REPORT DOCUMENTATION PAGE		Form Approved OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE May 1992	3. REPORT TYPE AND DATES COVERED Tech Report

4. TITLE AND SUBTITLE Validation and Verification of the Army Program Value Added Analysis	5. FUNDING NUMBERS

6. AUTHOR(S)

Michael G. Titone

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) OPERATIONS RESEARCH CENTER USMA WEST POINT, NY 10996	10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

19980804 062

12a. DISTRIBUTION / AVAILABILITY STATEMENT DISTRIBUTION STATEMENT A: APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED	12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Value Added Analysis (VAA) is the methodology used to aid senior Army decisionmakers in evaluating and prioritizing among competing alternatives in the Program Objective Memorandum (POM) building process. VAA helps to evaluate the relative contribution ("Value Added") of systems of interest to force level performance. VAA is fully capable of examining tradeoffs across a wide range of program issues. Recent systems that have been evaluated using VAA include: Air Defense Anti-Tank System (ADATS), Reconnaissance and Attack Helicopter (RAH-66), and the Line of Sight Anti-Tank (LOSAT) System. Because the methodology is expanding beyond the research, development, and acquisition (RDA) appropriations and growing in popularity there is a critical need to assess and improve it. The purpose of this report is to provide a timely and unbiased analysis of VAA and make recommendations for possible modifications to the methodology.

VAA is a useful tool to use in producing an acquisition strategy based upon cost effectiveness. It provides an insight to senior decisionmakers as to what systems are not feasible to buy when changes are made in the Total Obligation Authority (TOA). It can force particular systems to be procured and identify systems no longer recommended, indicating possible trade-offs. VAA output indicates the types and quantities of systems of interest to be procured which give the maximum effectiveness at any given TOA funding level. VAA output can also include a funding and acquisition stream which can be used for planning and programming the systems of interest.

14. SUBJECT TERMS VALIDATION AND VERIFICATION OF THE ARMY PROGRAM VALUE ADDED ANALYSIS			15. NUMBER OF PAGES 55
			16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18 298-102

USAPPC V1.00

United States Military Academy
West Point, New York 10996

Validation and Verification of the Army Program Value Added Analysis

Captain Michael G. Titone

OPERATIONS RESEARCH CENTER
TECHNICAL REPORT NO. FY92/92-2

May 1992

Validation and Verification of the Army Program Value Added Analysis

Captain Michael G. Titone

A TECHNICAL REPORT
OF THE
OPERATIONS RESEARCH CENTER
UNITED STATES MILITARY ACADEMY

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May 1992

Vita

Captain Michael G. Titone was born in Queens, New York, in 1957. He graduated
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and received his commission in the Reserves upon graduation. He entered active duty in
1981. In 1989, he received his MS in Applied Mathematics from the University of
Maryland in preparation for teaching undergraduate mathematics in the Department of
Mathematical Sciences, USMA. After teaching courses in Calculus, Differential
Equations, Probability and Statistics and being the Course Director for Pre-Calculus, he
was appointed to a research position at the Operations Research Center, USMA.

Acknowledgements

Table of Contents

List of Figures

List of Tables

Executive Summary

Value Added Analysis (VAA) is the methodology used to aid senior Army decisionmakers in evaluating and prioritizing among competing alternatives in the Program Objective Memorandum (POM) building process. VAA helps to evaluate the relative contribution ("Value Added") of systems of interest to force level performance. VAA is fully capable of examining tradeoffs across a wide range of program issues. Recent systems that have been evaluated using VAA include: Air Defense Anti-Tank System (ADATS), Reconnaissance and Attack Helicopter (RAH-66), and the Line of Sight Anti-Tank (LOSAT) System. Because the methodology is expanding beyond the research, development, and acquisition (RDA) appropriations and growing in popularity there is a critical need to assess and improve it. The purpose of this report is to provide a timely and unbiased analysis of VAA and make recommendations for possible modifications to the methodology.

VAA is a useful tool to use in producing an acquisition strategy based upon cost effectiveness. It provides an insight to senior decisionmakers as to what systems are not feasible to buy when changes are made in the Total Obligation Authority (TOA). It can force particular systems to be procured and identify systems no longer recommended, indicating possible trade-offs. VAA output indicates the types and quantities of systems of interest to be procured which give the maximum effectiveness at any given TOA funding level. VAA output can also include a funding and acquisition stream which can be used for planning and programming the systems of interest.

Several major issues impact the verification of the overall methodology. The first issue involves the measures of effectiveness (MOEs) generated by the different analytic methods[1]. The issues concerning MOEs are: comparing, combining, scaling, and weighting them. The second issue is the analytic framework used to prioritize among competing alternatives. The framework is based upon the analytic hierarchy process (AHP). The issues concerning the AHP are: the possibility of rank reversal, the frame of reference, and the scale of measure. The last issue is the use of the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) algorithm to combine different MOEs. The issues concerning TOPSIS are similar in nature to those concerning AHP, with one exception. TOPSIS output is in the form of rank ordered data coefficients based on an ordinal scale. This means the coefficients are based on a simple rank ordered and nothing more i.e, distance is not preserved. An example an ordinal scale can be found in the rank ordering of football teams. A team ranked number one in college football is not twenty times the value of the team ranked number twenty. Coefficients used in the optimization should have a ratio interpretation and should be based on a ratio

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[1]MOEs are criteria which express the extent to which a system performs a task assigned to that system under a specified set of conditions.

scale, which is distance preserving. The coefficients represent the relative benefit of competing systems and must express the relationship between the variables being compared. They also need to satisfy the requirements for a linear program model i.e, they must satisfy the properties of certainty and linearity[2].

The proposed solution to the issues is based on synthesis of the Analytic Hierarchy Process (AHP) assessment methodologies with Multi-Attribute Utility Theory (MAUT). The solution involves: modeling the preferences curves of decisionmakers, plotting actual combat and non-combat results on these curves to obtain their corresponding utility value, multiplying the utility values by weights obtained using the AHP, and using an additive measurable value function to combine effectiveness values. This eliminates the need for the TOPSIS algorithm and properly scales the coefficients for use in the objective function.

This report presents this issue and others and provides key recommendations. The proposed recommendations should make VAA an even better decision analysis framework for including or excluding various systems or mixes of systems from the modernization program.

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[2]Cook, Thomas M.,Introduction to Management Science, 4th edition , Prentice Hall, New Jersey, 1989, p50-51.

1. Overview

The report is comprised of two main sections: a validation section and a verification section. The validation section shows the process of determining the extent to which the overall VAA methodology accurately represents the real-world from the perspective of its intended use. The validation process is ongoing and is performed during each stage of the methodology in conjunction with the verification process. The verification section shows the process of determining if the models and simulations used in the methodology accurately represent the Concepts Analysis Agency's (CAA) conceptual description and specifications[1]. The verification process will examine stated and implied assumptions, relationships within and between different levels of the methodology, determine if the models and simulation logic correctly perform their intended functions, review model inputs and outputs, and check for unexpected sensitivity or lack of sensitivity to key inputs.

There are eight modules in the VAA standardized approach (see figure 1.1). The modules are: issue clarification, cost, explicit effectiveness, implicit effectiveness, effectiveness integration, optimization, resource allocation, and results and display. This report will focus on the first six modules. The resource allocation module and the results and display module were not developed for the prototype VAA study and will not be evaluated. The resource allocation module is included in figure 1.1 for display purposes.
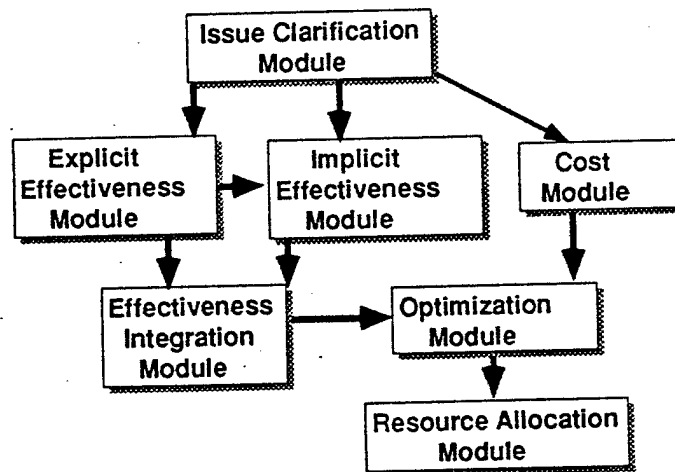
Figure 1.1. Value Added Analysis Methodology Overview

Each of the modules are interrelated. The issue clarification module consists of defining and understanding the elements of the tradeoff issue. The cost module calculates the costs associated with each alternative for the issue being investigated. The explicit effectiveness module measures the quantitative components of value and analyzes the contribution of the systems of interest to force level performance. The implicit effectiveness module measures the qualitative components of value and analyzes hard to quantify factors such as political risk, program flexibility, and contribution to industrial preparedness as well as other criteria. The effectiveness integration module uses the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) algorithm to combine the explicit and implicit measures of value. The rank ordered data coefficients from TOPSIS are used to form the objective function coefficient, v_{ij}, which is the per-item contribution of the system to force effectiveness. The optimization module takes v_{ij} and maximizes it with the quantity of that system procured in a particular year (x_{ij}). The maximization is then subjected to budgetary, force structure, and production constraints using a multiobjective linear program called the force modernization analyzer (FOMOA).

2. Validation

This section indicates the extent to which the overall methodology accurately represents the real-world from the perspective of its intended use.

2.1. Architecture

Each of the modules used in the standardized VAA approach are interrelated and designed to be self-contained. The issue clarification module identifies all elements of the tradeoff issue and any issue-related questions or problems. An information matrix may be used to categorize collected data. The costing module identifies all appropriate costs associated with each alternative for the issue being investigated. The Cost Quantity Model (CQM) and the Life Cycle Cost Model (LCCM) are used to couple the life cycle weapon system(s) cost elements with cost elements accounting for variations in procurement quantities. The explicit effectiveness module measures an issue's combat contribution to the program using the corps battle analyzer (CORBAN). The implicit effectiveness module measures an issue's subjective contribution to the program through the use of two surveys and Saaty's pairwise comparison technique. The effectiveness integration module combines the values obtained from both the explicit and implicit effectiveness modules using TOPSIS. The output from TOPSIS is in the form of effectiveness coefficients. The optimization module maximizes the coefficients and subjects them to cost constraints. FOMOA is then used to produce an acquisition strategy based on cost-effectiveness (see figure 2.1.).

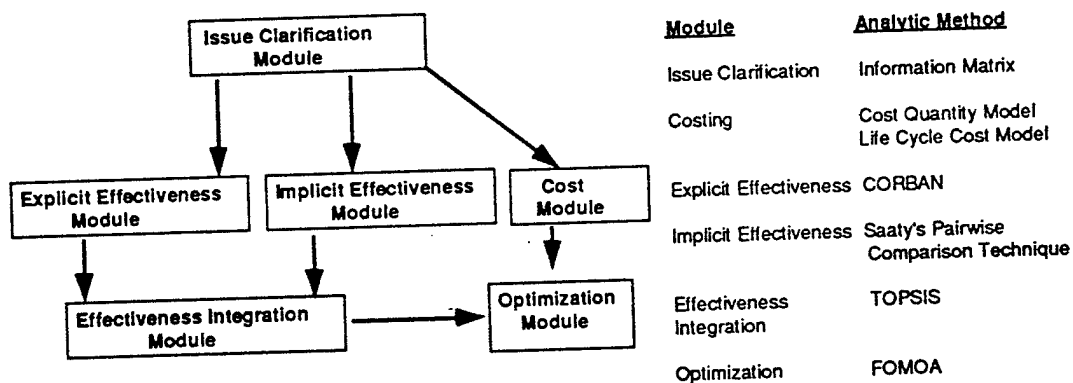| Module	Analytic Method
Issue Clarification	Information Matrix
Costing	Cost Quantity Model Life Cycle Cost Model
Explicit Effectiveness	CORBAN
Implicit Effectiveness	Saaty's Pairwise Comparison Technique
Effectiveness Integration	TOPSIS
Optimization	FOMOA

Figure 2.1. Overall Methodology and Analytic Methods

2.2. Input

Issues to be considered are decided jointly by project sponsors and VAA analysts. The selection of issues is based on the importance of the issue to the decision making process and the ability to do a credible job modelling the systems involved. The entire problem is framed by the selection of the systems to be considered and by the year/scenario of the combinations to be played[2].

