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MULTIPLE CRITERIA DECISION MAKING APPROACHES TO THE TRADOC BATTLEFIELD DEVELOPMENT PLAN

by

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INTRODUCTION

1.1 Introduction

The US Army Training and Doctrine Command (TRADOC) represents the battlefield user in developing doctrine, training, force structure, and material requirements for the future. To ensure these requirements stem from an overall battlefield concept and are based on sound analysis, information is provided to TRADOC from two main sources: Department of the Army and special mission area analysis (MAA) studies. Battlefield deficiencies should be identified and evaluated based on the information and conclusions given by these sources (8).

The Department of the Army provides guidance in the form of major Army planning vectors which translate into key operational capabilities. The Army staff determined that these key capabilities (supported by specific task-oriented objectives) are crucial to battlefield success. These capabilities along with supporting critical tasks were established only recently following thorough studies and analyses at many levels of command. This guidance pertains to the demands of the battlefield of the future (6).

MAA studies provide a detailed, long-term look at mission area requirements. These thorough analyses, conducted on the average of once every three years, focus on needs and methods to accomplish anticipated battlefield missions (13). Current mission area capabilities must be evaluated in terms of the conclusions of these studies.

An essential task conducted annually by TRADOC is the formulation of the Battlefield Development Plan (BDP). The BDP is primarily a prioritized list of battlefield deficiencies across 13 distinct mission areas within TRADOC (8). The key operational capabilities and separate MAA studies play an important role in the development of the BDP. Participants in the BDP formulation are shown in Figure 1.1. Each year, the 13 mission area proponents (subordinate headquarters) are requested to identify and evaluate their mission deficiencies in terms of the key operational capabilities and the conclusions of the MAA and any other appropriate studies. Once each proponent has prioritized the deficiencies within their mission area, TRADOC must integrate and prioritize the 13 deficiency lists into a single, ordered list of battlefield deficiencies, the BDP. The BDP contains only deficiencies that warrant Department of the Army visibility (5). In past years, this list has comprised over 400 deficiencies (11).

Because the great majority of battlefield deficiency corrective actions are material related, the BDP is firmly linked to long range material programs. Consequently, the BDP will guide the development of programs and the allocation of resources toward correcting deficiencies in the order of their importance. It is clear that the BDP process must be sufficiently structured and rigorous to produce consistent results from year to year. At the same time, this effort must be simple and well defined in order to be understood and accepted by the decision makers who use it (8).

1.2 Statement of the Problem

The BDP formulation is a prioritization problem. TRADOC must develop a process that will integrate and prioritize the 13 mission area proponent deficiency lists into a single, ordered list of mission deficiencies for the Army.

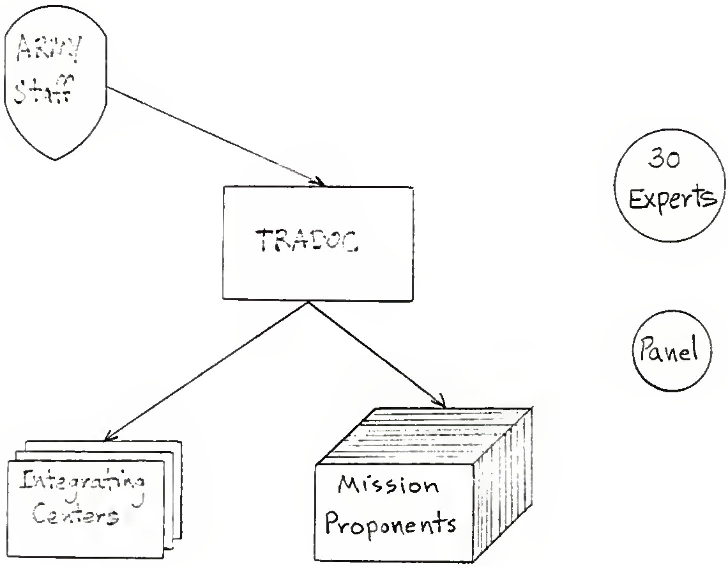


Figure 1.1 BDP Participants

1.3 Purpose

The BDP has a great influence in allocating millions of dollars each year for material programs that correct deficiencies. But other aspects of the BDP process also point to its significance. This 23-week process involves hundreds of high level military and civilian staff employees and commanders, including numerous general officers. Just as significant is the monumental effort of the MAA studies conducted by the proponents which contribute directly to the selection and prioritization of deficiencies for the BDP.

In this paper, the concept of Army planning and the shaping of the BDP from established battlefield guidelines is reviewed. TRADOC's current BDP process (and related metodologies) is examined to determine its merit. Since the BDP process has varied from year to year, the BDP-85 procedure is selected for study as the most complete procedure used by TRADOC. Application of multiple criteria decision making (MCDM) methods to the BDP problem are researched and presented. Using these methods, alternative approaches for solving the BDP prioritization problem are formulated. It is hoped that TRADOC and the US Army will benefit from this study.

The objectives of this thesis are:

1. Examine the formulation of the TRADOC Battlefield Development Plan and analyze the BDP-85 procedure.
2. Propose alternative approaches to the BDP problem using multiple criteria decision making techniques.

1.4 Definition of Terms

BDP - Battlefield Development Plan; annual plan that prioritizes battlefield deficiencies across all TRADOC mission areas.

BIBD - Balanced Incomplete Block Design; a technique that fairly distributes the elements of a population to be evaluated.

CBRS - Concepts Based Requirements System; the Army's long-range planning system.

Critical Tasks - These are determined by the Army staff to support certain key operational capabilities necessary to battlefield success.

LRRDAP - Long Range Research, Development and Acquisition Plan; applies to the material programs that support the Army's requirements.

MAA - Mission Area Analysis; detailed study that analyzes mission area requirements to support the Army's battle doctrine.

Pillars of Defense - categories established for battlefield deficiencies.

POM - Program Objective Memorandum; this document is submitted by the Army to Congress for approval of needed funding to meet mission requirements.

TRADOC - Training and Doctrine Command; responsible for implementing Army training, doctrine, force structure and material requirements.

1.5 Contents of the Thesis

Chapter 2 presents an overview of Army planning and establishes the BDP linkage to the Concept Based Requirements System (CBRS). The majority of the chapter is devoted to describing the three-phase procedure (BDP-85) used by TRADOC to solve the BDP problem. The final section presents a hypothetical numerical example to illustrate the methodologies of this present procedure.

In Chapter 3, the BDP problem is analyzed and strengths and weaknesses of the BDP-85 procedure are discussed. Finally, objectives key to establishing an effective BDP procedure are outlined.

Chapter 4 presents an alternative approach to solving the BDP problem. This evolutionary approach uses a portion of the current BDP framework and introduces a Multiple Attribute Decision Making (MADM) technique which evaluates deficiencies according to an established set of criteria.

Chapter 5 introduces a second alternative to solving the BDP problem. This procedure is a reformed approach and relies on a more structured scientific process.

Chapter 6 outlines the conclusions and recommendations of the study. Eight appendices (A thru H) are included to provide detailed explanations for special topics addressed in the study.

Chapter 2

BACKGROUND

2.1 An Overview of Army Planning

a. Concept Based Requirements System (14): Army warfighting requirements are derived from the Concept Based Requirements System (CBRS). The CBRS is a systematic and flexible approach to determining Army needs and resolving deficiencies in battlefield capabilities. As the name implies, a concept of what the Army must do on the battlefield drives the overall process.

The CBRS provides needed documentation for programs to ensure success on present and future battlefields. In the past, the Army development process permitted material and research efforts to drive the development of organizations, training, and doctrine. This approach tended to focus on high cost, politically acceptable items that could be "sold", and ignored essential requirements for battlefield success. Presently within CBRS, analytical studies are conducted to determine capabilities and deficiencies in the programmed force against the threat in defined scenarios. The Battlefield Development Plan (BDP) is an important and integral part of this process as it aims to prioritize the most important Army battlefield deficiencies. The BDP linkage to the CBRS is shown in Figure 2.1. The BDP focuses the Army's efforts in material and training development, force structure, and concepts in doctrine development. The BDP has evolved into a comprehensive strategy document in the CBRS by serving as the keystone for the TRADOC Mission Area Analysis (MAA).

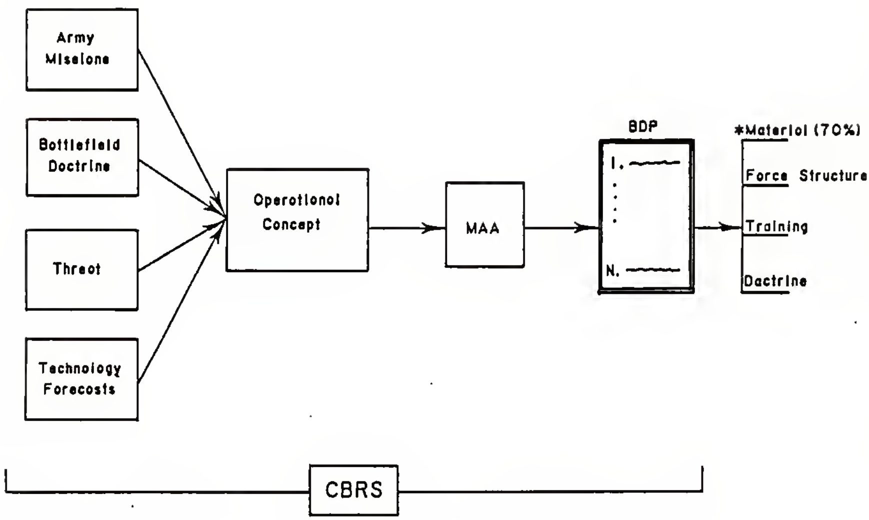


Figure 2.1 BDP linkage to the CBRS

b. Mission Area Analysis Process (13, 14): MAA is a detailed application of the CBRS focusing on the Army's wartime missions. The MAA's are detailed studies of the Army's ability to perform missions according to expected standards. The overall process facilitates the synthesizing of information gained through individual studies and analyses into a single, internally consistent framework which permits the needs of various combat and support missions to be understood in the context of Army needs. The Army's current doctrine is AirLand Battle (ALB). It describes how the Army will fight today and during the near and mid-terms. To develop a detailed analysis of the Army's ability to execute its wartime missions, the battlefield is viewed in terms of 13 specific mission areas. MAA's are currently conducted in each mission area by the responsible proponent.

An overview of the mission area analysis process is shown in Figure 2.2. It is based on the assumption that the Army will modernize according to the development and procurement schedules set forth in the Army Program Objective Memorandum (POM). Using the Army's programmed force, the projected threat, and AirLand Battle doctrine, each mission area proponent examines battlefield tasks to be accomplished, assesses the capability to accomplish these tasks, and develops a list of deficiencies. Identification of these deficiencies are the starting point as each proponent prepares the deficiency lists to be submitted to TRADOC as part of the BDP process.

The MAA process is an on-going analysis. A systematic scheduling for MAA revisions incorporates a MAA for each mission area every three or four years. Between these years, an annual update of findings is required by each mission area proponent. This update incorporates changes in MAA deficiencies that may have resulted from the changes in threat, mission, new studies, new doctrine, technology breakthroughs, or major resource revisions.

