Function for the Minimum Cost Version.** This objective function minimizes the sum of all procurement costs and all operations and support costs over the 5 year planning period. It is given by:

[H.04]

$$\text{Minimize } \sum_{T \in T} (CP * X + CO * EQ)$$

(2) **Objective Function for the Maximum Modernization Version.** This objective function maximizes the sum of the technical maximizer times 1000 and the annual total mission modernization weights WM. Any relatively large number can be used in place of 1000. It is given by:

[H.05]

$$\text{Maximize } 1000 * TMSTAR + \sum_{T \in T} WM$$

k. Constraints

(1) **Funding Constraints.** The following provides annual funding limits on procurement dollars:

[H.06]

$$\sum_{(I,J,K) \in ME} CP(I,J,K) * X(I,J,K) < TOA(I) \text{ for } I \in T.$$

(2) **Production Line Constraints.** The bounds statement on XP in the code provides the following annual lower and upper limits on the production lines:

$$LP(I,J) \leq XP(I,J) \leq UP(I,J) \\ \text{for } I \in T, L \in P.$$

(3) Mission Constraints

(a) **Minimum total requirements by mission.** The bounds statement on EQM in the code provides the following:

$$LM(I,J) \leq EQM(I,J) \leq UM(I,J) \text{ for } I \in T, J \in M.$$

(b) Minimum modernization fraction requirements by mission. The following enforce a minimum mission weight to mission size ratio:

$$WM(I,J) \geq RM(I,J) * EQM(I,J) \text{ for } I \in T, J \in M.$$

(4) Constraints on Vehicle Types (Other than Sums over Vehicle Types)

(a) Constraints on retirement decision variables for all vehicle types. The following ensure that no more vehicles of a given type are retired than are in the force the previous year.

$$\begin{aligned} Y(I,J,K) &\leq ST(I,J,K) \text{ for } (J,K) \in ME \\ Y(I,J,K) &\leq EQ(I-1,J,K) \text{ for } (J,K) \in ME \text{ and } I > 1. \end{aligned}$$

(b) Constraints on number of vehicles. The following can be used to retire old vehicle types:

$$EQ(I,J,K) \leq UE(I,J,K) \text{ for } (I,J,K) \in TME.$$

(5) Technical Constraints. These constraints are only for maximization runs. See discussion of the decision variable TMSTAR and of the maximization objective function above. (Multiplication by 100 is done below for scaling purposes to counteract the large denominator involving LM.)

$$TMSTAR \leq 100 * WM(SIZE(T),J) / LM(SIZE(T),J) \text{ for } J \in M.$$

(6) Procurement Constraints. The bounds statement on X provides the following:

$$\begin{aligned} LX(I,J,K) &\leq X(I,J,K) \leq UX(I,J,K) \\ &\text{for } (I,J,K) \in TME. \end{aligned}$$

H-3. USER'S INSTRUCTIONS FOR MS-DOS. To execute the FOMOA software independent from the capsule environment, the following steps should be taken:

a. Preparation of Input. A series of ASCII text files form the input for the FOMOA calculation engine. Each text file is used to mimic a relational table found in the database environment. Because of this "table" structure, the input has a particular structure, but is relatively free format otherwise. You never have to count columns or use numeric format codes. The text file may be prepared using a normal text editor, but is

most commonly prepared with a microcomputer spreadsheet program such as Microsoft Excel. Since all spreadsheets support the display of multiple rows and columns of data, it is particularly advantageous as a user interface. When the spreadsheet containing the inputs is finished, it is only necessary to save the output as "text," an option supported by all known spreadsheet products.

b. File Format. The format for all input files is generally as follows:

(1) Each input file is either a matrix or a vector (see Table H-1). At the beginning of the file are a series of optional "header" lines which label the vector or matrix column associated with each alternative. The header lines all begin with a TAB character (or a sequence of spaces) to distinguish them as header lines. There may be zero or any number of header lines in each file.