2.3. Procedures

The MOEs of an alternative are obtained using two different methods. The first method uses CORBAN to obtain the combat MOEs. CORBAN is a corps-scope, battalion resolution combat simulation. MOEs produced by CORBAN are battlefield snapshots, decision traces, and attrition statistics. Each battlefield snapshot indicates the locations, status, and current activities of all units in the simulated battle at a particular time. A decision trace records significant decisions made by all units over a particular interval in the battle. Attrition statistics indicate the particular types of assets, and the quantities destroyed by opposing weapon types. The second method uses two surveys to develop the subjective MOEs. One survey is given to senior Army leadership to determine the decision weights for the whole hierarchy and the second survey is given to subject matter experts to score investment alternatives. The AHP is used to make the comparative judgments. The AHP breaks down a problem into its smaller constituent parts and then calls for only simple pairwise comparison judgments to develop priorities in the hierarchy. The principle of comparative judgments calls for setting up matrices to carry out pairwise comparisons of the relative importance of elements at different levels of the hierarchy.

TOPSIS is an algorithm that combines both the simulated combat and leader subjective MOEs. TOPSIS characteristics include: a rank-ordered preference list of all candidate systems from a constrained set of initial alternatives, the ability to compare the relative strength of preference (on an ordinal scale) among the candidates, a set of quantifiable criteria related to attributes associated with each alternative, a set of weights which express the relative measure of importance the decision authority attaches to each criteria, a degree of confidence in the statistical independence and reliability of the measures associated with the different criteria, and a requirement for sensitivity measures associated with variance in input values or decision authority tolerance to error. TOPSIS output is used in the formulation of the objective function coefficient. This coefficient is the per-item contribution of the system to force effectiveness (v_{ij}). V_{ij} is maximized with the quantity of systems procured in a particular year (x_{ij}) in the optimization module. FOMOA subjects the maximized function to budgetary, force structure, and production constraints.

2.4. Outputs

The feasible region is defined by the constraints. The results of the maximization produce a range of solutions which are used to develop an acquisition strategy.

2.5. Issues

Issue 1: What is the context of the problem (purpose) VAA is designed to solve?

Response: The leadership at the 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. The purpose of VAA is 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 cost-benefit analysis[3].

Issue 2: Does VAA provide information of an acceptable type, quality, and direction to support the Army Staff in the program evaluation and POM development effort?

Background: In order to answer this question we need to explore how weapon systems get put into the budget. The planning phase of the Planning, Programming, Budgeting and Execution System (PPBES) process begins with Headquarters, Department of the Army (HQDA) providing guidance for the development of a Long-Range Research, Development and Acquisition Plan (LRRDAP). The LRRDAP establishes the strategy for force modernization (Research Development Test and Evaluation (RDTE) and procurement appropriations) for the POM and Extended Planning Period. The LRRDAP guidance is sent to all Major Army Commands (MACOMs), Army Component commanders, and Program Executive Offices (PEOs) for new RDA requirements and a sensing as to CINC/PEO modernization priorities. It directs the field proponents (US Army Training and Doctrine Command (TRADOC), US Army Materiel Command (AMC) and the Information Systems Command (ISC)) to develop a field LRRDAP, a prioritization of all research, development and acquisition (RDA) programs. The LRRDAP is prioritized in terms of Battlefield Development Plan (BDP) deficiencies. The field LRRDAP is submitted to the DCSOPS at HQDA for review and modification[4]. VAA is used in this review and modification process to analyze competing alternatives that fall at the baseline. The field LRRDAP is then approved by the Chief of Staff of the Army (CSA) at a Requirements Review prior to the POM build and becomes the basis for RDA requirements in the POM.

Response: The results from VAA do provide information of an acceptable type, and direction to support the Army Staff in the program evaluation and POM development process. VAA works well as a rapid response tool and is vital in answering "what if..." questions proposed by project sponsors. These sponsors and the VAA analysts work closely together in determining the mix of systems that they want evaluated, where they

5

want it evaluated, and when they want it evaluated. VAA can be used to vary the production scheduling of different systems, provide an insight to decision makers in determining what systems fall out when changes are made in the Total Obligation Authority (TOA), and provide decision makers with a means to justify or refute preferences.

The quality of the information can be improved by eliminating the TOPSIS algorithm from the methodology. The replacement for TOPSIS could be in the form of an additive or multiplicative measurable value function. This function can be obtained by utilizing the principles of multi-attribute utility theory (MAUT).

Issue 3: Is the overall architecture of the methodology well defined? What are the architectural and theoretical foundations used? Do these foundations adequately match the requirements?

Response: The overall VAA architecture is well defined. A hierarchical assessment framework is used to measure the contribution of a program alternative. The framework is designed to measure the effectiveness of the alternative both explicitly and implicitly. It combines these explicit and implicit effectiveness values together into a single measure of benefit . The combined measure is evaluated against cost using a multiobjective linear program to produce an acquisition strategy based on cost-effectiveness.

The analytical method, AHP, has merit in its contribution to analyzing the structure of an issue and in quantifying subjective judgments. AHP provides an added measure of consistency and is a good method for determining weights. There have been some criticisms within the analytic community with regards to the AHP and Saaty's pairwise comparison approach when alternatives are evaluated using this procedure. The criticisms address the possibility of rank reversal, the frame of reference, and the scale of measure.

CORBAN is the corps level combat model used to measure the combat effectiveness of systems. CORBAN focuses on overall corps effectiveness and capabilities with emphasis on maneuver actions, activities, and weapon systems[5]. TRADOC Analysis Center, Fort Leavenworth (TRAC-FLVN) is the proponent for CORBAN. They provided the accreditation package for CORBAN to the US Army Combined Arms Command-Combat Developments, Fort Leavenworth on 2 November, 1990. The package contains a complete set of model documentation, an overview of CORBAN's validation and verification, an information paper, and a configuration control policy. The model's strong and weak points are included in the information paper. The paper identified CORBAN's strong points as its availability, flexibility, speed and low staff requirements. The weak points were identified as being its non-modular structure (which made it extremely difficult to maintain and perform structured verification and validation), and its air and air defense portrayal[6].

6

TOPSIS is used to combine the implicit and explicit measures of value into a single measure of benefit for use in the optimization. TOPSIS normalizes the criteria scores, weights the scores based upon the known or previously determined relative importance of each of the criteria, and calculates the distance from an Ideal and Negative Ideal alternative. These extremes are used as standards for the final ranking process. The best alternative is the one farthest from the Negative Ideal and closest to the Ideal. TOPSIS is an easy to use, straight forward algorithm. It allows attributes of different units to be used to compare alternatives and gives a clear rank ordering of the alternatives being considered. The TOPSIS algorithm has several weaknesses associated with it. These weaknesses are the possibility of rank reversal, arbitrary ranking, and the scaling of the output coefficients. The rank reversal and arbitrary ranking problems should be eliminated if the modifications to the TOPSIS algorithm were made [20]. The major problem with the algorithm in its VAA application is that the output coefficients consist of rational numbers on an ordinal scale. This means the coefficients are simply rank ordered. The final optimization needs coefficients to be on a ratio scale.

The flaws within the structure can be corrected with minimal effort and should produce more precise results.

Issue 4: Are the assumptions/limitations specifically stated for the methodology and are they reasonable?

Response: The key assumptions for the overall methodology are reasonable. They are:

1) All tradeoff issues will only be those "on the margin".

2) There is no realignment of years prior to the current POM funding levels.

3) VAA would only be used to measure increments and decrements starting from a base represented by the current POM (FY 92-97) position.

4) TOA guidance may or may not be developed using the VAA methodology.

5) The methodology must allow for prioritizing between dissimilar program alternatives.

3. Verification

This section illustrates the process of whether the models and simulations used in the methodology accurately represent the Concepts Analysis Agency's (CAA) conceptual description and specifications[7].

3.1. Issue Clarification

This modules' primary purpose is the identification of the elements of the tradeoff issue and any issue-related questions or problems. The elements of the module include the receipt of an issue, its description, and a basic understanding of where the issue fits in terms of national goals and objectives.

Figure 3.1 illustrates where the issue clarification module fits in the overall methodology.
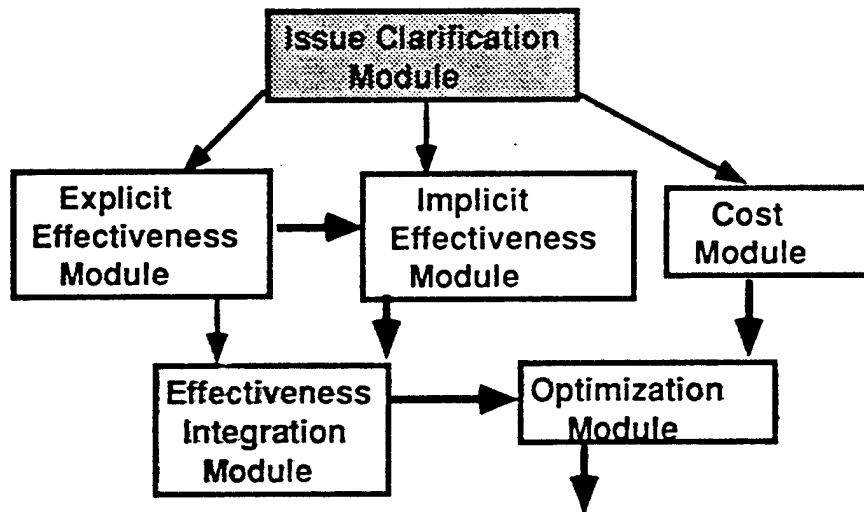
Figure 3.1. Issue Clarification

Figure 3.2 illustrates an example of an armor/anti-armor (A3) system trade-off.

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

Alternatives	Characteristics
Basecase	Europe Scenario with 25 systems
Alt 1	M1A2 NLOS-AT MLRS SADARM
Alt 2	M1A2 AMS-H BRADLEY BLK III MLRS SADARM

Figure 3.2. Representative Armor/ Anti-Armor (A3) Systems

3.1.1. Input

An issue is set up based upon the selection of the systems to be considered and by the year or scenario combination to be played. The selection process considers the breakout of related systems with their equipment and costs and any alternative systems. It also defines the scope of the study, the type of decision that needs to be made, and the extent to which the methodology will be used.

3.1.2. Procedures

The procedures are primarily related to defining the information needed, establishing critical relationships, and identifying the types of analytic tools and methods that might be useful. Guidance is received from the project sponsor. There was no specific tool or method developed for this module[7].

3.1.3. Outputs

The output consists of narrowing and clarifying the original issue and indicates what guidance may be important to the decision maker in conducting the analysis. The VAA analysts determine the list of systems to be considered and the year/scenario to be played. The combinations of systems that would never be played together are removed. The resulting combinations of systems drive the experimental design matrix used in the follow-on explicit effectiveness module.

Figure 3.3 shows an example of the form in which the data may be presented[8].

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
MISM Tree LIN	B54690 GA0167	C67900	E66300
AMM Priority	6	44	23

Figure 3.3. Information Matrix of A3 Systems

3.1.4. Issues

Issue 1: If there are currently 45 different systems to explore can all possible combinations of these systems be evaluated? Does the possibility exist that the optimal mix of systems may be discarded?

Response: The requirement to evaluate multiple systems in various combinations is extremely difficult and cannot be done in a timely manner if simulations are needed for every conceivable grouping of weapon systems. CAA determined that replacing weapon systems one at a time or doing every possible combination of systems were impractical methods because of combinatorial complexity. Response Surface Methodology (RSM) and the General Linear Model (GLM) were chosen to find the best combination of systems that give the greatest increase in the measures of effectiveness values. RSM is a collection of mathematical and statistical techniques useful for analyzing problems in which many independent variables may influence a dependent variable or response. The goal of RSM is to optimize that response[9]. The possibility still exists that the optimal mix of systems will be discarded, but it is remote.