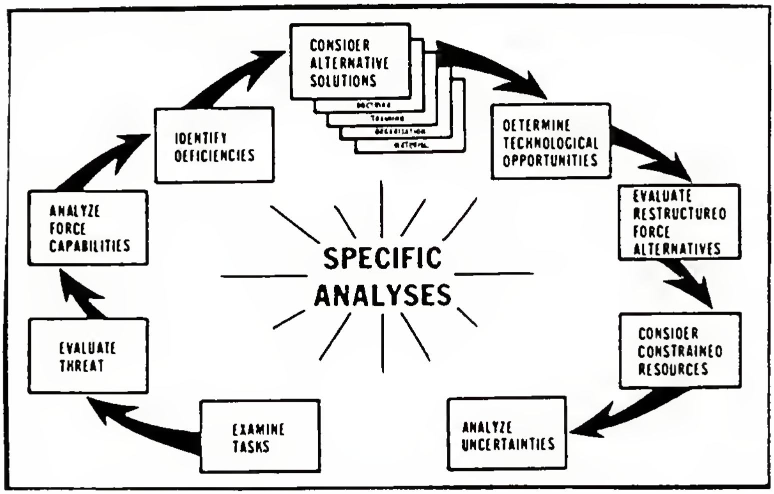


Figure 2.2 The MAA process (TRADOC Pamphlet 11-8, p. C-3)

2.2 Description of the TRADOC BDP (BDP-85) Process (5,6,8,12)

The TRADOC BDP evolved from BDP-I published in November 1978 to the present BDP-86 process. Over this time, it expanded from a framework of limited analysis of Army deficiencies and corrective actions to a BDP that addresses and prioritizes an unconstrained set of specific battlefield deficiencies. The BDP effort anticipates continuing changes in formulation and content as the Army looks to addressing Corps level deficiencies in the BDP-87 document.

The transformation of the BDP since 1981 can be linked directly to the MAA studies conducted by the various mission area proponents. BDP-83 provided an integrated list of deficiencies identified through the 1982 MAA process. BDP-84 was a shortened process, using the BDP-83 list as a reference for adding, changing, and deleting deficiencies. Desiring more specific deficiencies and corrective actions, TRADOC decided to develop a new list for 1985. Subsequently, the BDP-85 process addressed a complete regeneration of deficiency lists by the mission area proponents. In comparison with other BDP's the BDP-85 procedure is considered a "complete" procedure.

The objective of this thesis is to study the BDP-85 methodologies and recommend alternative approaches to solve the BDP prioritization problem. The entire BDP-85 process lasted 23 weeks and involved participants at several different levels of command. The time schedule used for BDP-85 is shown in Table 2.1. The process is described according to three distinct phases. These phases are summarized in the remainder of the section, using the BDP-85 letter of instruction and the unclassified portions of the actual BDP-85 document as references. Finally, a hypothetical numerical example is presented in Section 2.3 to demonstrate the BDP-85 process.

Table 2.1 BDP PRIORITIZATION SCHEDULE FOR BDP-85
(reprint from Ref. 5)

Target Date	Event
	Phase I
Mid Dec 84	BDP-85 Warning Order to Field
Early Jan 85	LOI - Prioritization Methodology for BDP-85
4 Feb 85	Schools provide deficiency and fact sheets to respective integrating center, HQ TRADOC mission area director, and Studies and Analysis Directorate
25 Feb 85	Integrating center provide final fact sheets to HQ TRADOC. Proponents provide prioritized list of MA deficiencies to HQ TRADOC and respective integrating center.
	Phase II
18 Mar 85	Mailout to Phase II General Officers
8 Apr 85	Phase II GOs work due to HQ TRADOC
26 Apr 85	Send out strawman list with functional package for proponents' comment
	Phase III
10 May 85	Proponents return strawman and packages to HQ TRADOC
15 May 1985	Phase III read-ahead provided final panel members
5 Jun 85	Phase III GO panel

a. Phase 1: Identification and Prioritization of Specific MA Deficiencies (5): Phase 1 of the BDP process is shown in flow diagram form in Figure 2.3. This phase begins as TRADOC notifies subordinate integrating centers and proponent agencies of the requirement to implement the BDP formulation. There are 13 mission areas and corresponding proponents organized within TRADOC (see Table 2.2). These proponents are normally commanded by a major general and have a full staff, knowledgable in the proponent missions. Each proponent is responsible for a specific mission area. For example, the aviation proponent at the aviation center at Fort Rucker has the mission to qualify aviation personnel and develop the training and doctrine in the aviation arena. The aviation center is considered the "expert" in the facets of Army aviation and thereby assumes responsibility for all aviation related matters.

In Phase 1, each of the 13 proponents is directed by TRADOC to develop and submit a prioritized list of deficiencies in the scope of their specific mission area. The number of deficiencies contained in the list is unconstrained, but each deficiency must warrant Department of the Army visibility to influence the allocation of resources to correct the deficiency. Additionally, the deficiencies must meet the requirements established in Appendix A. The specificity of the BDP deficiency is important in improving the discriminating power of corrective actions to prioritize specific mission area deficiencies. In previous years, the number of deficiencies reported by each proponent has fluctuated between 10 and 100.

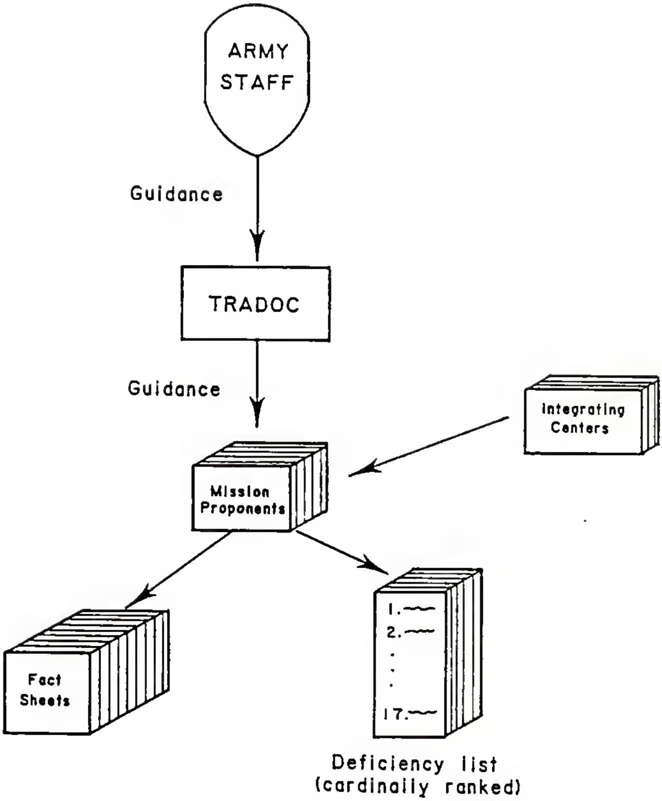


Figure 2.3 Phase 1 of the BDP-85

The first step taken by each proponent is to identify and describe each mission area deficiency using a TRADOC Mission Area Deficiency Fact Sheet (see Figure 2.4). The prepared fact sheet contains sufficient information about the deficiency and the action needed to correct it. As stated in the introduction, these deficiencies should relate to the critical tasks and key operational deficiencies outlined by the Army staff. In this way, all deficiencies listed by the various proponents support the Army's AirLand Battle concept. The fact sheets document the deficiency and follow it through the several stages of review in the BDP process. The fact sheet file is maintained at the proponent, since the same deficiency may need to be included in subsequent mission area proponent deficiency lists (certain deficiencies may require years to correct).

On the fact sheets, proponents must describe the mission area deficiencies by functional packages, DOD pillars of defense, and key operational capabilities. Appendix B describes these categories in detail. These classifications assist participants as adjustments are made to the BDP list. They also enable TRADOC to provide a list which can be better utilized by the Army staff to establish priorities for the Army.

After the deficiencies have been identified and documented, they must be prioritized by the proponent. It is the proponent's option which methodology to use in developing a cardinally ranked list of mission area deficiencies. Certain proponents (e.g. logistics center) have more than one agency or school providing input in compiling their deficiency list. Accordingly, the increased complexity may warrant a method different than other proponents. Experience has shown that the pairwise comparison methodology is the most widely used and understood. Additionally, the Balanced Incomplete Block Design (BIBD) is recommended by TRADOC as a method of reducing the burden of pairwise evaluations as well as increasing the validity of the pairwise evaluations. A detailed explanantion of BIBD is given in Appendix D. Regardless of the methodology, the final proponent mission area list must be prioritized with scalar magnitude which accurately depicts the proponent's prioritization desires.

Next, the fact sheets and deficiency lists are forwarded to the appropriate integrating center headquarters. These centers have the task of analyzing and correcting the documentation submitted by their proponents. Another function of the centers is to eliminate redundancy within and across mission areas by combining similar deficiencies. Since the centers receive copies of the fact sheets and deficiency lists from all proponents, they are able to analyze deficiencies over every mission area to accomplish this function. Documentation that requires correction is returned to the proponent for action. Finally, the integrating centers consolidate fact sheets by mission area into read-ahead books to be used by the general officer experts in Phase 2. A file of the fact sheets and deficiency lists is maintained by the centers as the BDP process continues.

MAA proponents submit their finalized deficiency lists and fact sheets to TRADOC headquarters to complete the 10-week Phase 1 process.

Table 2.2 TRADOC Mission Areas and Proponents

	Mission Area	Proponent School
1.	AIR DEFENSE	Air Defense
2.	ARMY AVIATION	Aviation Ctr
3.	CLOSE COMBAT (H)	Armor Ctr
4.	CLOSE COMBAT (L)	Infantry
5.	COMBAT SERVICE SUP	LOG Center
6.	COMBAT SUP., ENGR.	ENGR
7.	COMBAT SUPPORT NUCLEAR CHEMICAL BIOLOGICAL	Chemical
8.	COMMAND & CONTROL	Combined Arms Ctr
9.	COMMUNCATIONS	Signal School
10.	FIRE SUPPORT	Field Artillery
11.	INTELLIGENCE ELECTRONIC WAREFARE	Intelligence School
12.	SPECIAL OPS FORCES	JFK Special Warfare Ctr
13.	COMBINED ARMS	Combined Arms Ctr

MISSION AREA DEFICIENCY FACT SHEET (Ltr, ATCD-AM, HQ TRADOC, Undtd, Subject: Mission Area Prioritization Process)	EXEMPT INFORMATION REQUIREMENTS Para 5-2g, AR 335-15

DEFICIENCY: (TITLE) Inadequate, Inability to:etc. (60 characters MAX) — Last Year's BDP Priority XXX *

DEFICIENT TASK (Mission Area Task or Subtask that deficiency relates to)

MISSION AREA REF (Page and Para No. from the MAA, SPR, COEA, etc)

DESCRIPTION AND DRIVING FACTOR:

Succinct, concise statements which describe the deficiency without exceeding the confines of this block.

* If applicable, show last year's final priority number.

DOD PILLARS: FORCE STRUCTURE ____ READINESS ____ MODERNIZATION ____ SUSTAINABILITY ____

KEY OPS CAP: BATTELFIELD LETH.____ BATTLEFIELD SUST.____ RSTA ____ C3 ____ SUPE ____

CORRECTIVE ACTION:		MID 5—10 YRS	FAR 10-15 YRS
DOCTRINE - general corrective action MATERIAL - general corrective action FORCE STRUCTURE - general corrective action TRAINING - general corrective action	Briefly describe the action required to correct the deficiency and indicate the applicable time frame.....		