Table H-1. Input Files by Type

Input File Name	Type File	Data Content
E = @FILE(eq list.dat)	Vector	List of Equipment Names
TOA = @FILE(toa.dat);	Vector	Accumulative Dollars By Year
CP = @FILE(cp.dat);	Vector	Procurement Dollars By System
CO = @FILE(co.dat);	Vector	O&S Dollars By System
LX = @FILE(lx.dat);	Vector	Lower Production Limit By System
UX = @FILE(ux.dat);	Vector	Upper Production Limit By System
LM = @FILE(lm.dat);	Vector	Lower Force Structure Limit By System
UM = @FILE(um.dat);	Vector	Upper Force Structure Limit By System
ST = @FILE(st.dat);	Vector	Starting Inventory By System
FE1 = @FILE(fel.dat);	Vector	1st Year Previous Fieldings
FE2 = @FILE(fe2.dat);	Vector	2nd Year Previous Fieldings
Z = @FILE(z.dat);	Matrix	Production Line Start/Stop By Year By System
VA = @FILE(va.dat);	Matrix	Value Added Coefficient By Year By System

(2) All subsequent lines after the header lines contain elements of the vector or rows of the matrix associated with each alternative. Each row begins with an alternative name (which can contain no blanks or tab characters), followed by the values associated with that alternative.

(3) Each data file has a particular name associated with the name of the vector or matrix in the formulation. The name itself is not hard-coded, but is specified by name in the formulation source file. For example, in the formulation there is a statement to associate the vector variable "TOA" with the data file "toa.dat" as follows:

TOA = @FILE(toa.dat);

c. **Command Invocation.** To use the FOMOA engine, simply double click on the application icon. You will be prompted for the input file name. This input file must end with the extension ".mod" in order to be found correctly. After FOMOA has computed its results, a file with the same name, but with extension ".out" will automatically be generated in the same folder. If there are no errors, FOMOA will operate silently producing no further output to the command interface.

d. **Output File.** The output file contains a detailed listing of the values associated with each decision variable in the linear programming formulation. A table of output values lists the number of systems to be procured by year for each year of the planning horizon. The number of years in the planning horizon is specified in the problem formulation source file. Table H-2 provides the output for the A3 case study.

Table H-2. Example Output

System	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	Lower	Upper
SADARM	513	391	382	360	360	360	360	360	360			360	513
AMSH	0	240	240	180	180	180	180	180	180	180	180	180	240
NLOS	0	0	16	16	16	16	16	16	16	0	0	0	16
M1A2	0	0	0	64	64	64	64	64	64	0	0	0	318
BRADLEY	0	0	0	0	0	0	0	0	0	0	0	0	198

e. **Possible Errors.** The following are typical errors, and the recommended corrective action:

- (1) "Could not open <filename> for input."

Usually the result of misspelling the input file name, or not having the appropriate extension (.dat) on the input file name. Also common when the input file is in another directory folder besides the current directory. Provide either the complete path and folder name or place the FOMOA icon in the appropriate directory before running FOMOA.

- (2) "Could not allocate xxx."

Usually the result of trying to run FOMOA on a machine with insufficient memory. MS-DOS machines have the most restricted memory and there is little you can do. Try using a Macintosh, which can handle much larger problems. If the problem persists on the Macintosh, turn multifinder off.

(3) "Invalid vector length." <Next line shows defective vector>

Usually the result of having too many or too few attribute scores in a particular row. Count them again. Also, look for blanks in the name of the alternative.

(4) "Invalid formulation statement." <Next line shows defective statement>

Usually the result of a syntax error in the original problem formulation. Error recovery for formulation syntax errors is not sophisticated. One error may generate (and most often does) numerous error statements. Some common syntax errors include:

- Failure to end each statement with a semicolon.
- Failure to declare an index or variable name prior to use.
- Unmatched parenthesis.
- Unrecognized arithmetic operator.
- Incorrect number of arguments in a formulation language function.
- Failure to include or use an inappropriate index for a decision set.

APPENDIX I
SPONSOR'S COMMENTS

DACS-DPA

4 December 1991

MEMORANDUM FOR US ARMY CONCEPTS ANALYSIS AGENCY

SUBJECT: Value Added Analysis (VAA) 90-97 Study Critique

1. The following report gives comments regarding your draft report #CAA-SR-91-9, dated October 1991, titled Army Program Value Added Analysis 90-97 (VAA 90-97) Study:

- a. There were no specific editorial comments.
- b. All key issues planned for analysis were adequately addressed in the report.
- c. The methodology used to conduct the study was adequate.
- d. This study will be useful to this organization by being a primary source document in formulating questions for analysis and in answering specific questions regarding the methodology.
- e. I believe that this study is a good initial report on the VAA methodology.