Issue 2: Are the right issues being identified and clarified and who decides on the issues being kept or discarded?

Response: Issues are identified by the project sponsors. Clarification of issues is performed by VAA analysts and project sponsors. The selection of issues is based on the importance of the issue to the decision making process and the ability to do a credible job modelling the systems involved.

Issue 3: In what way do the issues drive the experimental design matrix?

Response: Issues are framed by the selection of the systems to be considered, the year/scenario combinations to be played, and can involve different combinations of systems. The combinations of systems that would never be played together are removed. The systems that ultimately drive the experimental design matrix are randomly generated[2].

Issue 4: What are the types and formats of the required input data for the issue clarification module? Is the input data appropriate and available?

Response: Data used in the methodology is complex, varied, extensive and hard to come by in certain instances. The format for the data can either be narrative or quantitative. Data on existing systems and on future systems may only be engineering data. Policy data is mostly text and cost data is predominantly quantitative. The input data used in VAA is appropriate for use in the trade-off analysis.

Issue 5: Are the assumptions made in this module specifically stated and are they reasonable?

Response: There were no assumptions made in this module[10], but there should be some in regards to the discarding of alternatives and the lack of available data. Since there are presently up to 45 different systems to evaluated, the number of potential runs would be $2^{45} - 1$ or roughly 3.51×10^{13} if systems are to be evaluated individually. RSM alleviates the process of replacing weapons one at a time and the process of testing every combination, but there is a chance that the optimal solution may still be overlooked. Improving the range of alternatives to cover variations in tactics, materiel, and organization may help eliminate the possibility of the optimal solution being missed, but an assumption should be made to that effect. The lack of available and acquired data is a problem that will always occur no matter what methodology is employed. Data will always be incomplete or even contradictory and an assumption should be made that the lack of available data can be compensated for parametrically.

Recommendation.

In order to apply the principles of MAUT to the methodology, decisionmaker preference (or utility) curves should be developed as part of the issue clarification module. The purpose for these curves is to properly scale different combat and non-combat MOEs in the hierarchy so they can be combined. These curves also have the added benefit of attempting to "capture" the risk attitude of the decisionmaker.

The most important issues concerning MOEs throughout the methodology lies in their comparison, scale of measure, weight assigned, and combination. Comparison of MOEs involves analyzing individual MOE values for each alternative and determining that one value is a higher value than another. The scale of measure involves considering the ranges over which alternative scores are based and aligning MOEs on the same scale so ratio assessments can be made. The weight assigned to MOEs must vary based on the importance of each MOE to the decision making process. Combination of MOEs involves integrating the explicit and implicit MOEs for each alternative into a single measure for use in the optimization.

A direct comparison of individual MOE values by category between alternatives is straightforward since MOEs are quantitative measures. One can just look at a single MOE for an alternative and determine if that value is better than the corresponding MOE value for another alternative. A degree of difficulty arises, however, when alternatives must be compared using the totality of all MOEs. MOEs are based on different scales, have different ranges, and are valued differently by each decisionmaker. This is where the additive measurable value function (AMVF) can be used. The goal of using the function is to combine MOEs in order to make comparisons among alternatives. It makes use of decisionmaker preference curves to combine the MOEs. A separate preference curve can be developed for each decisionmaker for each MOE by asking the decisionmaker one question[16]. These preference curves can be developed using many different methods. The direct rating method is the one illustrated below.

Let the following scale represent the MOE effective battalions remaining (EBR). For simplicity, the scale goes from 0 to 1000, where 0 is no battalions remaining (total defeat) and 1000 is all battalions remaining (total victory). The decision maker is asked to mark numerically what he would consider to be a draw. This value may or may not fall directly in the middle of the scale as illustrated in figure 3.7 below:

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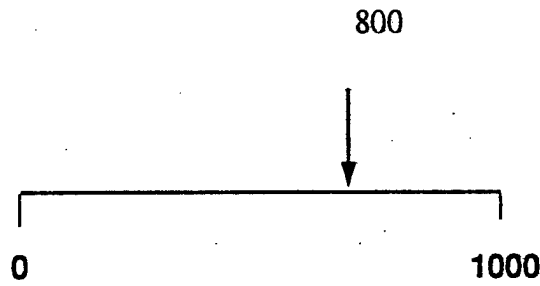
Figure 3.7. Decisionmaker's Numeric Scale

The decision maker's preference function can now be plotted for the MOE EBR, as shown in figure 3.8:
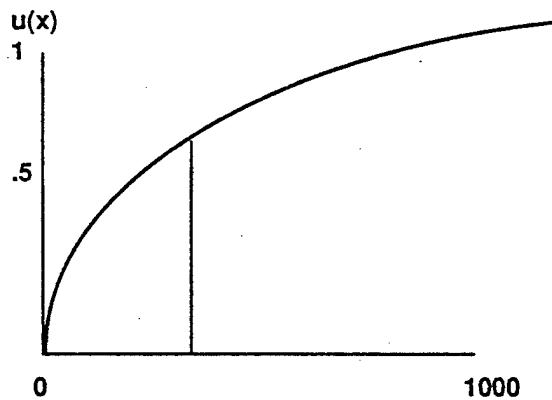
Figure 3.8. Decisionmaker's Preference Function Curve

The $u(x)$ is the relative score of the alternative on the MOE EBR. The maximum value for $u(x)$ is 1, the draw value is .5, and the minimum value is 0. Since the scale is logarithmic and the maximum, draw, and minimum values for $u(x)$ are known this enables us to plot and capture the decision maker's preference curve. All MOEs in the hierarchy can be scaled and compared using this approach.

The weights for the MOEs are obtained using the AHP. The decision maker is asked to answer a series of pairwise comparisons regarding the importance of each MOE. He should consider the ranges of the alternatives and the relative importance of going from the least preferred to the most preferred values for each MOE. The combination of each alternative's MOEs can then be performed using the AMVF. The following procedure can be used:

1) <u>MOEs are normalized on their respective base case</u>. This procedure is performed by taking the value of each MOE and dividing it by the value of the base case for that MOE. The values obtained will then reflect a given range. The upper and lower endpoint values for all the normalized MOEs can be set by the decision maker through a series of questions. The upper and lower endpoint values should not be used as a measure of attributes in general, but should be a reflection of going from the worst value to the best value.

2) <u>The decisionmaker's preference function curves are determined</u>. This can be done for the MOEs by asking the decision maker one question per MOE as previously shown. The normalized MOE values for all alternatives are then plotted on each of the decision maker's utility curves and all the u(x) values are determined.

3) <u>Weights are assigned to the MOEs</u>. The weights are assigned to each MOE as determined by the AHP. These weights are then multiplied by the corresponding $u(x)$ values and summed by the additive model $\sum w_i u_{ij}$. Where w_i is the weight of criterion i, and u_{ij} is the relative score of alternative j on the MOE i.

The result is an additive multi-attribute utility (MAU) function which is unique i.e, any other additive model using the same attributes that ranks alternatives consistent with the decision maker's preference is a positive linear transformation of the additive MAU. A benefit of this additive MAU function is that it can be assessed through the use of lotteries, trade-off questions, difference questions or ratio judgments. Alternatives can now be compared, scaled, weighted, and combined, with the decision maker playing a key role.

3.2. Costing

This module identifies all appropriate costs associated with each alternative for the issue being investigated. Two PC-based models, the Cost Quantity Model (CQM) and the Life Cycle Cost Model (LCCM) are used to couple the life cycle weapon system(s) cost elements with cost elements accounting for variations in procurement quantities.

Figure 3.9 illustrates where the cost clarification module fits in the overall methodology.

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          ┌─────────────────────┐
          │ Issue Clarification │
          │       Module        │
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┌──────────────┐  ┌──────────────┐  ┌──────────────┐
│   Explicit   │  │   Implicit   │  │     Cost     │
│ Effectiveness│→ │ Effectiveness│  │    Module    │
│    Module    │  │    Module    │  │              │
└──────────────┘  └──────────────┘  └──────────────┘

       ┌──────────────┐   ┌──────────────┐
       │ Effectiveness│   │ Optimization │
       │ Integration  │ → │    Module    │
       │    Module    │   │              │
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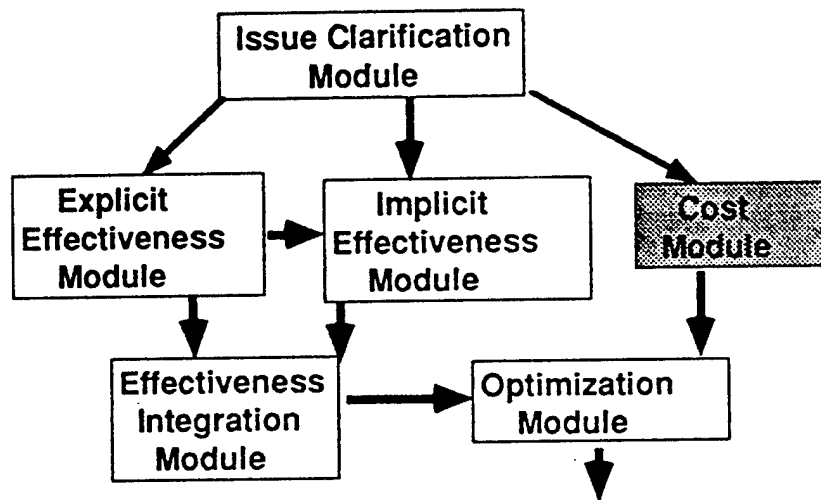
Figure 3.9. Cost

3.2.1. Input

Life cycle cost data is obtained from the Baseline Cost Estimate (BCE) or Army Cost Positions (ACP). Army Materiel Command (AMC) provides inflation indices. Production rates are obtained from the Assistant Secretary of the Army for Research, Development, and Acquisition or the Program Managers.

3.2.2. Procedures

The CQM estimates the experience curve for a given weapons system through the use of historical production cost, quantity, and rate data and computes production costs given the quantities desired. The LCCM redistributes production, fielding and sustainment costs once the optimal procurement quantities and production costs are calculated. The LCCM model is time-phased by appropriation, and the life cycle costs of the weapon system are computed in both constant and current dollars.

16

3.2.3. Outputs

The CQM provides equipment production and cost estimates based on budgetary constraints. It also provides experience curve parameter estimation, current and constant dollar estimates and can provide for programmed/unprogrammed changes in production costs by shifting the experience curve. The LCCM provides total life cycle costs for the weapon system, a breakdown of all costs by appropriation, and total procurement funded costs in both constant and current dollars[11].

3.2.4. Issues

Issue 1: Can the derivation of the most sensitive cost elements be improved without significant computational burden?

Response: The most sensitive cost elements are the production cost elements. The CQM and LCCM are useful methods for estimating the impact of variations in production quantities on the life cycle cost elements and appropriations. The derivation of cost elements using these two methods needs no improvement. However, the overall cost decision process can be improved if cost uncertainties, and the range of error they are likely to introduce, are incorporated into the cost estimate.

Cost uncertainty can be classified into two main categories: a requirements uncertainty, and a cost estimating uncertainty. Requirements uncertainty can be attributed to system configuration changes. For example, the original hardware design may fail to meet the desired performance characteristics and the hardware configuration must be changed. This uncertainty can be dealt with using parametric costing methods. Cost estimating uncertainty refers to variations in the cost estimates themselves. For example, the errors in the available cost data used to develop cost estimating relationships. This uncertainty is inherent in the VAA methodology because projections of future weapon system costs are based on historical data. The impact of uncertainty may eliminate certain alternatives from consideration and change the procurement scheduling of a variety of systems. The magnitude of the uncertainty for each system has to be determined.