FUNCTIONAL PACKAGES: ____/ ____/ ____/ ____/ ____/ ____/ ____/ ____/

	OFFICE	NAME	AUTOVON
PROPONENT SCHOOL			
HQ TRADOC			

CLASSIFIED BY	DATE:

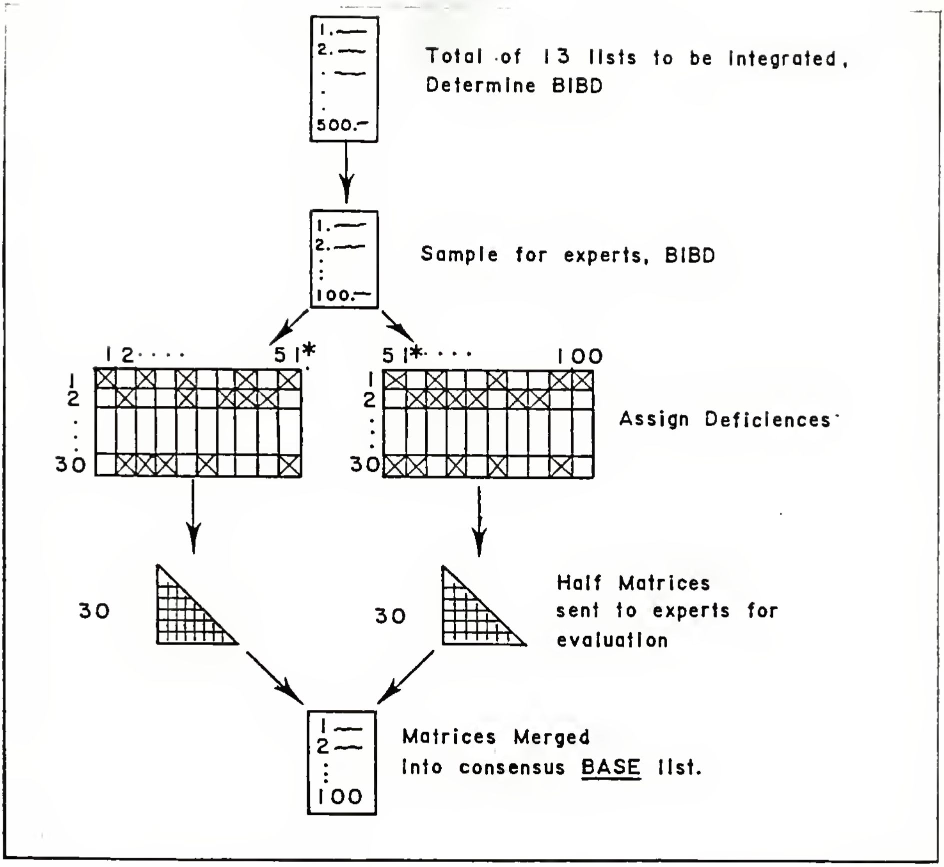
TRADOC FORM Mar 83 870 R — 8½ x 11

Figure 2.4 Deficiency Fact Sheet (TRADOC Form 870R)

b. Phase 2: Developing the BDP Strawman List (5): The 10-week long activities of Phase 2 take place at TRADOC headquarters and the separate locations of the general officer experts. The flow diagram shown in Figure 2.5 outlines the Phase 2 process. As soon as the fact sheets and deficiency lists arrive at TRADOC, the BDP database file is created. TRADOC consolidates all deficiencies (usually about 500) for the next step, a random sampling procedure.

A sample is taken from the population of deficiencies to reduce the number of pairwise evaluations that the 30 general officer experts must perform. If the total number of deficiencies were used in this phase, the task of pairwise comparisons would be monumental and place an undue burden on the experts. It is also evident that reducing the number of pairwise comparisons leads to an increased evaluation accuracy by the experts. This representative sample (usually about 20%) of all deficiencies includes some deficiencies from each proponent mission area list. The sample includes more deficiencies from the top of each mission area list, insuring that the higher priority deficiencies are evaluated with a greater degree of discrimination. The exact size of the sample is determined by the parameters of the Balanced Incomplete Block Design (BIBD) technique (see Appendix D).

The BIBD method is used to insure that each deficiency has an equal chance of being selected as a top priority and to reduce the burden on the general officer experts. Two parameters - the number of experts and the approximate number



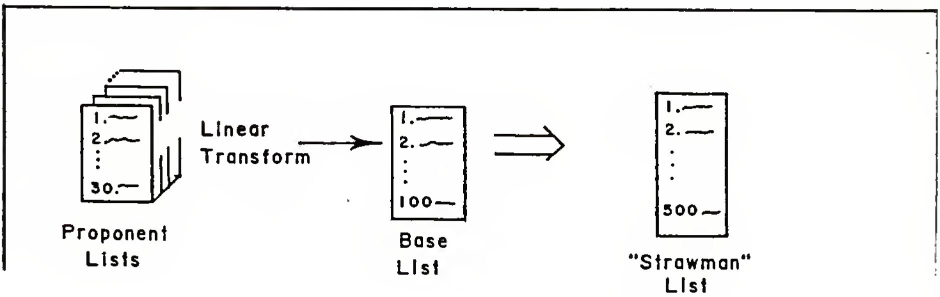


Figure 2.5 Phase 2 of the BDP-85

of pairwise evaluations to be performed by the experts are known. The BIBD will determine the reamining parameters which define the size of the random sample and insure a fair evsluation process.

An slgorithm csn support the BIBD by specifying the assignment of the deficiencies to be pairwise evaluated by each expert during this phase. It is common to split the random sample into subsets. This is done by referencing the BIBD. As mentioned esrlier, this will reduce the burden of evsluations while incressing overall accuracy. Accordingly, one or more half matrices containing the deficiencies of each subset and including at least one control deficiency will be prepared for each expert. Again, it is important to note that half mstrices with fewer deficiencies insures more consistent evaluations. These mstrices, along with the deficiency fact sheets and the percentile ranking of each deficiency (from its mission area list), comprise the package msiled out to the experts.

When complete, these separate packages are mailed with instructions to the general officers. The officers evaluate the deficiencies using the pairwise compsrison technique described in Appendix C. The psirwise evsluations utilize a comparison scale that will result in a cardinal ranking or priority for the deficiency. There is at least one deficiency common to each of the half matrices. This common or 'control' deficiency allows for the merging of the experts' evaluations at a later time. The experts have approximately two weeks to complete the evaluations and return them to TRADOC.

Next, TRADOC analysts consolidate the experts' half matrices and calculate eigenvector weights of priorities for each deficiency. The Saaty eigenvector approximation method is used for these calculations (see Appendix C). Now, these cardinally ranked deficiencies from the different half matrices must be merged into a single list (the size of the original random sample). This merging of the subset deficiency lists is accomplished using the formulation detailed in Appendix E. The merging procedure uses the control deficiency common to each of the experts' half matrices to determine a constant. The constant is used to formulate new cardinal values for the deficiencies as the matrix lists are merged one at a time into one of the prioritized lists selected at the start of the procedure. The final merged list is referred to as a "base" list and represents the consensus of the experts on the prioritization of the sampled deficiencies.

The second major portion of this phase involves developing a "strawman list" using the base list and the original 13 mission area lists. This strawman list can be likened to a draft BDP. It is a complete list of deficiencies that has been developed by combining the judgments of the mission area proponents and the general officer experts.

Developing the strawman list is accomplished using a piecewise linear transformation (see Appendix F). Using the base list as a reference, the proponent lists of deficiencies are transformed one at a time into the base list. This results in the integration of all deficiencies into the single, cardinally ranked strawman list.

Once the strawman list has been formulated, it is forwarded to each mission area proponent for review and comment. Issues surfacing from the proponents' review are provided to TRADOC at the conclusion of Phase 2.

c. <u>Phase 3: Finalizing the BDP</u>

About four or five weeks are allocated for the activities of Phase 3. A diagram of Phase 3 is shown in Figure 2.6. If the variances of the experts' evaluations in Phase 2 is significant, TRADOC will convene a commandant's panel to reduce the variance. Otherwise, preparations are made directly to convene a final general officer integrating panel. This panel is composed of Army staff, TRADOC representatives, and the commanders of six major Army commands. The general officers of this integrating panel are some of the most highly regarded in the entire Army.

The main objectives of the integrating panel are to make final decisions on unresolved issues, review the strawman list horizontally by functional packages and pillars of defense, and make final adjustments to the strawman list of mission area deficiencies. The integrating panel normally accomplishes these tasks in a single day. This panel is the final step in the BDP prioritization process and produces the single integrated and ordered list of deficiencies across all TRADOC mission areas. The Phase 3 BDP list is submitted to the TRADOC commander for approval to complete the entire BDP process.

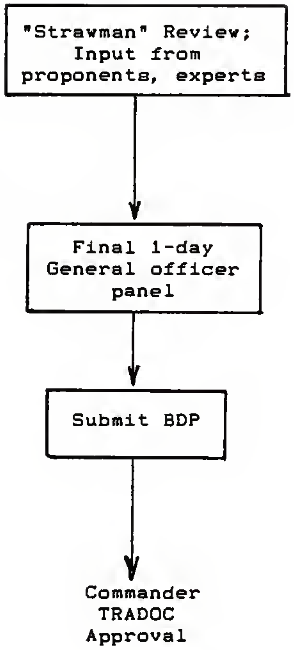


Figure 2.6 Phase 3 of the BDP-85

2.3 Numerical Example

The numerical example that follows is hypothetical. For simplicity, only three mission area proponents and 14 experts participate. Deficiencies are fewer than would normally be expected and they are identified only by number (e.g. LOG 01). No fact sheets are provided for explanation of the deficiencies in this example. The example follows the three phases of the BDP-85 process.

a. Phase 1: (Obtaining the proponents' prioritized lists) The three mission area proponents, combined arms, logistics, and aviation use their own methodology to produce the cardinally ranked deficiency lists shown in Table 2.3. Any similar deficiencies among the proponents would have been identified and consolidated into one "parent" deficiency by the integrating centers.

Table 2.3 Mission Proponents Ranked Deficiencies (Example)

PROPONENT	DEFICIENCY	CARDINAL VALUE
Combined Arms Center	CAA 01	0.223
	CAA 02	0.169
	CAA 03	0.133
	CAA 04	0.115
	CAA 05	0.077
	CAA 06	0.073
	CAA 07	0.066
	CAA 08	0.063
	CAA 09	0.061
	CAA 10	0.015
Logistics Center	LOG 01	0.105
	LOG 02	0.102
	LOG 03 *	0.097
	LOG 04	0.088
	LOG 05	0.082
	LOG 06	0.077
	LOG 07	0.062
	LOG 08	0.060
	LOG 09	0.056
	LOG 10	0.050
	LOG 11	0.046
	LOG 12	0.046
	LOG 13	0.035
	LOG 14	0.026
	LOG 15	0.025
	LOG 16	0.015
	LOG 17	0.015
	LOG 18	0.013
	LOG 19	0.001
Aviation Center	AVN 01	0.120
	AVN 02	0.119
	AVN 03	0.112
	AVN 04	0.107
	AVN 05	0.093
	AVN 06	0.084
	AVN 07	0.077
	AVN 08	0.071
	AVN 09	0.070
	AVN 10	0.069
	AVN 11	0.062
	AVN 12	0.018

* Control deficiency

b. Phase 2: (General Officer Evaluations): In this phase, TRADOC consolidates the total population of 41 deficiencies. Analysts consult the Balanced Incomplete Block Design (BIBD) to determine a reasonable sample size based on the number of general officer experts available and the desired burden of work to be performed by the experts. Phase 2 follows the steps outlined below:

Step 1 - (Consult BIBD: determine sample size) The decision is made to sample 15 deficiencies from the total of 41. This sample list shown in Table 2.4 is weighted to the top ranked proponent deficiencies and includes the top and bottom deficiency from each list. This sample is further divided into two subset lists (Set 1, Set 2) of eight deficiencies each. One deficiency, LOG 03, is the control deficiency common to each subset list. The assignment of deficiencies according to the parameters established by the BIBD insures a fair chance for each of the 15 deficiencies to be selected as the top or bottom deficiency by the general officer experts. Table 2.5 and 2.6 show the actual assignment of the subset lists of deficiencies for the 14 experts (A thru N). The BIBD parameters are also shown below each table.