2. I hope that these comments are helpful. Please feel free to direct any questions regarding this critique to myself or to MAJ Carlton in my office, phone: (703) 225-7737, or (AV) 695-7737.

for Robert B. Clarke
for ROBERT B. CLARKE MAJ, LTC
Colonel, GS
Chief, Acquisition and Support
Program Analysis Division

APPENDIX J
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GLOSSARY**ABBREVIATIONS, ACRONYMS, AND SHORT TERMS**

A3	armor antiarmor
AAO	Army authorization objective
ACP	Army cost position
AHP	analytical hierarchy process
ALM	algebraic lot mid-point
AMC	US Army Materiel Command
AMM	Army modernization memorandum
ARCPS	Army Capabilities Study
ARIM	Army Resource Integration and Management (study)
ARSTAF	Army Staff
ASARDA	Assistant Secretary of the Army for Research, Development, and Acquisition
ASIOE	associated item(s) of equipment
ASM	armor systems modernization
BCE	baseline cost estimate
BFS	Blue force surviving
BTU	British thermal unit
CAA	US Army Concepts Analysis Agency
CAB	cost analysis brief
CEAC	US Army Cost and Economic Analysis Center
CECOM	Communications and Electronics Command
CER	cost estimating relationship
CERL	US Army Construction Engineering Research Laboratory
CFV	cavalry fighting vehicle
CI	consistency index

CINC	commander in chief
COFM	correlation of forces and means
CORBAN	Corps Battle Analyzer
CORMO	Corps Model
CQM	Cost Quality Model
CR	consistency ratio
CY	calendar year
DA	Department of the Army
DG	Defense Guidance
DM	decisionmaker(s)
DOD	Department of Defense
DPAE	Director, Program Analysis and Evaluation
EBR	effective battalions remaining
EEA	essential element(s) of analysis
EUL	economic useful life
FAS	Force Accounting System
FER	force exchange ratio
FOMOA	Force Modernization Analyzer
FORSCOM	Forces Command
FR	force ratio
FY	fiscal year
GPS	global positioning systems
hex	hexagon
km	kilometer(s)
HQDA	Headquarters, Department of the Army
IPR	in-process review
IPS	Illustrative Planning Scenario

JCS	Joint Chiefs of Staff
LCC	life cycle cost
LCCM	Life Cycle Cost Model
LER	loss exchange ratio
LIN	line item number
LP	linear programming
LRRAMP	Long-Range Research and Development Modernization Plan\
m	meter(s)
MA	mission accomplishment
MACOM	major Army command
max	maximum
mBtu	millions of British thermal units
MCA	military construction, Army
MDEP	Management Decision Package
MFCM	movement force center of mass
MILP	mixed integer linear programming model
min	minimum
MISM	major item system map
MOE	measure(s) of effectiveness
MSR	minimum sustaining rate
NDR	nominal discount rate
NATO	North Atlantic Treaty Organization
NCE	noncombat effectiveness
NTC	National Training Center
OCSA	Office of the Chief of Staff, Army

ODCSOPS	Office of the Deputy Chief of Staff for Operations and Plans
OLSQ	ordinary least squares regression
O&M	operation and maintenance
OMA	operation and maintenance, Army
OMB	Office of Management and Budget
OPLAN	operation plan
ORSA	operations research and analysis
O&S	operation and sustainment
OSD	Office of the Secretary of Defense
PAED	Program Analysis Evaluation Directorate
PEG	Program Evaluation Group
PEO	Program Executive Office
PK	probability of kill
PM	program manager
PO	procurement objective
POM	Program Objective Memorandum
PPBES	Program Planning Budgeting and Execution System
PV	photovoltaic
RAM	reliability, availability, and maintainability
RDA	research, development, and acquisition
RDT&E	research, development, testing, and evaluation
SER	system exchange ratio
SIAM	secondary impact analysis modifiers
SLEP	service life extension program
SME	subject matter expert
SOF	Special Operations Forces