The application of chance-constrained programming[3] could be used to admit random data variations and permit constraint violations up to specified limits. This method derives deterministic linear constraints which can be used to define a feasible region. Constraints can be determined by sampling a distribution-free chance constraint set from within a distribution-free tolerance region (Allen, Braswell, and Rao, 1974). Range error estimates can be made using generalized statistical estimating techniques and confidence intervals.

---

[3]Major Joseph A. Waldron, USMA, Department of Systems Engineering.

Issue 2: Who obtains the information from the BCE and ACP? How accurate are the BCE and ACP for life cycle cost data?

Response: CAA, in coordination with the US Army Cost and Economic Analysis Center (CEAC), collect all cost data. The BCE and ACP are the data available and come from the program manager. CAA updates the data as revisions are needed and new data becomes available[2].

Issue 3: Are the assumptions in this module specifically stated and are they reasonable?

Response: The assumptions stated are reasonable and are[12]:

1) Economies of scale are reflected by existing or derived composite learning curves.

2) Analogous system may be used for future systems when future system cost data are not available.

3) BCE and ACP data are used for Base Case unit production cost and quantities, when available.

4) Cost quantity relationships exist as defined.

5) Component driven models are impractical in a quick reaction environment.

6) Regression analysis of historical or projected annual weapon system production costs can be used to calculate system first unit costs.

7) Experience and production rate curves that generate average annual production cost can be determined within an acceptable margin of error.

8) No contractual penalties are incurred if production quantities are changed.

9) O&S costs are based on cumulative fielding of systems and begin when the first system produced is fielded.

3.3. Explicit Effectiveness

Three submodules comprise this module: combat, soldier quality of life, and other Army objectives. The combat submodule is the only submodule that is analyzed due to the limited scope of the VAA Phase I study. The context of the combat submodule is based upon the scenarios modeled, force structure, and doctrine employed. The overall purpose of the combat submodule is to measure combat effectiveness.

Figure 3.10 illustrates where the explicit effectiveness module fits in the overall methodology.
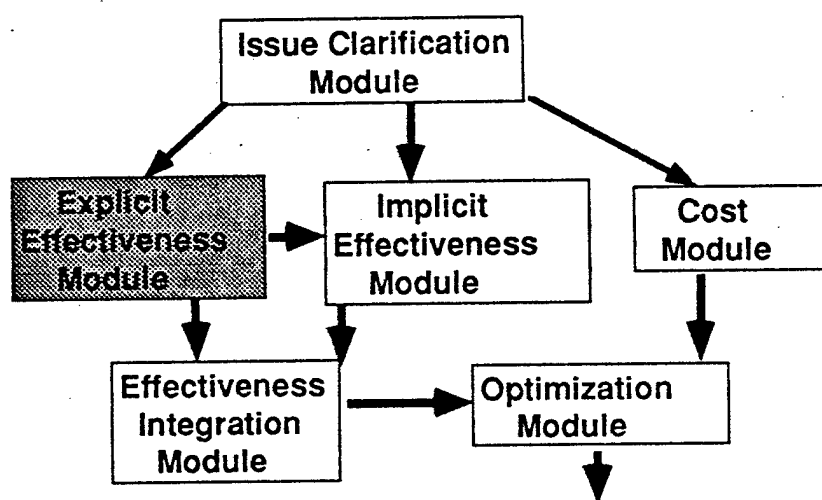
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        │   Explicit   │→ │   Implicit   │  │   Cost   │
        │ Effectiveness│  │ Effectiveness│  │  Module  │
        │    Module    │  │    Module    │  │          │
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        ┌──────────────┐  ┌──────────────┐
        │ Effectiveness│→ │ Optimization │
        │ Integration  │  │    Module    │
        │    Module    │  │              │
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Figure 3.10. Explicit Effectiveness

3.3.1. Input

CORBAN is the model used for determining combat effectiveness. The input to CORBAN consists of: scenario, terrain, representative Red Forces and Blue Forces, missions, and orders. This includes asset characteristics such as target types, fire rate, probability of acquisition, ammo type, fuel use, crew levels, vulnerabilities, search patterns, and sensor classes.

3.3.2. Procedures

RSM was chosen to take the place of the case by case introduction of alternatives. The RSM technique takes specific combinations of the total combinations possible. The combination results are averaged to find an estimate for a system's contribution to the

measure of effectiveness[13]. RSM uses a design matrix that varies the inputs so that a linear model can be built to forecast the effects of the systems with respect to the outputs. The average improvement given the new weapon system takes the form of a set of coefficients.

3.3.3. Outputs

The MOEs that CORBAN analysts most commonly use are: correlation of forces and means (COFM), force ratios (FR), loss exchange ratios (LER), fractional exchange ratios (FER), systems effectiveness ratios (SER), killer-victim table, effective battalions remaining, movement of force center of mass, mission accomplishment, front line trace, and plots of unit locations[14].

3.3.4. Issues

Issue 1: What are some of the problems associated with the MOEs? Are there MOEs which are able to provide better operational insights? Do the MOEs reflect the issues or the systems under consideration?

Response: MOEs are criteria expressing the extent to which a combat system performs a task assigned to that system under a specified set of conditions. The MOEs should depend on the possibility of quantifying or modeling the weapon system objective[15]. The MOEs that analysts most commonly use are too dependent and very similar in nature. For example, the LER is the measure of the combat value of Red systems lost to the combat value of Blue systems lost and the FR is the measure of the overall Red forces remaining with respect to the overall Blue forces remaining. The FER is the ratio of proportion of Red systems value lost to the proportion of Blue systems value lost. SER is a ratio of the number of Red systems killed by a blue system to the number of Blue systems killed. Killer-victim tables show losses and killers by asset and asset category but are not considered MOEs.

Recommendation: MOEs used should be reflective of the issues or systems under consideration. MOEs that may be incorporated into the combat model include percentage of blue force casualties and combat system utilization[3] . Percentage of blue force casualties is the ratio of blue force casualties/ initial blue force strength. Combat system utilization is the percentage of kills by a system/ the percent of those systems in the force. The MOE, LER, is redundant and can be eliminated.

Issue 2: Are there any credibility issues concerning CORBAN?

Response: TRAC-FLVN stated in the accreditation package for CORBAN that they were not aware of any functional area concerns over model credibility by any of the schools or centers[6].

Issue 3: What are some of the problems associated with RSM?

Response: RSM gives combat estimates with respect to different scenarios and years. The coefficients are a reflection of those systems in battle. The main problems associated with RSM involve understanding and explaining some of the results that are obtained. CAA noted that in every case in which these strange or unusual results have occurred the cause has been from data input errors.

RSM does provide for the amount of replication needed to achieve sufficient precision as long as the location of the region of interest is properly identified and the appropriate scalings and transformations for the input and output variables are made[17].

Issue 4: Are the assumptions in this module specifically stated and are they reasonable?

Response: The assumptions stated are reasonable and are that[12]:

1) Two years after the end of the POM is when the equipment will arrive in units.

2) Current M+10 force will be used in both 1999 and 2004.

3) COFM is the measure of the Red Force commanders' perception of success.

4) BFS is the Blue Force commanders' ability to prosecute his plan.

5) Quantities modeled are similar to quantities bought so new effectiveness simulations do not need to be run.

There are several assumptions that must be made to obtain the AMVF for use in this module[16]. The first assumption regards the strength of preference the decision maker has for an alternative. This is where the decision maker must articulate how much more he prefers one alternative over another. The second assumption regards the ordering of expressions of preference of the decision maker. For example, if the decision maker's preference for alternative A over alternative B is greater than his preference for alternative C over alternative D, then his preference for having to accept alternative D over alternative C should be greater than his preference for having to accept alternative B over alternative A. The third assumption is that the decision maker's preferences satisfy the properties of connectedness. This means that if the decision maker prefers alternative a to alternative b, then he can not also prefer alternative b to alternative a. The fourth assumption is that the decision maker's preferences satisfy the property of transitivity. Transitivity implies that if the decision maker prefers alternative a to alternative b and he prefers alternative b to alternative c, then he prefers alternative a to alternative c. The fifth assumption regards preference independence the decision maker has for an alternative. The best way to explain preference independence is with an example. Let us assume we have two alternatives and we wish to show they are preference independent. These alternatives are alternative a and alternative b respectively. Let us also assume that only three MOEs result from running CORBAN. These MOEs are FER, EBR, and COFM. We can write these alternatives in terms of their MOEs as vectors, $a = (a_1, a_2, a_3)$

21

and $b = (b_1, b_2, b_3)$ (where a_1 was the FER for alternative a etc...). If the decision maker prefers (a_1, a_2, a_3) to (b_1, b_2, a_3), he indicates that he prefers the FER and EBR values for alternative a over those for alternative b. He does not wish to consider the COFM values for alternative b and only likes those COFM values from alternative a. He preferences are independent if and only if he now prefers (a_1, a_2, b_3) to (b_1, b_2, b_3) i.e, he would still prefer FER and EBR from alternative a over alternative b if the COFM values for alternative a were not considered.

If it is determined that the decisionmaker's utility function is not logarithmic in nature, then we must assume we can determine the function through the use of lotteries. Once all of these assumptions are met, the AMVF from MAUT can be used to scale, compare, and combine the MOEs generated from CORBAN.

3.4. Implicit Effectiveness

This module has two objectives: weighting all the levels of the assessment hierarchy (see appendix b) and individual criteria, and scoring each alternative using Secondary Impact Analysis Modifiers (SIAM) factors. These SIAM factors are subjective decision criteria (see appendix c). The module is designed to quantify the subjective elements of the decision process so they can be used to conduct tradeoff analyses

Figure 3.11 illustrates where the implicit effectiveness module fits in the overall methodology.
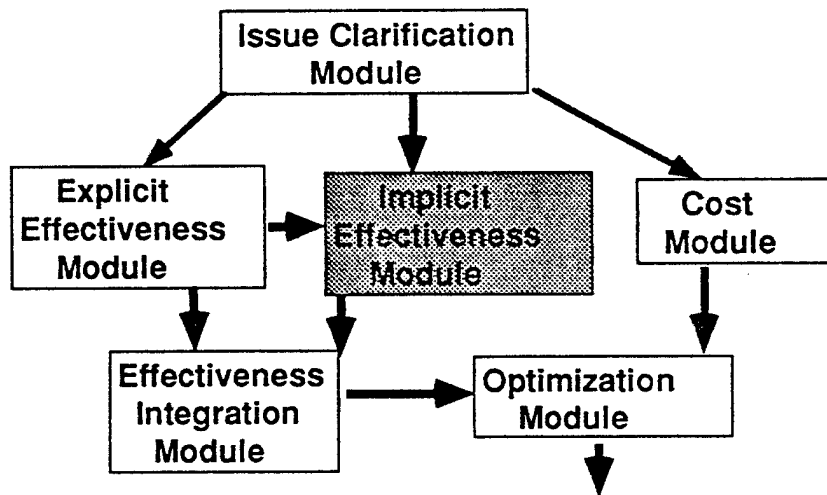

Figure 3.11. Implicit Effectiveness

3.4.1. Input

An Army leadership survey is used to weight all the levels of the assessment hierarchy and individual criteria. A subject matter expert survey is used to score investment alternatives using the SIAM factors.

3.4.2. Procedures

The establishment of relative strength or priority (weights) is accomplished using Saaty's pairwise comparison technique. A ratio judgment is made using these scores. The weights are computed using the geometric mean method and normalized so they sum to one. Subjective judgments are made by subject matter experts on the relative value of weapons systems with respect to SIAM factors. These judgments are also made using Saaty's pairwise comparison technique. The number of judgments is based upon the number of alternatives (for n alternatives, an n x n matrix of $(n^2 - n)/2$ judgments is

23

developed i.e, if n=7 there are 21 judgments). Experts rate each of the weapon systems using verbal comparisons. This verbal interpretation is translated to a numeric interpretation on a scale from 1 to 9. A ratio judgment is then made using the scores.

3.4.3. Outputs

The output consists of a rank ordering of alternatives to be used in the effectiveness integration module. The TOPSIS algorithm, in the effectiveness integration module, combines these rankings with the explicit effectiveness rankings and comes up with a single measure of effectiveness.