If sampling was not performed in this step, the number of paired comparisons performed by each expert would have been

$$\frac{n(n-1)}{2} \text{ or } \frac{41(40)}{2} = 820.$$

Therefore, reducing the paired comparisons required from 820 to six for each subset (total of 12 per expert) is a considerable reduction of effort and gain in accuracy. In actual BDP processes, the aim of TRADOC has been to keep the number of paired comparisons around 300.

Table 2.4 Sample Deficiency List (Example)

Deficiency	Cardinal Value
CAA 01	0.223
CAA 04	0.225
CAA 10	0.025
LOG 01	0.105
LOG 03 *	0.097
LOG 05	0.082
LOG 07	0.062
LOG 09	0.056
LOG 12	0.046
LOG 19	0.001
AVN 01	0.120
AVN 03	0.112
AVN 04	0.107
AVN 06	0.084
AVN 12	0.018

* Control deficiency

Table 2.5 BIBD Assignment of Deficiencies (Example) - SET 1

	SET 1 Deficiency							
	CAA01	CAA10	LOG01	LOG07	LOG19	AVN01	AVN06	LOG03
Expert								
A	X	X	X	X				
B	X	X					X	X
C	X		X			X		X
D	X			X		X	X	
E					X	X	X	X
F			X	X	X	X		
G		X		X	X		X	
H		X	X		X			X
I	X	X			X	X		
J	X		X		X		X	
K	X			X	X			X
L			X	X			X	X
M		X		X		X		X
N		X	X			X	X	

(BIBD Parameter Summary)

Number of deficiencies = 8
Number of experts = 14
Number of appearances of each deficiency = 7
Number of identical pairs = 3
Number of deficiencies per expert = 4
Number of paired comparisons required = 6

Table 2.6 BIBD Assignment of Deficiencies (Example) - SET 2

	SET 2 Deficiency							
	CAA04	LOG05	LOG09	LOG12	AVN03	AVN04	AVN12	LOG03
Expert								
A	X	X	X	X				
B	X	X					X	X
C	X		X			X		X
D	X			X		X	X	
E					X	X	X	X
F			X	X	X	X		
G		X		X	X		X	
H		X	X		X			X
I	X	X			X	X		
J	X		X		X		X	
K	X			X	X			X
L			X	X			X	X
M		X		X		X		X
N		X	X			X	X	

(BIBD Parameter Summary)

Number of deficiencies = 8
Number of experts = 14
Number of appearances of each deficiency = 7
Number of identical pairs = 3
Number of deficiencies per expert = 4
Number of paired comparisons required = 6

Step 2 - (Preparation of expert half-matrices) Using the assignment of deficiencies, the two half mstrices for each general officer expert is prepared. The half matrices for expert A are shown in Figure 2.7. In s similar manner, the remsining pairs of half mstrices for the other 13 experts (B-N) are prepared and mailed out for evaluation.

Step 3 - (Calculation of experts' evaluations) After each of the 14 experts have completed their half matrices, they are submitted to TRADOC for computation and merging. The example results (eigenvector weights) for the 14 experts are shown in Table 2.7 for Set 1 and Table 2.8 for Set 2. Consistency of the evaluations is also measured, however inconsistent evaluations (ratios greater than .10) are not required to be evaluated again until they are consistent. Shown at the bottom of Tables 2.7 and 2.8 are the csrdinsl values for each deficiency which were calculated ss the column averages for each subset.

Rating Scale

A ==> EQUAL IMPORTANCE
B
C ==> WEAKLY PREFERRED
D
E ==> STRONGLY PREFERRED
F
G ==> ABSOLUTE DOMINANCE

* B,D,F, RATINGS USED FOR COMPARISONS WHICH FALL BETWEEN DESCRIBED VALUES

Set 1

	CAA 01	CAA 10	LOG 01	LOG 07
CAA 01	A			
CAA 10	F	A		
LOG 01	C	E	A	
LOG 07	B	B	C	A

Set 2

	CAA 04	LOG 05	LOG 09	LOG 12
CAA 04	A			
LOG 05	A	A		
LOG 09	A	C	A	
LOG 12	D	F	A	A

Results

LOG 01	0.50	LOG 05	0.42
CAA 01	0.28	CAA 04	0.30
LOG 07	0.15	LOG 09	0.21
CAA 10	0.07	LOG 12	0.07

Figure 2.7 Expert 'A' Pairwise Evaluations (Example)

Table 2.7 Results of Experts' Evaluations - Set 1
(eigenvector weights within the table)

SET 1

Expert	CAA01	CAA10	LOG01	LOG07	LOG19	AVN01	AVN06	LOG03
A	.28	.07	.50	.15				
B	.55	.14					.12	.18
C	.57		.15			.16		.11
D	.48			.23		.21	.09	
E					.06	.59	.17	.18
F			.28	.09	.04	.58		
G		.28		.26	.08		.38	
H		.06	.53		.06			.35
I	.50	.21			.20	.09		
J	.19		.63		.07		.11	
K	.37			.32	.05			.26
L			.58	.13			.05	.24
M		.09		.12		.36		.44
N		.06	.63			.24	.08	
Column Avg.	0.21	0.07	0.24	0.09	0.04	0.16	0.07	0.13

Set 1 - Ordered Listing

Rank	Def.	Value
1	LOG 01	0.236
2	CAA 01	0.210
3	AVN 01	0.159
4	LOG 03	0.126
5	LOG 07	0.093
6	AVN 06	0.072
7	CAA 10	0.065
8	LOG 19	0.040

Table 2.8 Results of Experts' Evaluations - Set 2
(eigenvector weights within the table)

SET 2

Expert	CAA04	LOG05	LOG09	LOG12	AVN03	AVN04	AVN12	LOG03
A	.30	.42	.21	.07				
B	.30	.32					.07	.30
C	.48		.11			.16		.25
D	.58			.07		.27	.09	
E					.45	.31	.05	.20
F			.11	.06	.49	.35		
G		.37		.15	.34		.13	
H		.41	.07		.12			.41
I	.09	.53			.19	.20		
J	.18		.26		.47		.08	
K	.47			.06	.23			.24
L			.22	.14			.05	.59
M		.47		.05		.17		.31
N		.24	.08			.61	.07	
Column Avg.	0.17	0.20	0.08	0.04	0.16	0.15	0.04	0.16

Set 1 - Ordered Listing

Rank	Def.	Value
1	LOG 05	0.197
2	CAA 04	0.172
3	LOG 03	0.164
4	AVN 03	0.163
5	AVN 04	0.148
6	LOG 09	0.076
7	LOG 12	0.043
8	AVN 12	0.039

Step 4 - (Merging the experts evaluations of Set 1 and Set 2) Using the explanation of the merging procedure in Appendix E, a constant (a) must be determined where

$$a = \frac{\text{control cardinal value from base list}}{\text{control cardinal value from merging list}}$$

With two subsets from the sample, there are two lists (Set 1, Set 2). Set 1 is selected as the base list and Set 2 as the merging list. The list with the control deficiency closest to center should be selected as the base.

Transcribing these prioritized lists from Table 2.7 and 2.8 yields:

Set 1 (base)			Set 2 (merging)		
Rank	Def.	Value	Rank	Def.	Value
1	LOG 01	0.236	1	LOG 05	0.197
2	CAA 01	0.210	2	CAA 04	0.172
3	AVN 01	0.159	3	LOG 03*	0.164
4	LOG 03*	0.126	4	AVN 03	0.163
5	LOG 07	0.093	5	AVN 04	0.148
6	AVN 06	0.072	6	LOG 09	0.076
7	CAA 10	0.065	7	LOG 12	0.043
8	LOG 19	0.040	8	AVN 12	0.039

Using the cardinal values of the control deficiency (*LOG 03), we can find the value for the constant a.

$$a = \frac{.126}{.164} = .768$$

Now each value in the merging list is multiplied by the constant to obtain transformed values to be merged into the existing base list.

a * (value from merging list) = (new value for base list)

Def.	Value		Transformed Value
LOG 05	0.197		0.151
CAA 04	0.172		0.132
LOG 03	0.164		0.126
AVN 03	0.163	* (0.768) =	0.125
AVN 04	0.148		0.114
LOG 09	0.076		0.058
LOG 12	0.043		0.033
AVN 12	0.039		0.030

To obtain the consensus of general officer experts (Base List), the transformed values are merged into the existing base list:

BASE LIST

Rank	Deficiency	Cardinal Value
1	LOG 01	0.236
2	CAA 01	0.210
3	AVN 01	0.159
4	LOG 05	0.151
5	CAA 04	0.132
6	LOG 03	0.126
7	AVN 03	0.125
8	AVN 04	0.114
9	LOG 07	0.093
10	AVN 06	0.072
11	CAA 10	0.065
12	LOG 09	0.058
13	LOG 19	0.040
14	LOG 12	0.033
15	AVN 12	0.030

<u>Step 5 - (Developing the Strawman List</u> The consensus of general officers or the base list provides a cardinally ranked

list across all (3 in this case) of the mission areas. These experts have integrated only a percentage of the deficiencies from each mission area into a single prioritized list. To obtain a complete list of deficiencies, the remaining 26 deficiencies that were not included in the sample of 15 must be integrated into the base list. Since the base list includes 15 deficiencies from each of the three proponent lists, a piecewise linear transformation can be used to integrate the remaining deficiencies. This process is accomplished by merging the mission area proponent lists, one at a time, into the base list utilizing the sampled deficiencies as reference points. This integrated list, called a strawman list, will have uniform precision across all deficiencies (5).

To begin, the CAA mission area list is merged into the base list. Three deficiencies (CAA 01, CAA 04, and CAA 10) are common between the two prioritized lists.

BASE LIST

Deficiency	Value
LOG 01	0.236
CAA 01	0.210
AVN 01	0.159
LOG 05	0.151
CAA 04	0.132
LOG 03	0.126
AVN 03	0.125
AVN 04	0.114
LOG 07	0.093
AVN 06	0.072
CAA 10	0.065
LOG 09	0.058
LOG 19	0.040
LOG 12	0.033
AVN 12	0.030

CAA PROPONENT LIST

Deficiency	Value
CAA 01	0.223
CAA 02	0.169
CAA 03	0.133
CAA 04	0.115
CAA 05	0.077
CAA 06	0.073
CAA 07	0.066
CAA 08	0.063
CAA 09	0.061
CAA 10	0.025

These three common deficiencies are plotted on an x-y graph with the proponent value as the x value and the base value as the y value. Lines are drawn to connect these points so that values for the other seven deficiencies can be determined graphically (see Figure 2.8). The straight line appearance of the entire graph and the positive slopes are indicators of the general officer experts' evaluation in comparison to the proponent rankings of deficiencies. A positive slope indicates no conflict between the experts and the proponents. A negative slope indicates a conflict - in other words, the general officer consensus places a deficiency in different order than the proponent. The straight-line appearance of Figure 2.8 also shows that the experts place nearly the same cardinal ranking (relative difference) among the CAA mission deficiencies (a 1:1 slope indicates exact comparison).