SSPK	single shot probability of kill
TACOM	Tank-Automotive Command
TAEDP	Total Army Equipment Distribution Program
TAP	The Army Plan
TC	total cost
TGW	terminally guided weapon
TOA	total obligation authority
TOE	table(s) of organization and equipment
TOPSIS	Technique for Order Preference by Similarity to Ideal Situation
TRAC	TRADOC Analysis Center
TRAC-FLVN	TRADOC Analysis Center, Fort Leavenworth
TRADOC	US Army Training and Doctrine Command
USAREUR	US Army, Europe
VAA	Value Added Analysis
VIC	Vector-In-Commander
WESTCOM	Western Command
Wh	watt-hours



**ARMY PROGRAM VALUE ADDED
ANALYSIS 90-97
(VAA 90-97)**

**STUDY
SUMMARY
CAA-SR-91-9**

THE REASON FOR PERFORMING THE STUDY was to provide the Director for Program Analysis and Evaluation, and the Deputy Chief of Staff for Operations and Plans (DCSOPS) an analytical methodology and capability to support the development of a balanced and effective Army Program.

THE STUDY SPONSORS are the Director for Program Analysis and Evaluation (DPAE), Office of the Chief of Staff, Army, and the Technical Advisor, Office of the Deputy Chief of Staff for Operations and Plans (ODCSOPS), Headquarters, Department of the Army (HQDA).

THE STUDY OBJECTIVES were to:

(1) Formulate an analytic method for estimating the marginal value of competing management decision packages (MDEP) to the Army. The methodology will provide a common understandable basis for the analysis of affordability issues.

(2) Identify or develop prototype models that support the Value Added Analysis methodology and provide management tools for the analytic method developed.

(3) Establish within DPAE and ODCSOPS an in-house capability to conduct program issue tradeoffs.

(4) Conduct a proof of concept analysis during the building of the 92-97 Program Objective Memorandum (POM).

THE SCOPE OF THE STUDY included the research, development, and acquisition (RDA) appropriations for selected items of equipment in fiscal year (FY) 1999 and FY 2004.

THE MAIN ASSUMPTION of this study is that HQDA needs a relatively quick method for conducting program tradeoffs which has sound analytical underpinnings.

THE BASIC APPROACH of this study was to:

(1) Identify and develop an analytical approach to evaluate program issue tradeoffs.

(2) Develop a capability for implementing the methodology to include software modules where appropriate.

(3) Demonstrate the methodology and capability by using issues from the 90-97 POM issue cycle.

THE PRINCIPAL FINDINGS of the study were:

(1) Two generalized categories of measures of effectiveness (explicit and implicit) were determined to be important in judging relative value.

(2) A linear combination of value components appears to be useful in creating a single measure of an investment's marginal value.

(3) VAA uses a system of judgment weights which measures an investment's value in a dual context.

(4) The VAA methodology as demonstrated holds promise as the decision analysis framework that should be used for conducting Army program tradeoff analyses. Further work in the areas of quick turnaround combat modeling, dynamic costing, and data collection need to be conducted.

(5) A highly aggregated combat model can provide useful insights for answering macro-level program tradeoff questions and, to a more limited degree, is capable of providing specific program guidance.

(6) In order for aggregated combat models to be useful, they must be calibrated to more detailed models and data.

(7) HQDA has a perspective which does not include the Training and Doctrine Command's (TRADOC) blueprint of the battlefield per se. Their headquarters is organized along the lines of Planning, Programming, Budgeting, and Estimation System (PPBES) functions, and, although the headquarters has some overlap, the specific thrust is the generation of forces through planning and programming.

(8) The cost-benefit analysis in the form of the optimization model requires further research into the use of dynamic costing of the procurement costs.

THE STUDY EFFORT was directed by LTC James A. Richmann, Force Systems Directorate, US Army Concepts Analysis Agency (CAA).

COMMENTS AND QUESTIONS may be sent to the Director, US Army Concepts Analysis Agency, ATTN: CSCA-FSR, 8120 Woodmont Avenue, Bethesda, Maryland 20814-2797.



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