3.4.4. Issues

Issue 1: There have been some criticisms within the analytic community with regards to the AHP and Saaty's pairwise comparison approach. The general criticisms address the possibility of rank reversal, the frame of reference and scale of measure, and the comparison of AHP with traditional utility theory (UT). How valid are these criticisms and are they applicable to the VAA methodology?

Background: The possibility exists that rank reversal may occur when using a technique based on hierarchic composition. The following example by Dyer and Wendell illustrates the ranking reversal problem[18]. It should be noted that this example of rank reversal is occurring under specific conditions i.e, equal weights are assigned to all criteria.

Four alternatives alt 1, alt 2, alt 3, and alt 4 are compared against four criteria C_1, C_2, C_3, and C_4 by a single decisionmaker on an arbitrary scale from 1 to 9 (see table 3.4.1)

	C_1	C_2	C_3	C_4
alt 1	1	9	1	3
alt 2	9	1	9	1
alt 3	8	1	4	5
alt 4	4	1	8	5

Table 3.4.1. Rank Reversal Problem

24

For simplicity, we assuming that the four criteria are judged to be equally important (same weight), the rankings for the first three alternatives are shown in table 3.4.2 below:

	C_1	C_2	C_3	C_4	Score	Rank
alt 1	1/18	9/11	1/14	3/9	.320	3
alt 2	9/18	1/11	9/14	1/9	.336	2
alt 3	8/18	1/11	4/14	5/9	.334	1

Table 3.4.2. AHP Rankings

The column normalized matrix values are obtained by taking the original scored entries and dividing them by the sum of the entries in their particular column.

Adding the fourth alternative creates the effect shown in table 3.4.3:

	C_1	C_2	C_3	C_4	Score	Rank
alt 1	1/22	9/12	1/22	3/14	.264	1
alt 2	9/22	1/12	9/22	1/14	.243	4
alt 3	8/22	1/12	4/22	5/14	.246	2
alt 4	4/22	1/12	8/22	5/14	.246	2

Table 3.4.3. AHP Addition of Fourth Alternative

where alternatives 1 and 3 have reversed rankings.

An inspection of the results provides some insights into the problems that are inherent in hierarchic composition. In order to obtain the scores shown above, the numbers in the columns are each multiplied by .25 (reflecting the assumption that the criteria are equally important) and summed across the rows. The reason rank reversal occurs is because when only three alternatives alt 1, alt 2, and alt 3 are considered, 8/18 of the weight on criteria C_1 is allocated to alt 3 by the first term in the calculation of the score for alt 3, and 9/11 of the weight on criteria C_2 is allocated to alt 1 by the second term in its score calculation. Alt 3 has higher scores than alt 1 on criteria C_3 and C_4 which are enough to

25

give it a higher ranking than alt 1. When the new fourth alternative is introduced it does not do well on criteria C_1, C_3, and C_4, which is where alt 3 gets most of its allocated score in the case of the three alternatives. Therefore it dilutes the allocation of the scores of these criteria. Since alt 1 performed poorly across these criteria, it did not suffer significantly because it had such a small portion of this weight initially. However alt 4 has poor performance on criteria C_2 where alt 1 excels, so the fraction of the weight of C_2 allocated to alt 1 falls from 9/11 to 9/12. As a result, alt 3 is hurt more by the introduction of alt 4 than alt 1, and a rank reversal occurs.

Response: Since the AHP is used and it is based on a hierarchical structure, the possibility exists that rank reversals can occur. There is a great deal of concern in the analytic community regarding the frame of reference and scale of measure used in making pairwise comparisons. Decisionmakers are asked to reply to questions on a verbal scale and the verbal response is then translated into a number from 1 to 9. This number may not be reflective of the true feelings of the decision maker. For example, the scale value of 3 implies 'weak' importance of one objective over another in a verbal description, but the 3 rating means one objective is 3 times more important than the other. This assignment of 'weak' importance to a weight of 3 is not justifiable. These 1 to 9 ratings may also vary from decisionmaker to decisionmaker. The assigned value of 6 from one decisionmaker may only translate to an assigned value of 4 by another decisionmaker. The scale used lacks a ratio interpretation in the sense that only numbers from 1 to 9 are used and an assigned value of zero is impossible to make.

There may be a problem if the normalization procedure used for determining the weights in the hierarchy is used for evaluating the relative sizes of alternatives. Use of this procedure may eliminate the ratio interpretation of the alternatives which was obtained from the surveys. The following example illustrates how this normalization is performed and where the problem lies:

A single decisionmaker compares three alternatives against the same three alternatives using Saaty's pairwise comparison technique and the following matrix is determined:

	A	B	C
A	1	5	1
B	1/5	1	1/5
C	1	5	1

Table 3.4.4. Saaty's Pairwise Comparison Technique

This matrix is called a reciprocal matrix because it has positive entries everywhere and satisfies the reciprocal property $a_{ji} = 1/a_{ij}$. The scale used in the formulation of the matrix goes from 1 to 9. Reciprocals are obtained when comparing alternative versus alternative. (Using the above matrix, a strong preference for alternative C over alternative B results in an assignment of 5 in the row C column B position. Corresponding to that entry, the reciprocal value of 1/5 is assigned to the row B column C entry.)

Using these assigned values, the geometric mean vector, V, is then computed to be:

$$V =$$

$$\begin{bmatrix} ((1)(5)(1))^{1/3} \\ ((1/5)(1)(1/5))^{1/3} \\ ((1)(5)(1))^{1/3} \end{bmatrix} = \begin{bmatrix} 1.70997 \\ .34200 \\ 1.70997 \end{bmatrix}$$

The normalized geometric mean vector, V_n, is then formed with the V values:

$$V_n =$$

$$\begin{bmatrix} .4545 \\ .0909 \\ .4545 \end{bmatrix}$$

Notice that the sum of the elements of V_n sum to 1. These values should only sum to 1 if they are used for weighting the hierarchy and not for evaluating alternatives. If they are used for evaluating alternatives, the scale will lose some of its ratio interpretation.

The values of V_n for alternatives could have been values such as:

$$V_n =$$

$$\begin{bmatrix} .2250 \\ .0450 \\ .2250 \end{bmatrix} \quad \text{or} \quad \begin{bmatrix} .9000 \\ .1800 \\ .9000 \end{bmatrix}$$

These values are in the same ratio as the previous V_n and there is no reason why they cannot be used.

If this is the method used to evaluate alternatives, a suggestion to correct this problem would be to apply the principles of MAUT to rescale the normalized geometric mean vector. This application of MAUT assigns the maximum value a 1 and the minimum value a 0 which maintains the ratios that have been determined using the AHP. The following rescaling steps should be then be taken:

1) Take the normalized scores from AHP [.4545, .0909, .4545].

2) Subtract the lowest score from all of the scores [.4545 - .0909,.0909 - .0909,.4545 - .0909] = [.3636, 0, .3636].

3) Divide this result by the largest number [.3636/.3636,0/.3636,.3636/.3636] = [1,0,1]

This rescaling is a translation of the normalized scores and gives the best alternative a 1 and the worst alternative a 0. The final product is an AHP ratio assessment which results in an additive MAU function. The values obtained using this MAU function can be directly combined with the scaled explicit effectiveness MOEs in the effectiveness integration module.

The comparison of utility theory with the AHP is not a valid comparison to make. AHP has no risk involved in its assessment techniques. The questions involved in the risky case should involve risk and should try to capture the decision makers attitude toward risk, incorporating that attitude in the assessment technique.

Issue 2: Are the assumptions in this module specifically stated and are they reasonable?

Response: The assumptions made for this module are[12]:

1) The objective function for the SIAM factors are representative of the decision function.

2) The objective function for each of the SIAM factors is correct.

The assumptions made in the explicit effectiveness module need to carry over to this module if MAUT is applied.

28

3.5. Effectiveness Integration

This module combines the implicit and explicit effectiveness values with the decision makers' weights and integrates these multiple measures of effectiveness into a single measure of value. This value is then used to conduct a cost effectiveness evaluation.

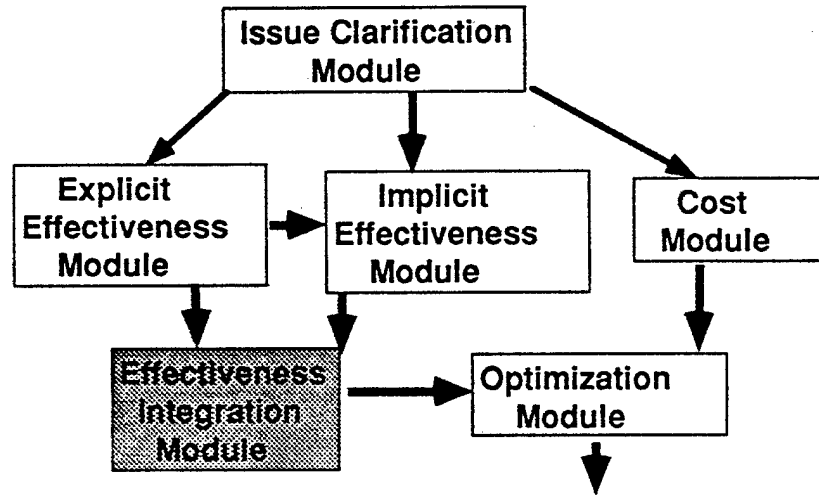Figure 3.12 illustrates where the effectiveness integration module fits in the overall methodology.

Figure 3.12. Effectiveness Integration

3.5.1. Input

The input consists of: soldier quality of life scores, CORBAN effectiveness scores, other Army objectives scores, and the implicit rank order of alternatives. The input is in the form of an ASCII text file which is commonly prepared by using a microcomputer spreadsheet program.

3.5.2. Procedures

The TOPSIS value measures the distance of an alternative from an ideal solution. This is the single measure of value and becomes the effectiveness coefficient in the objective function. TOPSIS characteristics include: a rank-ordered preference list of all candidate systems from a constrained set of initial alternatives, the ability to compare the relative strength of preference (on an interval scale) among the candidates, a set of quantifiable criteria related to attributes associated with each alternative, a set of weights that express

29

the relative measure of importance the decision authority attaches to each criteria, a degree of confidence in the statistical independence and reliability of the measures associated with the different criteria, and a requirement for sensitivity measures associated with variance in input values or decision authority tolerance to error.

3.5.3. Outputs

The output consists of the TOPSIS coefficient and the relative ranking among the listed alternatives. The TOPSIS coefficient is used in the optimization module as a means of calculating the cost effectiveness evaluation. This value can also be used to rank order alternatives.

3.5.4. Issues

Issue 1: Does the TOPSIS methodology, as currently implemented, reflect a suitable and intrinsically meaningful process for the generation of value coefficients for use in the optimization?

Response: The use of Ideals and Negative Ideals has some advantages. The entire space between the two ideals defines the feasible region. This enhances sensitivity and aids in differentiating between alternatives. TOPSIS is easy to use, simplistic in design, and gives a clear ranking of alternatives. The output from the TOPSIS algorithm, however, is not appropriate for use in the objective function. This relative ranking consists of coefficients that are based upon an ordinal scale.

Issue 2: Is the relative ranking from the TOPSIS algorithm an appropriate coefficient for the objective function?

Response: Several weaknesses of the TOPSIS algorithm exist that make it inappropriate for use in the objective function. These weaknesses are rank reversal, arbitrary ranking, and inappropriate scaling. The following example shows the problem with rank reversal and arbitrary ranking:

30

Using a base case with three alternatives (see table 3.5.1), random number TOPSIS input may be [20]:

	Combat Effectiveness	Soldier Quality of Life	Secondary Impact Analysis Modifiers
	(-)	(-)	(+)
base case	3	250	100
alt 1	4	350	95
alt 2	3	350	87
alt 3	1	339	91

Table 3.5.1. TOPSIS Rank Reversal.