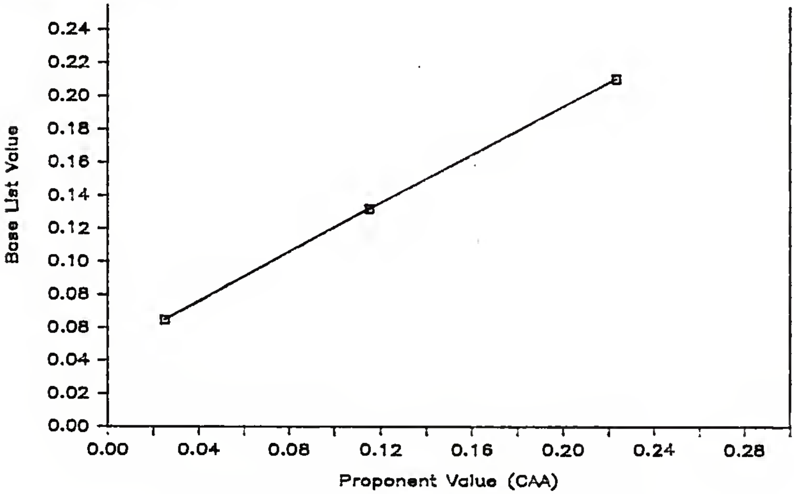


Figure 2.8 Linear Transformation of CAA List

The transformed values for the CAA deficiencies can also be determined using the linear equation y = ax + b. In the case of determining the transformed value for CAA 07, the slope (a) and intercept (b) of the line between CAA 04 and CAA 10 are calculated as follows:

$$a = \frac{y_2 - y_1}{x_2 - x_1} = \frac{(.132 - .065)}{(.115 - .025)} = 0.744$$

$$b = y - ax = .132 - .744(.115) = 0.046$$

The x value (.066) for CAA 07 issued to find the new y value (transformed value):

$$y = (0.744) x (.066) + 0.046 = 0.095$$

Similarly, all other values for the CAA proponent list are determined. These new values are shown below.

CAA TRANSFORMED VALUES

CAA 01	0.210
CAA 02	0.168
CAA 03	0.142
CAA 04	0.132
CAA 05	0.100
CAA 06	0.097
CAA 07	0.096
CAA 08	0.093
CAA 09	0.092
CAA 10	0.065

In the same manner the remaining two mission proponent lists (LOG, AVN) are merged into the base list one at a time. The results of these mergings are shown next and in Figure 2.9 for LOG and Figure 2.10 for AVN.

LOG TRANSFORMED VALUES		AVN TRANSFORMED VALUES	
LOG 01	0.236	AVN 01	0.159
LOG 02	0.195	AVN 02	0.154
LOG 03	0.126	AVN 03	0.125
LOG 04	0.140	AVN 04	0.114
LOG 05	0.151	AVN 05	0.087
LOG 06	0.125	AVN 06	0.072
LOG 07	0.093	AVN 07	0.067
LOG 08	0.080	AVN 08	0.064
LOG 09	0.058	AVN 09	0.063
LOG 10	0.043	AVN 10	0.062
LOG 11	0.033	AVN 11	0.058
LOG 12	0.033	AVN 12	0.030
LOG 13	0.035		
LOG 14	0.036		
LOG 15	0.036		
LOG 16	0.038		
LOG 17	0.038		
LOG 18	0.038		
LOG 19	0.040		

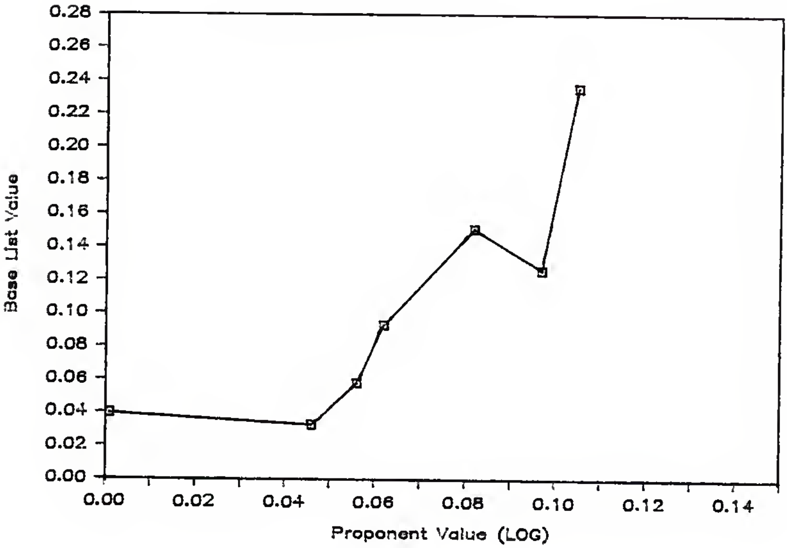


Figure 2.9 Linear Transformation of LOG List

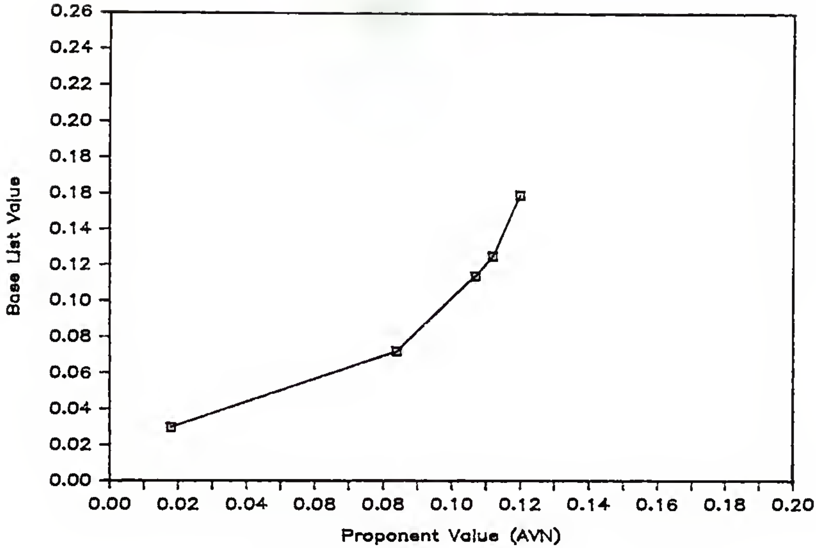


Figure 2.10 Linear Transformation of AVN

Now it becomes a simple matter of collecting and ordering the cardinal values of each transformed mission area list. This prioritized list is the strawman list which is sent out to each proponent for review and comment. Ths strawman list for the example is shown in Table 2.9.

Table 2.9 Strawman List (Example)

Rank	Deficiency	Cardinal Value
1	LOG 01	0.236
2	CAA 01	0.210
3	LOG 02	0.195
4	CAA 02	0.168
5	AVN 01	0.159
6	AVN 02	0.154
7	LOG 05	0.151
8	CAA 03	0.142
9	LOG 04	0.140
10	CAA 04	0.132
11	LOG 03	0.126
12	LOG 06	0.125
13	AVN 03	0.125
14	AVN 04	0.114
15	CAA 05	0.100
16	CAA 06	0.097
17	CAA 07	0.096
18	CAA 08	0.093
19	LOG 07	0.093
20	CAA 09	0.092
21	AVN 05	0.087
22	LOG 08	0.080
23	AVN 06	0.072
24	AVN 07	0.067
25	CAA 10	0.065
26	AVN 08	0.064
27	AVN 09	0.063
28	AVN 10	0.062
29	LOG 09	0.058
30	AVN 11	0.058
31	LOG 10	0.043
32	LOG 19	0.040
33	LOG 18	0.038
34	LOG 17	0.038
35	LOG 16	0.038
36	LOG 15	0.036
37	LOG 14	0.036
38	LOG 13	0.035
39	LOG 12	0.033
40	LOG 11	0.033
41	AVN 12	0.030

c. Phase 3 - (Final GO Panel) For the purpose of this example, there is no need to make any changes to the strawman list. During this phase, the general officer panel would review and make decisions on any unresolved issues or comments from the proponents regarding the strawman list. The cardinal values of each deficiency make it easy for the panel to change the rankings of various deficiencies. The final step in the BDP-85 process is to submit the list determined by the panel to the TRADOC commander for approval.

Chapter 3

ANALYSIS OF THE BDP PROBLEM

3.1 Problem Analysis

As outlined in Chapter 1, the problem facing TRADOC is the integration of 13 separate mission area proponent lists into a single, prioritized list of Army deficiencies. Following an analysis of the BDP, several other factors that contribute to the problem and an effective solution become evident. The BDP-85 process developed by TRADOC certainly produces a prioritized list of mission deficiencies across the 13 mission areas. But, does this process provide the best framework for decision makers to formulate the best possible prioritization scheme? To answer this important question, the problem must be analyzed and understood in greater detail. This is accomplished by presenting and discussing three main contributing factors which are inherent in the BDP problem solving process.

1. What criteria do the decision makers consider as they evaluate deficiencies?

This is apparently the key issue. Not only do the decision makers at the mission area proponents need to evaluate each deficiency in terms of overall importance within the mission area, but these deficiencies must also be evaluated on a broader scale across all mission areas. In this way, overall importance of the deficiencies and their impact on the success of the Army forces on the battlefield can be determined.

Currently, the proponents identify deficiencies based on the MAA and other appropriate studies. One objective underlying these studies is to identify deficiencies in the proponents' ability to complete mission tasks according to prescribed standards and AirLand Battle doctrine. The MAA studies are conducted every three or four years, hence there are in-between periods where the reevaluation of mission area deficiencies is required.

The impact of mission area deficiencies on battlefield success rests on the subjective judgments of the participating decision makers. This is an extremely difficult task, since several criteria must be simultaneously considered in the decision process. Guidance from TRADOC states that "proponent schools and integrating centers are requested to evaluate deficiencies in terms of critical tasks and key operational capabilities" (6). It is difficult enough for a decision maker to consider two or three criteria when comparing deficiencies for prioritization. Therefore, attempting to evaluate deficiencies based on seven critical tasks and five key operational capabilities becomes very complicated. The fact is there are many factors or criteria that deserve consideration in the prioritization process. Most are subjective criteria (e.g., level of impact on battlefield success), but some are objective (e.g., cost of material programs to correct deficiencies). These criteria are usually provided in the form of guidance or directives by the Army staff and TRADOC. The guidance relates directly to the issue of "impact on battlefield success." The guidance may be broad, but recently, it has been more clearly defined and is changing from year to year as the factors that influence the battlefield also change. An appropriate example of a new criteria or guidance is the concept of "lightness." According to the Army guidance, lightness applies to all aspects of development and must be considered in the BDP process (6). Without doubt, multiple criteria exist in the BDP. Hence, the TRADOC BDP process must provide the best possible framework for the evaluation of multiple criteria by decision makers.

2. Subjective Judgments of Multi-Criteria Deficiencies

In the BDP process, decision makers must make a choice among many alternatives (deficiencies), each of which consists of several subjective criteria. Often however, the decision maker is not satisfied with his ranking of deficiencies even though he evaluated them according to his own subjective standards. In (10), Shepard states that this may be due to "man's demonstrable inability to take proper account, simultaneously, of the various component attributes of the alternatives"; that is, although he will probably experience little difficulty in evaluating the alternatives with respect to any one of these subjective criteria, his ability to arrive at one overall evaluation by weighing and combining or "trading off" all of these separate attributes at the same time is likely to be less impressive. When using all available information and all possible criteria, the best possible solution for decision makers assumes enormous complexity. The pairwise comparison methodology used in the BDP-85 process is easy to understand, but it has distinct weaknesses as an effective technique for evaluating and prioritizing multiple criteria mission deficiencies.

Since decision makers are unprepared for the increasing load of logical and combinational manipulation characteristics of a multiple, conflicting criteria problem, they should seek the aid of computer facilities. Shepard (10) states, "It is true that the computer's powers of abstracting important invariants from the raw environment are poor in comparison with ours; but, once we have performed these abstractions for it, the computer far exceeds us in ability to sustain sequences of logical and numerical operations on these abstractions." Therefore, a division of labor between the decision maker and the computer is necessary in the multiple criteria, multiple alternative BDP process.

It is obvious that a number of subjective criteria are relevant to the BDP decisions that must be made, yet many decision makers feel that the weighting and combining of factors required for such subjective decisions can only be performed by human intelligence, not computerized machinery. The BDP process can certainly benefit from a reduction of this prejudice and through a better understanding of the complexity of the problem. Then the true value of the computer and its decision support models can be recognized by the decision makers. There is no replacing the human being as the decision maker, but computer support can be a tremendous asset in the BDP decision processes.

3. Consistency and Flexibility

Consistency is important to the BDP process in two respects; consistent evaluations of deficiencies by decision makers and the consistency of the BDP deficiency list from year to year. Losing consistency in the evaluation of deficiencies results in biased conclusions or inaccurate deficiency rankings. Inconsistency in the BDP from year to year can be even more devastating. Any significant change in the prioritization of deficiencies can affect resource allocation for long- and short-term material programs that correct deficiencies. The TRADOC commander has clearly stated his intentions to develop and maintain a consistent BDP (12).

Another characteristic desired in the BDP process is flexibility. The process must be flexible to the changing criteria that influence identification and prioritization of mission area deficiencies. Flexibility must be integrated in a manner that does not threaten consistency.

3.2 BDP Strengths

There are certain strengths or advantages of the BDP-85 process that have become evident in the study. Four strengths, discussed here, seem to stand out from analysis of the BDP-85.

1. Flexibility for the Mission Area Proponent

It makes sense to recognize the 13 mission area proponents as the experts in the aspects of their unique mission area and associated mission tasks. TRADOC recognizes this and provides the proponents complete control over the prioritization of their deficiency lists. Because only a percentage of deficiencies are sampled for evaluation in Phase 2, the majority of mission deficiencies will retain the order determined by the proponents. In Phase 2, general officers from the proponents participate in the evaluation of deficiencies across all mission areas. After the strawman list has been developed, each proponent has the option of submitting justification to change the order of any particular deficiencies. These factors contribute to a needed flexibility for the mission area proponents and strengthen their impact on the final BDP prioritization.

2. Reduced Burden on Phase 2 Experts

The Balanced Incomplete Block Design (BIBD) technique, utilized in BDP-85, is an effective method for reducing the burden on the general officer experts and increasing the accuracy of their pairwise evaluations. It would be totally unrealistic to ask the experts to evaluate all battlefield deficiencies using pairwise comparisons (over 95,000 comparisons). Since these general officers have full-time responsibilities as proponent commanders, one concern of the TRADOC commander is to reduce the burden on the general officers to the maximum possible extent (12). The BIBD divides the population of deficiencies into manageable subsets of half matrices for evaluation. The pairwise comparison methodology is an easy to understand technique for these decision makers to use, further reducing their burden in evaluation.

3. Phase 3 General Officer Expert Panel

This panel is an important part of the BDP process. These highly respected leaders lend a final measure of importance to the BDP effort. Their task of deciding unresolved issues and finalizing the strawman list is an important one. The current method used to convene and conduct this panel is well-suited to the overall purpose of the group.

4. Familiarity

Transition to a new method or system in any work environment can be difficult, especially in obtaining the acceptance of the affected workforce. User familiarity of the BDP-85 process and its related methodologies can be considered a strength of the BDP effort in the sense that it is accepted by the decision makers (12). Worker acceptance is critical to the overall effectiveness of any system. If you can't sell the decision support system to the decision makers who will use it, then there is certain to be a lot of wasted effort and a lack of overall confidence.

3.3 BDB-85 Weaknesses

Study of the BDP-85 prioritization process has revealed four distinct weaknesses which are analyzed here.

1. Ineffective Link with Army Objectives

Almost yearly the Army reforms and issues guidance and new objectives which are key to the effective application of AirLand Battle doctrine and battlefield success. In the BDP-86 instructions, specific critical tasks and supporting key operational capabilities were outlined by the Army staff as crucial to overall mission effectiveness. These objectives were to be strongly considered by each mission area proponent as mission deficiencies are identified and prioritized for BDP-86. However, as discussed in Section 3.1, the task of considering the full scope of these objectives or criteria cannot be effectively performed using the pairwise comparison logic. Without establishing the Army's objectives as separate criteria to be examined by the decision makers, it is unlikely that these objectives will have the desired impact on the BDP.

In the same respect, the current BDP process is inflexible to changing objectives. Prioritized mission area lists may require significant reordering in subsequent years based solely on the consideration of one or more new Army objectives. Since there is no direct linkage of these objectives to the deficiency evaluation process, there is little assurance that needed revisions to proponent lists and the BDP will occur.

2. <u>Percentage Random Sampling Technique</u>

The percentage random sampling technique used in the BDP-85 process does not provide an adequate cross section of mission area deficiencies for evaluation. This sampling effort produces a subset that includes deficiencies from each proponent mission area, including the top and bottom deficiencies from each of the 13 lists. In addition to these 26 deficiencies, the reamining deficiencies are sampled more heavily from the top quartiles to ensure greater discrimination in the top deficiencies. Constrained by the requirement to reduce the burden on the general officer experts, TRADOC analysts aim to keep the required paired comparisons for each expert at about 300 (11). Using BIBD, this results in a sample size of about 100 deficiencies or approximately 20% of the total population. Although the BIBD provides a fair representation for each sampled deficiency, the limitations imposed by the small sample impacts unfavorably on the validity of the general officers' consensus base list. This conflict between sample size and the burden on the general officer experts should be handled in a more efficient manner.

3. <u>The BDP-85 is a Limited Scientific Method</u>

The BDP problem, like many issues in our world, is a complex problem. The prioritization process presents a number of subjective and objective judgments that must be made by decision makers at many levels. The need to order priorities (ranking deficiencies) depends on their ability to make complicated comparisons. It is often difficult to agree which objective outweighs another, especially where a wide margin of error is possible when making necessary tradeoffs. Intuitive thought processes that serve as well in familiar matters can mislead us on complex matters where information and opinions are diverse and constantly changing (9).

Rather than a more complicated way of thinking to solve the complex BDP problem, we need a more scientific and ordered framework/methodologies. The decision process must provide interaction among the complex factors of the problem, yet still enable the users to think about them in a simple way.

The BDP-85 process uses scientific methods, but neglects the diverse criteria that should be judged in the decision process. Instead, personal preferences of the decision makers prevail over clear and straight logic. An improved scientific method integrated with suitable criteria determined by Army decision makers is necessary in the BDP prioritization process.

4. Phase 2 Evaluations are Non-Transparent

One advantage of the pairwise comparison methodology is the readily available computer programs that will calculate the resulting eigenvector weights. In this way, the decision maker can determine the impact of his pairwise decisions and check his overall consistency. However, as the general officer experts perform their pairwise comparisons in Phase 2 of the BDP-85, these computer programs are not used. Therefore, these experts are unaware of the impact of their pairwise evaluations and the consistency of these evaluations. Only following the submission of the completed half matrices to TRADOC are the results calculated (11). At this point, each expert's list of sample deficiencies is prioritized and the consistency is determined. However, experts are not allowed to revise their evaluations. Additionally, evaluations are accepted regardless of consistency. The inability of the Phase 2 experts to observe and revise their evaluations is a serious shortfall of the BDP-85 process, especially when the number of deficiencies is large and the possibility of inconsistency is increased.

3.4 Objectives of the BDP

Study of the BDP problem and the TRADOC BDP-85 process has revealed several objectives of an efficient and suitable process. Some of these objectives are inherent to a prioritization process, while others have been specifically outlined by TRADOC. Although the objectives listed below are not clearly defined by the Army, they have become evident in this study.

These objectives are clarified here as brief explanations. This outline provides a natural link in the formulation of alternative BDP approaches. While additional objectives may be considered necessary by TRADOC, the eight listed here address the demands of a viable BDP process.

1. Link Army Objectives

The objectives determined to be critical to battlefield survivability and success must be considered in the BDP process. The Army goals/objective supplement the conclusions of key MAA studies. They may be revised according to the various factors affecting the present and future battlefield.

2. Understandable to Decision Makers

A prioritization process too complicated or foreign to the users and decision makers will quickly lose merit. The process must present procedures and information clearly and provide an understandable mapping of steps toward a logical solutions.

3. Transparent Decision Structure

The process should provide a transparent decision structure at every stage. Without transparency, decision makers are unaware of the impact of their decisions and unable to revise decisions according to their actual intentions.

4. Proponent Impact on the BDP

The mission area proponents, as the responsible experts in specific mission areas, must have a significant impact on the prioritization of deficiencies.

5. Consistency

Inconsistent judgments indicate lack of information or lack of understanding. Consistency does not need to be perfect, but uncontrolled, it can be damaging to the decision process. The BDP process must establish acceptable standards of consistency for decision makers and provide a framework for BDP consistency from year to year.

6. Flexibility

The BDP process must be adaptable to new objectives that impact on the identification and prioritization of battlefield deficiencies. Rapid changes in the threat, battlefield doctrine, and weapons technology dictate equally frequent changes in the Army objectives key to battlefield success. Therefore, flexibility to incorporate new criteria/objectives is a key ingredient in the BDP framework.

7. Increase objectivity

The BDP process is mainly subjective. However, there are certain objective criteria that should be considered in the ranking of battlefield deficiencies for the Army. Ease of corrective action for mission area deficiencies should be an important factor to determine where a deficiency should be ranked. Ease of corrective action can be represented by time and cost estimations. In other words, deficiencies that compare similarly in impact on mission accomplishment, should be analyzed regarding the cost and time associated with correcting each deficiency. This analysis may present a clear advantage in ranking one over the other. The BDP process can be improved by integrating objective criteria into the decision making. Researching more objective factors will raise the level of accuracy and boost the overall consistency associated with the process.

8. <u>Ease of Automation</u>

An automated BDP process is inevitable. Army decision makers are overloaded with responsibilities and mission tasks, and the computer must be accepted and used as an administrative and decision support tool. It is prudent to plan computer support into every possible stage of the BDP process. This objective is the key in the evolution of the process and the numerous links between the BDP prioritization and other aspects of Army planning and development.

Chapter 4

AN EVOLUTIONARY APPROACH USING MULTIPLE CRITERIA DECISION MAKING

4.1 Introduction

The importance of the BDP cannot be overstated. It is used extensively by TRADOC and other Army agencies in many aspects of planning, research, and development. The decisions that formulate the prioritized BDP influence the allocation of significant funds and manpower resources. Chapter 3 analyzed the complexities of these decisions based on the multiple factors which contribute to a precise evaluation of battlefield deficiencies. Based on that analysis, strengths and weaknesses of the current BDP were presented. The path to alternative approaches for solving the BDP prioritization problem should exhibit those strengths and correct the weaknesses.

The alternative presented here is considered an evolutionary approach. Multiple Criteria Decision Making (MCDM) techniques are used to improve the process both here and in the approach presented in Chapter 5. The key concepts of MCDM are presented in Appendix G. The Technique for Order Preference By Similarity to Ideal Solution (TOPSIS), a multiple attribute decision making (MADM) technique, is well suited for the multiple criteria decision processes of the BDP. A description of TOPSIS and the algorithm are described in Appendix H. The description of this evolutionary approach follows the same three phases of the BDP-85 process. Since Phase 3 of BDP-85 is well designed, it is left intact in both proposed MCDM approaches.

For the TRADOC prioritization to be effective, requirements must be specified in terms of the time and resources required (the "price" to pay) for corrective action. Deficiencies must also be evaluated in terms of the guidance provided by the Army and the prioritization process must be auditable. The approach presented here meets these requirements.