These values are then normalized and weighted. The TOPSIS scores are shown in table 3.5.2 below:

	Results		
	D*	D⁻	TOPSIS Score
base case	.067612	.086587	.561525
alt 1	.127548	.012852	.091535
alt 2	.104527	.033806	.244383
alt 3	.069978	.101974	.593037 ** ranked number 1

Table 3.5.2 Normalized TOPSIS Values

The D^* and D^- indicate the distance from the Ideal and Negative Ideal respectively.

The addition of a fourth alternative, alt 4, leads to the following (see table 3.5.3):

	Combat Effectiveness	Soldier Quality of Life	Secondary Impact Analysis Modifiers
	(-)	(-)	(+)
base case	3	250	100
alt 1	4	350	95
alt 2	3	350	87
alt 3	1	339	91
alt 4	5	275	95

Table 3.5.3 TOPSIS Addition of Fourth Alternative

The results from TOPSIS are shown in table 3.5.4 below:

	Results		
	D*	D⁻	TOPSIS Score
base case	.051640	.089626	.634449 ** ranked number 1
alt 1	.105218	.028247	.211641
alt 2	.089626	.051640	.365551
alt 3	.064359	.103731	.617116
alt 4	.105032	.054358	.341037

Table 3.5.4 TOPSIS Results

The addition of a less optimum alternative, alt 4, changed the position of the top two alternatives. This is due to alt 4 changing one of the negative ideal boundaries. Therefore the ranking is not preserved.

This problem can be eliminated by establishing a fixed Ideal and Negative Ideal [20].

Issue 3: Is there another method of combining effectiveness values into a single measure that may be used in lieu of the TOPSIS algorithm?

Response: The AMVF (shown previously) allows for the combination of the u(x) effectiveness values from the explicit and implicit effectiveness modules. These u(x) values are multiplied by the weights obtained using the AHP and then summed for each alternative. The alternatives are then rank ordered. This can all be performed without using the TOPSIS algorithm.

Issue 4: Are the assumptions in this module specifically stated and are they reasonable?

Response: There were no assumptions made in this module but the same assumptions that were made in the explicit and implicit effectiveness module apply to this module.

3.6. Optimization

This module is used to conduct the cost effectiveness evaluation. It allows the user to simultaneously trade off alternatives based on their cost effectiveness and schedule an alternative's acquisition.

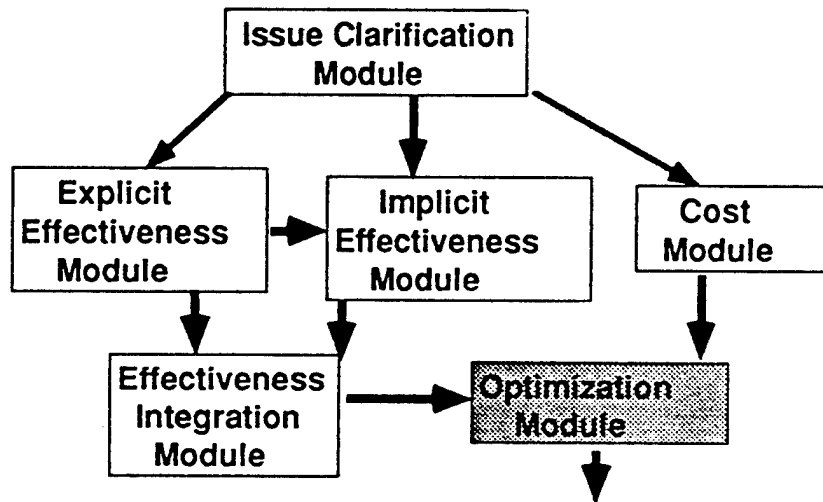Figure 3.13 illustrates where the optimization module fits in the overall methodology.

Figure 3.13. Optimization

3.6.1. Input

The rank ordered data coefficients from TOPSIS are used to form the objective function coefficient. This coefficient is maximized with the quantity of the system procured in a given year. This maximization is subjected to budgetary, force structure, and production constraints using FOMOA. The result is a feasible acquisition strategy.

3.6.2. Procedures

Three sets of constraints are used to maximize effectiveness. The first set insures procurement expenditures will be no greater than the total obligation authority. The second set minimizes (or maximizes) the number of each system needed based on force structure requirements. The third set addresses the total number of systems of each type that can be economically produced by the industrial base.

3.6.3. Outputs

The output of this module consists of the number of each type of system that can be produced during a given time period.

3.6.4. Issues

Issue 1: Do the variables and the coefficients used in the optimization fully accomplish their intended effect?

Background: There are two approaches to use when making a cost-effectiveness evaluation[15]. They are a fixed effectiveness approach and a fixed budget approach. The fixed effectiveness approach has a specified level of effectiveness to be attained in the accomplishment of a given objective. This approach attempts to determine which alternative (or combination of alternatives) is likely to achieve the specified level of effectiveness at lowest economic costs. The fixed budget approach has a specified cost level to be used in attainment of a given objective. This approach attempts to determine that alternative (or combination of alternatives) which is likely to produce the highest effectiveness. The overall objective in either approach is minimizing costs per unit of effectiveness or maximizing effectiveness per unit of cost.

Response: The VAA methodology uses a fixed budget approach and considers different TOA funding levels, each of which is evaluated as a separate optimization run. Systems that appear at one TOA level may not necessarily appear at the others. Percent changes in combat effectiveness values appear to be minimal regardless of the TOA level. This indicates that the methodology may be improved if is were based on a fixed effectiveness approach rather than a fixed budget approach. The objective function could be changed to reflect a cost/ quantity relationship rather than an effectiveness/ quantity relationship. This relationship may achieve that specified level of effectiveness at the lowest economic cost.

Issue 2: Are the assumptions in this module specifically stated and are they reasonable?

Response: There were no assumptions made for this module[12].

4. Validation and Verification

4.1. Summary

The overall VAA methodology is valid for assisting decision makers in evaluating and comparing competing alternatives in the POM building process. The verification of the methodology must be an ongoing process as VAA matures and expands into other areas. VAA is capable of examining tradeoffs across a full range of program issues. Future expansion for VAA may include different functional or mission areas. Trade-offs of this type could even involve such areas as military pay vs OMA vs RDA.

The methodology uses several analytic methods to measure the contribution of an alternative to the current program base. These measurements are performed quantitatively through the use of the combat model CORBAN and the costing models CQM and LCCM. The measurements are performed qualitatively through the use of the AHP and Saaty's pairwise comparison technique. The TOPSIS algorithm combines these two measures into a single measure for use in the optimization. The combined measure is then evaluated against cost using FOMOA.

There are several major issues that exist in the current methodology that need to be addressed. These issues involve the comparison, scaling, and combination of different MOEs and the assessment framework used to prioritize among competing alternatives. These issues may cause rank reversals and arbitrary ranking among alternatives. There are other issues that should also be addressed. They involve the uncertainty inherent in the cost decision process and the fixed budget approach performed in the optimization.

4.2. Conclusions

Several enhancements can be made to the current methodology . These enhancements include the proposed application of the principles of MAUT to the MOEs generated by CORBAN in the explicit effectiveness module, and the synthesis of MAUT with AHP in the implicit effectiveness module. This application can be performed through the use of either an additive or multiplicative multi-attribute model. This would eliminate the need for the TOPSIS algorithm. The TOPSIS algorithm needs to be eliminated because the output from TOPSIS is just a ranking of alternatives. The coefficients forming the objective function need to have a ratio interpretation. TOPSIS considers the decisionmaker to be risk-neutral and this may not be the case. The application of MAUT will incorporate the risk preference of the decisionmaker into the decisionmaking process. Other enhancements that can be made include: incorporating cost uncertainty and the range of error it is likely to produce in the cost estimate,adding new MOEs which incorporate the principles of Airland Battle Doctrine, and using a cost/quantity approach rather than an effectiveness/quantity approach in the optimization.

5. References.

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3. Army Program Value Added Analysis 90-97, August 1991, Study Report CAA-SR-91-9 prepared by Force Systems Directorate US Army Concepts Analysis Agency, chapter 1, section 1-2, page 1-1.

4. Army Command and Management: Theory and Practice, US Army War College, 1989-1990, Army Planning, Programming , Budgeting, and execution System, page 14 -15.

5. Memorandum dtd 1 November 1990, SUBJECT: CORBAN Information Paper, section 1, H. Kent Pickett, TRAC-FLVN.

6. Memorandum dtd 1 November 1990, SUBJECT: Accreditation Package for CORBAN, section 2b-2, H. Kent Pickett, TRAC-FLVN.

7. Army Program Value Added Analysis 90-97, August 1991, Study Report CAA-SR-91-9 prepared by Force Systems Directorate US Army Concepts Analysis Agency, Section 4, page 4-2.

8. Army Program Value Added Analysis 90-97, August 1991, Study Report CAA-SR-91-9 prepared by Force Systems Directorate US Army Concepts Analysis Agency, Section 3-3, page 3-6.

9. Montgomery, Douglas C. Design and Analysis of Experiments, Georgia Institute of Technology, John Wiley & Sons, New York, 1984, p445.

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12. Army Program Value Added Analysis 90-97, August 1991, Study Report CAA-SR-91-9 prepared by Force Systems Directorate US Army Concepts Analysis Agency, Appendix D-9, page D-2-2 and section 6-2a, page 6-3.

13. Army Program Value Added Analysis 90-97, August 1991, Study Report CAA-SR-91-9 prepared by Force Systems Directorate US Army Concepts Analysis Agency, Section 5-1d page 5-2.

14. Army Program Value Added Analysis 90-97, August 1991, Study Report CAA-SR-91-9 prepared by Force Systems Directorate US Army Concepts Analysis Agency, Section 5-2 page 5-11.

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17. Box, George P. and Draper, Norman R., Empirical Model-Building and Response Surfaces, John Wiley & Sons, NY, page 13.

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20. Kloeber, J,M., "A Critical Analysis of The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Report Number 91-1, July 1991 Department of Systems Engineering West Point N.Y. 10996

Appendix A. Analytic method used at TRADOC:

TRADOC analysts use a concept based requirements system (CBRS), AHP, battlefield importance, and a capital allocation algorithm to prioritize modernization initiatives in terms of their level of importance to the conduct of airland operations[19]. CBRS defines how the Army intends to fight and allows TRADOC to plan and program modernization initiatives in a given cycle of time. Battlefield importance is related to resource value and is expressed in terms of a benefit-to-resource ratio. The capital allocation algorithm is applied to their prioritized list to determine overall affordability. TRADOC chose the AHP and Saaty's pairwise comparison process as the analytical technique for prioritizing the benefits associated with modernization initiatives.

The CBRS contributes to the development of the Army Modernization Memorandum (AMM) and the Long Range Army Materiel Requirements Plan (LRAMRP). The AMM is a plan for improving the Army in the areas of doctrine, training, leader development, organization, and materiel. The AMM prioritizes recommendations for future Army modernization. AMM 94-08 prioritized about 500 candidate modernization initiatives, of which 400 were materiel initiatives and 100 were in the areas of doctrine, leader development, training, and organization. The LRAMRP is the materiel annex to the AMM. It provides ordered year-by-year RDA funding recommendations to HQDA for the management decision packages (MDEPs). MDEPs are developed by the proponents in conjunction with program managers and are the subcomponents of the AMM modernization initiatives.