The flexibility and structure of the decision making process using MCDM methods represents the major advantage to be realized from adopting this sytematic approach to the TRADOC prioritization problem.

4.2 Establishing Criteria

The first step in using MCDM methods for the BDP formulation is the development of a list of potential criteria. Many criteria are relevant to the identification and prioritization of mission deficiencies and care should be taken to prevent overlooking any important factors. There is no one correct number of criteria to be used. Shepard states that experience in applications of multiple criteria scoring models indicates that, in general, five to ten criteria is adequate (10). Being able to determine dissimilar criteria makes it easier to understand tradeoffs when they occur among different criteria.

Determining the appropriate criteria is critical, and BDP participants at all levels should have some input in this stage. Certain criteria will undoubtedly remain intact from year to year while others can reflect revisions in Army guidance according to battlefield scenario changes. The adjustability of criteria for MCDM reflects the flexibility of the method.

Selection of an appropriate scale for each criteria is an equally important step in establishing the structure of the MCDM problem. Certain criteria will have natural measures (dollars for cost, years for time), while others may require an artificial scale (high-low) to incorporate the subjective judgments of decision makers.

After discussion with TRADOC analysts who have been involved with the development of the BDP, the following list of possible BDP criteria with scales has been developed (11,12):

1. Criticality to battlefield success. How critical is this deficiency to the success of the mission area under AirLand battle?

essential ... indirect contribution

2. Measure of ineffectiveness. What is the gap between the mission task standard and the current capability in performing the mission?

enormous ... slight

3. Impact on key operational capabilities. What impact does the task have on the Army's key operational capabilities?

enormous ... slight

4. Impact on pillars of defense. What level of impact does the task have on the four DOD pillars of defense?

enormous ... slight

5. Proponents priority. What is the proponents cardinal priority or ranking for the deficiency?

actual value

6. Previous BDP priority. What was the previous years' BDP priority for this particular deficiency?

high ... low

7. Ease of corrective action. How easy is it to rectify the deficiency? The "price" of corrective action can be measured in terms of time and cost.

(Time) less than 10 years ... greater than 10 years
(Cost) less than $500,000 ... greater than $1 billion

8. Frequency of occurrence. What is the frequency of occurrence of the deficiency among mission area proponents?

high ... low

9. Lightness. How does the deficiency/corrective action affect the Army's concept of "lightness"?

favorable ... adverse

The criteria "proponent's priority" (#5) should be used in a special manner since the proponents will determine the cardinal values of deficiencies based on their own unique weighting schemes. The intent of this particular criteria is to increase the impact of the proponents' ranking on the final strawman list. A special procedure that permits the use of this criteria equitably is presented in Section 4.4. The numerical example in Section 4.5 presents two separate solutions to the BDP problem; the first (Part I) omits proponent's priority as a criteria and the second (Part II) includes it as a criteria.

The addition of criteria in the BDP process and specifically some of the above proposed criteria, improves the scope of information needed for the decision processes. Many of the weaknesses associated with the BDP-85 can be corrected through the use of certain criteria. For example, including the previous years' BDP priority as a criteria will have a positive impact on consistency of the BDP list. Additionally, the Army's guidance on deficiency prioritization is directly linked to the first two proposed criteria. The impact of each criteria can justly contribute through any desired weighting scheme to the BDP prioritization process.

4.3 Description of the Evolutionary Approach

This MCDM approach to the TRADOC BDP problem is described according to the same phases of formulation used in the BDP-85 process. As mentioned in Section 4.1, Phase 3 will remain unchanged in this alternative approach. Phase 3 is an important final step in the BDP process and the general officer panel serves a necessary function in the BDP formulation. On the other hand, Phase 1 and Phase 2 are significantly modified according to the structure of the MCDM problem. A flow diagram of the evolutionary approach is shown in Figures 4.1 and 4.2.

a. Phase 1: Proponent prioritization of deficiencies

There are four main steps in Phase 1:

1) Determine criteria
2) Proponents develop decision matrices
3) Panel validates proponent decision matrices
4) Proponents submit prioritized mission area lists

Step 1 - (Determine criteria) In this first step, criteria that influence the identification and prioritization of mission area deficiencies must be determined. It seems appropriate that each participating command in the BDP process should be involved to some extent in criteria selection. However, the Army staff and TRADOC logically deserve the main influence in deciding which criteria to use and the evaluation scale to select for each criteria. Options to accomplish criteria selection include the various group decision making methods such as voting methods and social choice functions (3). After a general set of criteria is established, an appropriate letter of instruction is issued to all BDP participants. (Note: If proponent's priority is chosen as a criteria the procedure explained in Section 4.4 should be used.)

Step 2 - (Proponents develop decision matrices) Identification of deficiencies occurs through the MAA process described in Chapter 2. These deficiencies are specific in nature and they are explained by the proponents in accordance with the TRADOC deficiency fact sheet (see Figure 2.4). Proponents evaluate each deficiency by rating them against each of the established criteria. The proponent experts/analysts most knowledgable with the mission deficiencies determine these ratings using the same criteria that every proponent will consider. Since there are a finite number of deficiencies and multiple criteria, the evaluation can be formulated as a multiple attribute decision making (MADM) problem (4).

The distinguishing aspect of MADM is a finite number of alternatives associated with multiple attributes or criteria, which may not necessarily be quantifiable (4). MADM methods are classified according to the various forms of preference information from the decision maker. Figure 4.3 presents a taxonomy of MADM methods developed by Hwang and Yoon (4). Since the objective of the BDP process is to produce a cardinally ranked list of battlefield deficiencies, the methods from Set 2.3 of this figure are used for consideration.

The technique for Order Preference by Similarity to the Ideal Solution (TOPSIS) developed by Hwang and Yoon (4), is selected for application in Phase 1 and Phase 2. This MADM method is explained in detail in Appendix H. The availability of computer software for the TOPSIS algorithm and its overall simplicity make it an excellent MADM method to solve the prioritization problem. The ranking of alternatives is based on the concept that the best alternative (deficiency) will have the shortest distance from the positive ideal and the farthest position from the negative-ideal solution. The prioritization of deficiencies using TOPSIS is dependent upon the criteria weighting scheme given by the decision makers.

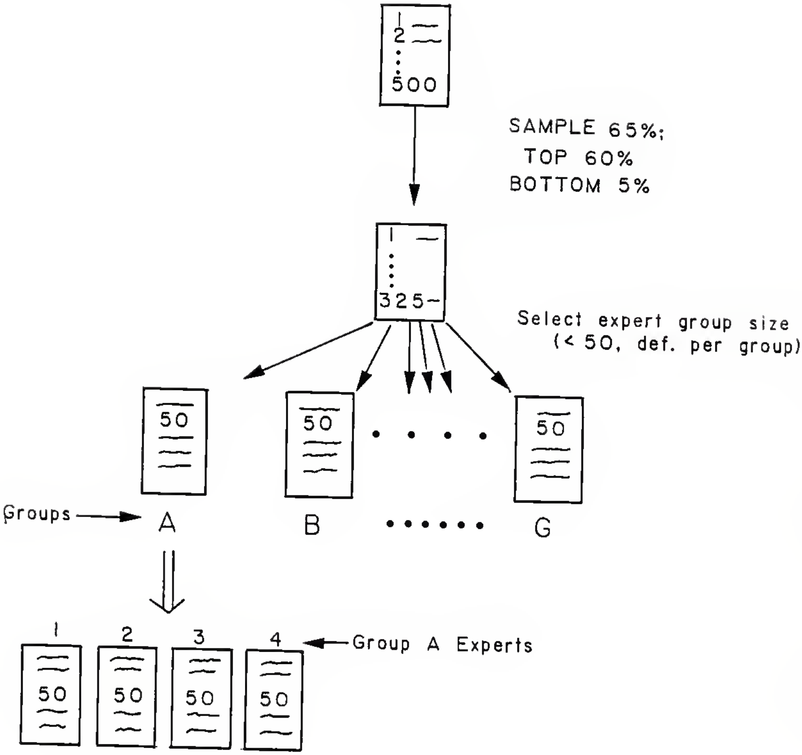


Figure 4.1 Flow Diagram of Evolutionary Approach (Phase 2 - Step 1,2)

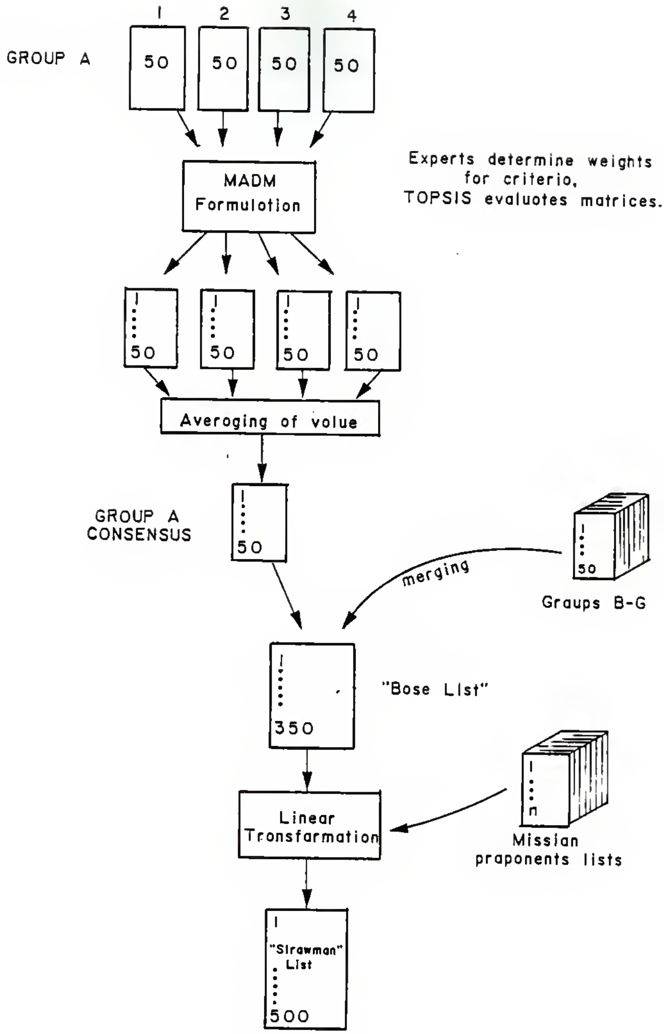


Figure 4.2 Flow Diagram of Evolutionary Approach (Phase 2, Step 3-6)

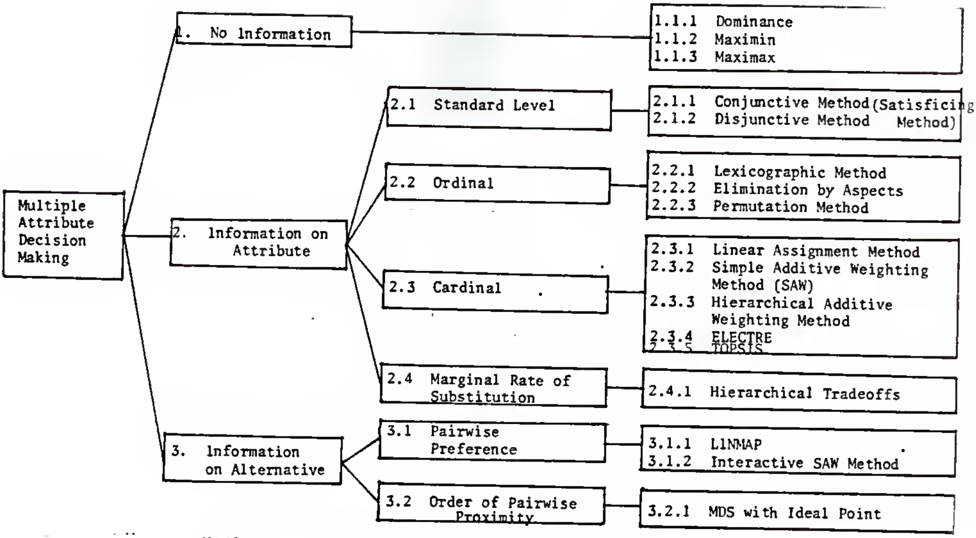


Figure 4.3 A taxonomy of MADM methods (Ref. 4, p.9)

Using the TOPSIS computer program in this stage, the decision makers at each proponent determine and create a decision matrix of m deficiencies (rows) and n criteria (columns) as shown below:

$$
D = \begin{array}{c} \\ \text{AVN } 01 \\ \text{AVN } 02 \\ \vdots \\ \text{AVN } m \end{array}
\begin{array}{c}
\begin{array}{cccc} X_1 & X_2 & \cdots & X_n \end{array} \\
\begin{bmatrix}
X_{11} & X_{12} & \cdots & X_{1n} \\
X_{21} & X_{22} & \cdots & X_{2n} \\
\vdots & \vdots & & \vdots \\
X_{m1} & X_{m2} & \cdots & X_{mn}
\end{bmatrix}
\end{array}
$$

The scoring of each deficiency against all n criteria is important, therefore careful analysis and accuracy in formulating the decision matrix is crucial.