The AMM development process is hierarchically structured. The first level is the force types to be modernized, which is examined in terms of conflict intensity. The second level is the battlefield functional mission area (BFMA) elements. The third level is comprised of 28 capability packages which make up the BFMA. These packages are developed jointly by TRADOC schools and centers (see figure A.1).
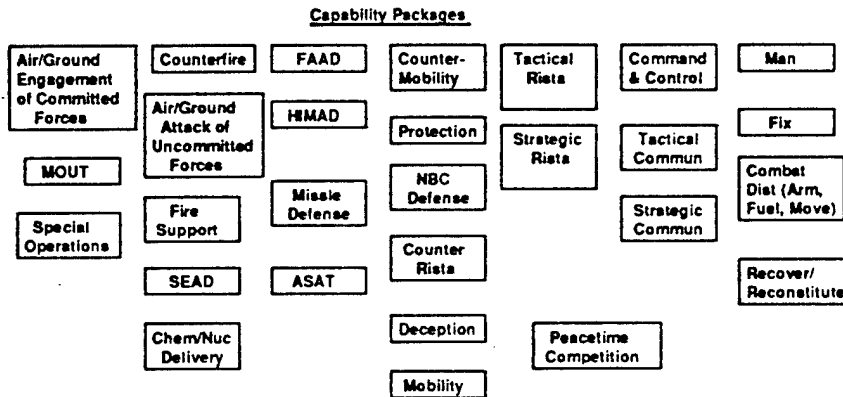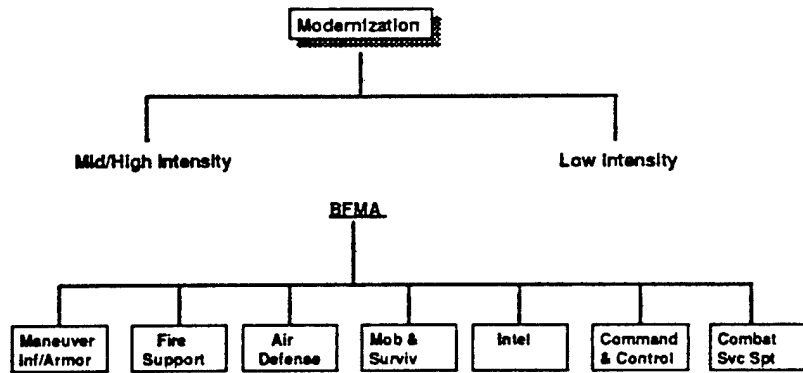
Figure A.1. AMM Development Process

Once the packages are developed, the AMM process continues in three stages. In the first stage evaluation boards are convened to prioritize modernization actions within each capability package. The boards are provided with information regarding capability package definitions, assessments,war fighting results, analyses examining current and future required capabilities for selected capability packages, and results of analyses of special issues (such as branch planning analyses). Boards use the pairwise comparison process to assess the relative importance of modernization actions and establish priority weights. In stage two a senior review board is assembled to validate the resulting priorities. The validation process examines where the emphasis is placed within and across modernization actions. This board uses the same pairwise comparison process as the evaluation boards. The upper level of the hierarchy (force type and conflict intensity) is evaluated by senior Army commanders. A complete list is then assembled by merging the results of stage one, stage two, and the goal priorities from the senior commanders. Stage three compares the projected cost with the priority list using their capital allocation software. This culminates in TRADOC's input into the Army-wide modernization strategy.

40

Appendix B. Establishment of weights.

The implicit effectiveness module develops the hierarchical weights for all of the levels of the assessment hierarchy and individual criteria. The assessment hierarchy consists of three levels (see figure B.1).
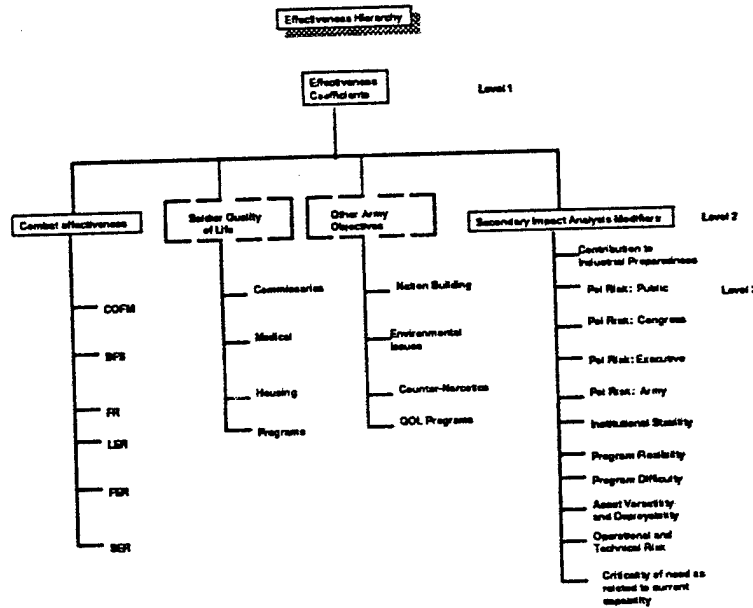

Figure B.1 Effectiveness Hierarchy

Level one is the output from the effectiveness integration module. These are the effectiveness coefficients that are used in the optimization module. Level two is a hierarchical breakdown of level one and are the components of value which are found in the explicit and implicit effectiveness modules. The dashed lines in the above figure indicate those components of value which have not been evaluated at this time. Level three are the measures of effectiveness generated by either a quantitative or qualitative model.

The establishment of weights is accomplished by making pairwise comparisons within the hierarchy i.e, comparing the elements in pairs against a set criteria. An example of such a comparison is shown in figure B.2 :

```
┌─────────────────────────────────────────────────────────────┐
│ Asset Versatility              Political Risk:                │
│ and Deployability        vs.   Public Opinion                │
│                                                               │
│ Asset versatility and          The public opinion measure of │
│ deployability measures the     political risk is a subjective │
│ applicability of a program to  evaluation of the attitudes of │
│ multiple theaters of operation. the general public toward a  │
│                                proposed program.             │
│                                                               │
│                                                               │
│          Very                          Very                   │
│ Absolute Strong Strong Weak  Equal Weak Strong 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 B.2. Sample Pairwise Comparison

The relative importance the decisionmaker assigns to each of the elements during the comparison is then translated to a 1 - 9 scale. The translated numbers and their inverses are placed into a decision matrix and the geometric mean method is used to determine the weights. The weights for all MOEs under each component of value must sum to one.

Pairwise comparisons are also made between the components of value i.e, combat effectiveness vs. SIAM factors. Weights are obtained for each of the components of value and together they also sum to one.

Appendix C. Secondary Impact Analysis Modifiers (SIAM) Factors.

SIAM factors are key factors which are considered in the decisionmaking process, but are not official Army measures of effectiveness[4].

1. **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.

2. **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.

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

4. **Political Risk: Executive Branch Opinion.** The executive branch opinion of political risk is a subjective evaluation of the attitudes of the Office of Management and Budget, the Office of the Secretary of Defense, and the Joint Chiefs of Staff toward a proposed program. It ranges from significant positive support for the program to significant opposition to the program.

5. **Political Risk: Internal Army Opinion.** The internal Army opinion 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.

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

7. **Program Flexibility.** A measure of the funding flexibility associated with a program. It measures how much latitude is available to reprogram resources or change decisions with regards to the program. For example, a multiyear contract with a significant penalty clause would have low flexibility.

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[4]CAA Study Report 91-9 p.7-3

8. 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.

9. 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 a relatively high rating for asset versatility.

10. 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 would roughly correspond to the stage of materiel development for the system. For example, a system in stage 6.1 will have a higher risk than a system in stage 6.3.

Appendix D. Glossary.

Abbreviations, Acronyms, and Short Terms:

ACP	Army cost position
AHP	analytic hierarchy process
AMC	US Army Materiel Command
ARIM	Army Resource Integration and Management Study
AMM	Army Modernization Memorandum
AMVF	additive measurable value function
BDP	battlefield development plan
BFMA	battlefield functional mission areas
BFS	blue force surviving
BCE	baseline cost estimate
CAA	Concepts Analysis Agency
CBRS	concept based requirements system
CEAC	US Army Cost and Economic Analysis Center
CER	cost estimating relationship
COFM	correlation of forces and means
CORBAN	Corps Battle Analyzer
CQM	Cost Quantity Model
CSA	Chief of Staff of the Army
DA	Department of the Army
DCSOPS	Deputy Chief of Staff for Operations
DPAE	Director, Program Analysis and Evaluation
EBR	effective battalions remaining

FER	force exchange ratio
FOMOA	Force Modernization Analyzer
FR	force ratio
FY	fiscal year
ISC	Information Systems Command
LER	loss exchange ratio
LCCM	Life Cycle Cost Model
LP	linear program
LRRDAP	Long-Range Research, Development and Acquisition Plan
LRAMRP	Long-Range Army Materiel Requirements Plan
MACOM	major Army command
MAU	multi-attribute utility
MAUT	multi-attribute utility theory
MCA	military construction, Army
MOE	measure(s) of effectiveness
OMA	operation and maintenance, Army
OPLAN	operation plan
POM	Program Objective Memorandum
PPBES	Program, Planning, Budgeting and Execution System
RAM	reliability, availability, and maintainability
RDA	research, development, and acquisition
RDTE	research, developing, testing, and evaluation
RSM	response surface methodology

SER	systems exchange ratio
SIAM	secondary impact analysis modifiers
TOA	total obligation authority
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
TRADOC	US Army Training and Doctrine Command
UT	utility theory
VAA	Value Added Analysis

Appendix E. Briefing Slides

Operations Research Center
United States Military Academy
West Point, New York 10996

Validation and Verification of the Army Program Value Added Analysis

Project Sponsor	Program Analysis and Evaluation
Analyst	CPT Michael G. Titone

Essence of VAA

VAA is a way of bringing together all of the different constraints that impact acquisition strategy. It defines the feasible region for decision makers.

POM
Building
Process

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Purpose of Analysis

To provide a timely and unbiased analysis of the Army Program Value Added Analysis and make recommendations for desirable modifications to the methodology.

PA&E

USMA   CAA

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The Task

Validation - Building the right model.
*the process of determining the extent to which models and simulations accurately represent the real-world from the perspective of the intended use of the model.

Verification - Building the model right.
* the process of determining that models and simulations accurately represent the developer's conceptual description and specifications.

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Citation of Related Work

Kloeber, Jack M. Jr.
Major, USA
A Critical Analysis of "The Technique for Order Preference by Similarity to Ideal Solution" TOPSIS.
West Point, NY: Report Number 91-1, July 1991

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Dyer James S. "Remarks on the Analytic Hierarchy Process", Management Science vol 36, No. 3, March 1990

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Example: Representative Armor/Anti-Armor Systems

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

Alternatives	Characteristics
Basecase	Europe Scenario with 25 systems
Alt 1	M1A2
	NLOS-AT
	MLRS SADARM
Alt 2	M1A2
	AMS-H
	BRADLEY BLK II
	MLRS SADARM

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Description of Approach

➡ Overview.

➡ Validation.

➡ Verification.

➡ Summary.

➡ Conclusions.

Overview

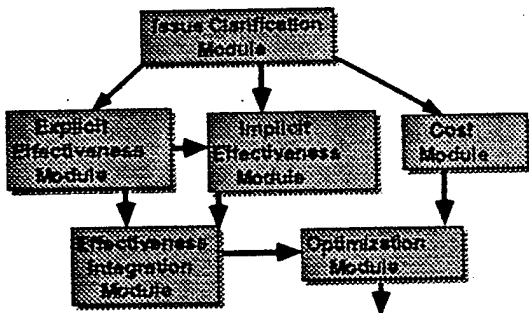➡ Eight modules are in the standardized VAA approach*.

➡ Each of the modules are self-contained and interrelated.

* Note - The resource allocation and results and display modules are not evaluated due to the limited scope of the first VAA study.

Overview

Module	Analytic Method
Issue Clarification.	Information Matrix
Costing	Cost Quantity Model
	Life Cycle Cost Model
Explicit Effectiveness	CORBAN
Implicit Effectiveness	Saaty's Pairwise Comparison
	Technique
Effectiveness Integration	TOPSIS
Optimization	FOMOA

Validation

<u>Overall Methodology</u> - Major Issues

➡ Does VAA provide information of the right type, quality and direction to support the Army Staff in the POM development effort?

➡ Is the overall architecture well defined?

➡ What are the theoretical foundations used and do they match the requirements?

Validation

<u>Overall Methodology</u> - Responses

➡ The overall methodology is well structured and well defined.

➡ A hierarchical assessment framework is used to measure the contribution of a program alternative.

Validation

Overall Methodology - Responses

An alternative is measured both explicitly and implicitly.

Issues associated with AHP
Issues associated with MOEs
Issues associated with scaling

Values are combined into a single measure of benefit. That measure is optimized against cost.

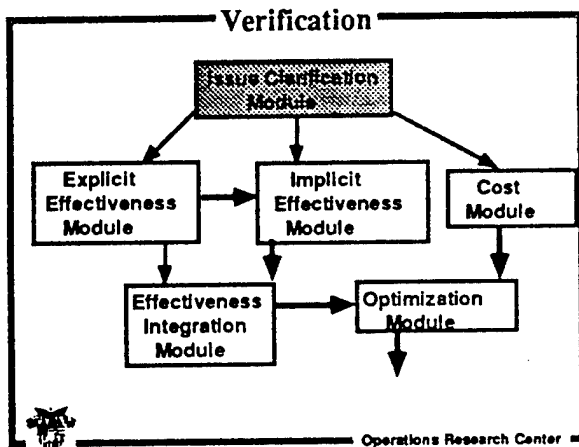Issues associated with TOPSIS

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Validation

Overall methodology - Comments

Flaws within the structure can be corrected, and with minimal effort, should produce more precise results.

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Verification

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Verification

Issue Clarification - Major Issues

What are the ramifications of discarding certain alternatives when evaluating multiple systems in various combinations?

Who decides on issues being kept or discarded?

How do issues drive the experimental design matrix?

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Verification

Issue Clarification - Responses

Response surface methodology is used to take specific combinations of the total combinations possible.

Sponsors and VAA analysts decide the issues. Selection of issues is based on the importance of the issue and the ability to model the systems involved.

Issues are framed by the selection of the systems and the year/scenario combinations to be played.

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Verification

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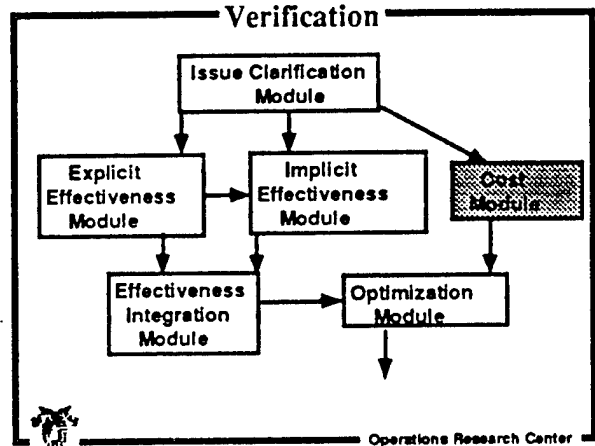
Verification

Costing - Major Issues

➡ Can the derivation of the most sensitive cost elements be improved without significant computational burden?

➡ Who obtains the information from the Baseline Cost Estimate (BCE) and Army Cost Position (ACP) and how accurate are they for life cycle cost data?

Verification

Costing - Response

➡ - Production cost elements are the most sensitive. The CQM and LCCM estimate the impact of production variations on life cycle cost elements and appropriations. These methods need no improvement.

➡ CAA collects all cost data in coordination with CEAC. BCE and ACP data come from Program Managers.

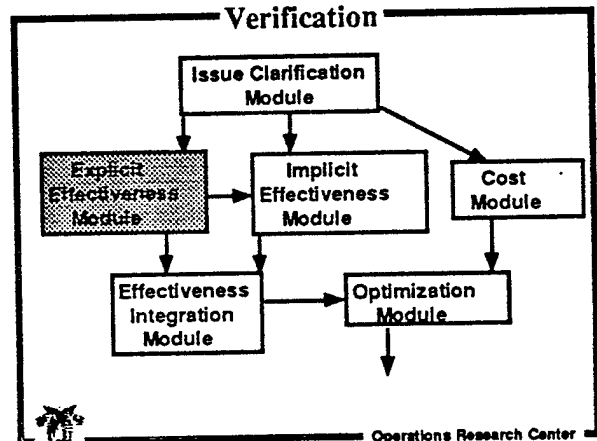## Verification

Costing - Enhancements

➡ The overall cost decision process could be improved if cost uncertainties, and the range of error they are likely to introduce, are incorporated in the cost estimate.

Verification

Verification

Explicit Effectiveness - Major Issues

➡ What are the problems associated with the Measures of Effectiveness (MOEs) generated by the combat model?

➡ Are there MOEs that give better insights?

Verification

Explicit Effectiveness - Response

➡ MOEs are too dependent and similar in nature. MOEs should support the type of Army you want to build based on the Airland Battle tenets.

➡ The MOE, Loss Exchange Ratio, is redundant and can be eliminated. MOEs incorporated into the combat model could be the percentage of blue force casualties, and combat system utilization.
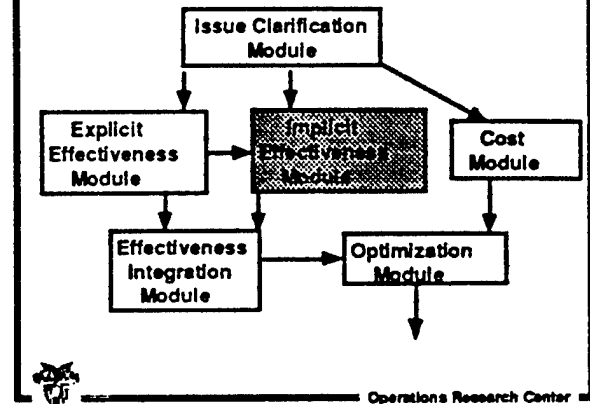
51

Verification

Explicit Effectiveness - Enhancements

Multiattribute utility theory can be used to develop DM preference functions for each MOE. MOEs could then be scaled and effectively combined among alternatives.

Verification

Verification

Implicit Effectiveness - Major Issue

What are the remarks critical of the AHP and Saaty's pairwise comparison approach?

Verification

Implicit Effectiveness - Response

The possibility exists that rank reversal and arbitrary ranking may occur with the use of AHP and Saaty's approach.

AHP is a good techniques for obtaining the weights in the hierarchy. Alternatives being evaluated need to be rescaled.

Verification

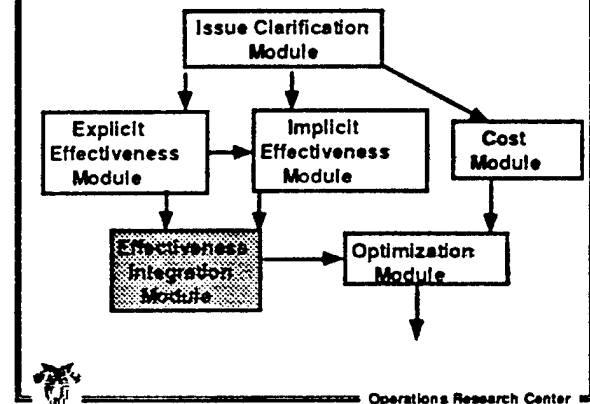**Implicit Effectiveness** - Enhancements

The synthesis of MAUT with the AHP will eliminate the possibility of rank reversal and arbitrary ranking among alternatives.

Application of MAUT will provide a frame of reference and an appropriate scale of measure to combine all implicit and explicit MOEs.
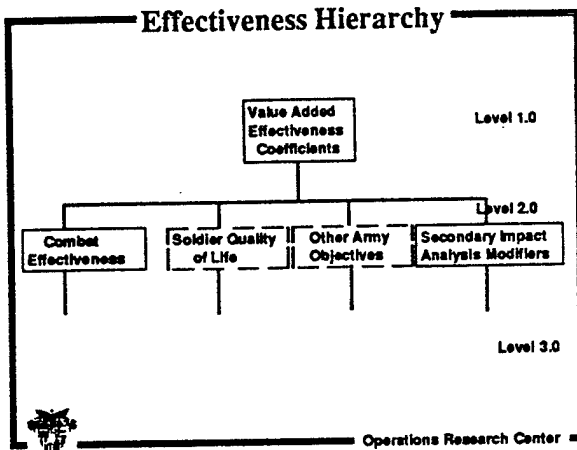
Verification

Effectiveness Hierarchy

```
                  ┌──────────────┐
                  │ Value Added  │       Level 1.0
                  │Effectiveness │
                  │ Coefficients │
                  └──────┬───────┘
          ┌──────────┬───┴──────┬───────────┐      Level 2.0
    ┌─────────┐ ┌──────────┐ ┌────────┐ ┌──────────┐
    │ Combat  │ │Soldier Quality│ │Other Army│ │Secondary Impact│
    │Effectiveness│ │ of Life │ │Objectives│ │Analysis Modifiers│
    └────┬────┘ └────┬─────┘ └───┬────┘ └────┬─────┘
         │           │           │           │           Level 3.0
```

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Verification

Effectiveness Integration - Major Issue

➡ Does the TOPSIS methodology reflect a suitable and intrinsically meaningful process for the generation of value coefficients for use in the optimization?

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Verification

Effectiveness Integration - Response

➡ The TOPSIS output consists of coefficients that are based on an ordinal scale. They need to be on a ratio scale for use in the optimization.

➡ TOPSIS may have a problem with rank reversal and arbitrary ranking.
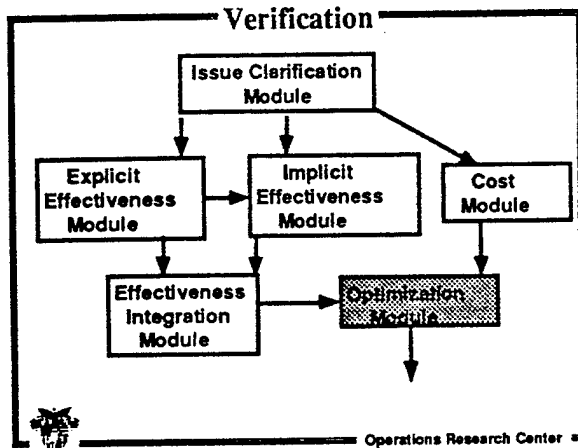
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Verification

Effectiveness Integration - Enhancements

➡ The synthesis of MAUT with AHP eliminates the possibility of rank reversal and arbitrary ranking among alternatives that may occur using TOPSIS.

➡ The AMVF from MAUT allows MOEs to be directly combined using either an additive approach or a multiplicative approach and The TOPSIS algorithm does not need to be used.

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Verification

```
           ┌──────────────────┐
           │ Issue Clarification│
           │     Module        │
           └──┬──────┬──────┬──┘
     ┌────────┘      │      └──────────┐
     ▼               ▼                 ▼
┌─────────┐    ┌──────────┐      ┌────────┐
│ Explicit │    │ Implicit │      │  Cost  │
│Effectiveness│→│Effectiveness│   │ Module │
│ Module  │    │ Module   │      └────┬───┘
└────┬────┘    └────┬─────┘           │
     └──────┐       │                 │
            ▼       ▼                 ▼
       ┌──────────┐    ┌──────────────┐
       │Effectiveness│→ │ Optimization │
       │Integration │   │   Module     │
       │  Module   │    └──────┬───────┘
       └──────────┘           ▼
```

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Verification

Optimization - Major Issue

➡ Do the variables and coefficients used in the optimization accomplish their intended effect?

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53

Verification

Optimization - Response

The methodology uses a fixed budget approach in making their cost effectiveness evaluation.

Percent changes in combat effectiveness appear to be minimal regardless of the TOA level. This indicates a fixed effectiveness approach should be considered.

Verification

Optimization - Enhancements

The objective function should be changed to reflect a cost/ quantity relationship rather than an effectiveness/ quantity relationship.

Summary

There are several major issues that exist with the current methodology that need to be resolved. These issues involve the comparison, scaling, and combination of different MOEs and the assessment framework used for prioritization. These issues can cause rank reversal and arbitrary ranking.

The application of MAUT should resolve the issues. This application can be performed using either a linear or multiplicative model.

Conclusions

The overall methodology is valid for assisting decision makers in evaluating and comparing competing alternatives in the POM building process.

The verification of the methodology must be an ongoing process as VAA matures and expands into other areas.

Appendix F. Distribution

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