Step 3 - (Panel validates proponent decision matrices) To control inconsistency and promote fairness among proponents, the integrating centers should convene a two- or three-day panel to validate the decision matrices by analyzing the proponents' scoring of deficiencies against criteria. These panels would be attended by one or more experts/analysts selected by each respective mission area proponent. These experts should be directly involved and knowledgable in the BDP process and able to express the opinions of their commandants. Most probably, the rank structure of these attendees would be field grade officers.

Directing each panel would be the responsibility of a ranking officer from the integrating center. In this way, the integrating center is directly involved and better acquainted with the information presented by the proponents. Most importantly, these panels must display and analyze the mission deficiency data from each proponent in a group atmosphere. This will insure that proponents understand the criteria and fairness prevails in the rating (data) of each decision matrix. The significance of the tasks performed by these validation panels cannot be overstated. The mission area proponents must be fully prepared to discuss all aspects of their mission area deficiencies, especially defending the rating of their decision matrices. At the conclusion of these panels, the proponent's decision matrices are finalized, similar deficiencies are consolidated, and deficiency fact sheets are approved.

Step 4 - (Proponents submit prioritized mission area lists) Following the integrating center validation panels, each mission area proponent has the necessary information to submit to TRADOC except their separate prioritized deficiency lists. Calculation of this cardinally ranked deficiency list is accomplished with minimal effort using the TOPSIS program. The decision that must be made now by the proponent is what criteria weighting to use. Weighting can be performed by any number of methods for weight assessment, but pairwise comparison (eignvector solution) or direct entry are two of the more common approaches (4). Using group consensus to recommend a weighting scheme to the commandant is also a reasonable procedure for this step.

After the criteria weights have been determined, the decision matrix is solved and a prioritized listing of deficiencies can be displayed. If the decision maker is not satisfied with the cardinally ranked list, the weighting of criteria can be easily revised and a different prioritization determined. Deficiency fact sheets, decision matrices, and the cardinally ranked deficiency lists are submitted by mission area proponents to conclude Phase 1.

b. Phase 2: Developing the "strawman" list

There are six steps in determining the Phase 2 strawman list:

1) Sampling procedure
2) Assignment of deficiencies
3) General officer expert evaluations
4) Determining consensus within groups
5) Formulating the base list
6) Formulating the strawman list

Step 1 - (Sampling) The highest priority items of the BDP are seldom in danger, however, the middle deficiencies risk falling below the cutoff line and, as a result, might lose funding for corrective action. In order to provide a more complete list of deficiencies among the top and middle sectors, a sample of the top 60% and bottom 5% of deficiencies from each proponent list is determined by TRADOC. This sample provides a majority of the total population of deficiencies and allows for merging of non-sampled deficiencies including top and bottom boundaries from each list.

Step 2 - (Assignment of deficiencies) The pool of TRADOC general officer experts is divided into smaller groups so that each group evaluates no more than 50 different deficiencies. A sample larger than 50 deficiencies would be too difficult for the experts to review, evaluate and revise. For example, considering a total population of 500 deficiencies, a 65% sample would consist of 325 deficiencies. Dividing 325 by 50 deficiencies yields 6.5, so at least seven groups of experts are needed in order to keep the number of deficiencies to be evaluated by each group below 50. Considering a total of 28 experts, each of the seven groups would have four members. Each group would be assigned 47 (325/7) different deficiencies for evaluation. The experts within groups evaluate the same deficiencies. At least one control deficiency, common to each group, must be chosen to allow for merging of the different group lists at a later time. Continuing under these conditions, 47 to 50 deficiencies can be assigned to each group, providing up to three control deficiencies for the merging process.

Other characteristics of this process are:

- Each group will receive a random assignment of deficiencies from each mission area.
- Percentile rankings (from the proponents prioritized lists) will be displayed for each deficiency.
- Cross level the expertise within each group (i.e., at least one combat expert, at least one service support expert).

Once the deficiency assignments are made, the decision matrix data are matched with the specific deficiencies and mailed to each general officer expert.

Step 3 - (General officer expert evaluations) The general officers evaluate their deficiency set upon receipt from TRADOC. Each package will include deficiency fact sheets, the decision matrix of their assigned deficiencies (on computer disk and hard copy), and an explanation of criteria to be used. The evaluation of the decision matrix is performed in the same manner used in Phase 1 by the mission area proponents. The experts determine a preference for criteria weights using a pairwise comparison of criteria or the direct assessment method. Both methods are programmed on the computer for ease of computation and to provide a consistency ratio for the decision maker. Regardless of the method of assessment, certain restrictions must be imposed by TRADOC (i.e., maximum limits of weighting for criteria). In this way, each criteria will receive some weight and no single criteria will completely overwhelm the other criteria. TOPSIS solves the MADM problem immediately and the impact of the weighting scheme is observed by the decision maker in the resulting cardinally ranked list of deficiencies.

The 50 (or fewer) deficiencies assigned to each group allows the experts to logically assess the ranking of deficiencies. If not satisfied with the results, the decision maker can revise the criteria weights and the TOPSIS program can quickly solve the problem again.

Step 4 - (Determining consensus within groups) To obtain a consensus on the prioritization of deficiencies within each group, the simple averaging of each deficiencies cardinal values is performed, and the resulting cardinal value for each deficiency is determined. This procedure will produce as many cardinally ranked lists as there are expert groups. Now a merging of the group lists must be accomplished in order to obtain an overall consensus of the experts. This consensus is termed the base list.

Step 5 - (Formulating the base list) The control deficiencies present in each group's prioritized list are used to merge the group lists into the base list, the size of the original sample. The merging formulation used here is the same process used in BDP-85 and explained in Appendix E. The base list is used in the next step, development of the strawman list.

Step 6 - (Formulating the strawman list) The deficiencies that were not sampled from the total population in Step 1 must be merged into the base list to obtain a complete list of cardinally ranked deficiencies across all mission areas. This is accomplished through the piecewise linear transformation used in BDP-85 and explained in Appendix F. Since only 35% of the total number of deficiencies must be integrated, this is a less complicated task than currently performed by TRADOC.

4.4 Using the Mission Area Proponents' Priority as a Criteria

In order to use the mission area proponents' priorities for deficiencies as a separate criteria, a special procedure is used. The objective in this case is to strengthen each proponents' prioritization scheme in the formulation of the strawman list. In the procedure described in Section 4.3, the proponent rankings of deficiencies are utilized only in the merging of the non-sampled deficiencies into the base list (Section 4.3, Step 6). It would not be unusual for the general officer experts to reorder the deficiencies within a mission area. Since the proponents are best qualified to prioritize their deficiencies, TRADOC may desire to minimize reordering of deficiencies within mission areas. By considering the proponents priority as a criteria, there will be some control or adjustment to this reordering of deficiencies within mission areas.

The proponents' priority for deficiencies could be quantified on a "high-low" scale for a MADM problem, but this does not reflect the actual difference in cardinal value between the deficiencies. The actual cardinal values cannot be used in the decision matrix since the weighting between proponents is likely different, resulting in possible advantages for one mission area or another. Therefore, when the proponent priority is desired as a criteria, the following steps are proposed to solve the BDP prioritization problem:

Phase 1
(same as Section 4.3)

1) Determine criteria
2) Proponents develop decision matrices
3) Panel validates proponent decision matrices
4) Proponents submit prioritized mission area lists

Phase 2

1) Sampling procedure
2) Assignment of deficiencies
*2a) Prepare weighted decision matrices
3) General officer expert evaluations
*4) Determine consensus within groups
5) Formulating the base list
6) Formulating the strawman list

----

* different from procedure of Section 4.3

a. Phase 1: Proponent prioritization of deficiencies The four main steps of Phase 1 are identical to those described in Section 4.3.

b. Phase 2: Developing the "strawman" list The sampling procedure (Step 1) and assignment of deficiencies (Step 2) follow the same procedure as described in Section 4.3.

Step 2a - (Prepare weighted decision matrices) At this step, TRADOC analysts revise the proponent decision matrices by multiplying each deficiency (matrix entry) by the weights used by the proponent for that criteria. This is shown on the following page:

(Proponent decision matrix)

$$D = \begin{array}{c} \\ AVN01 \\ AVN02 \\ \vdots \\ AVN\ m \end{array} \begin{array}{c} \begin{array}{cccc} X_1 & X_2 & \cdots & X_n \end{array} \\ \left[\begin{array}{cccc} X_{11} & X_{12} & \cdots & X1n \\ X_{21} & X_{22} & \cdots & X_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ X_{m1} & X_{m2} & \cdots & Xmn \end{array}\right] \end{array}$$

Analysts recall the proponents established set of criteria weights $\underline{w} = (w_1, w_2, \ldots, w_n), \sum_{j=1}^{n} w_j = 1.$

The weighted decision matrix is calculated by multiplying each column of the matrix D with its associated weight, w_j. The weighted decision matrix is equal to

$$V = \left[\begin{array}{cccc} w_1x_{11} & w_2x_{12} & \cdots & w_nx_{1n} \\ w_1x_{21} & w_2x_{22} & \cdots & w_nx_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ w_1x_{m1} & w_2x_{n2} & \cdots & w_nx_{mn} \end{array}\right]$$

Analysts assemble the decision matrices for the experts by extracting the values from the matrix V for each of the sampled deficiencies. Step 3 (General officer evaluations) is conducted in the same manner described in Section 4.3.

<u>Step 4 - (Determining consensus within groups</u> Within groups, each expert has determined cardinal values for each deficiency using TOPSIS. Now, for each deficiency an average

cardinal value is calculated. If, for example, there are four experts in one group and their cardinal values for the LOG01 deficiency are 0.776, 0.674, 0.819, then the average for the group is 0.756. Each groups average list will be determined in this manner.

To determine each separate groups consensus, the original proponent priority list and the group average list are <u>weighted</u> and <u>combined</u>. The final consensus for each group depends on the weights (importance) attached to each of the two lists, a TRADOC responsibility.

A reasonable weighting scheme would be for the proponent list to contribute 1/3 and the expert list contribute 2/3 of the total. If the LOG mission proponent value for LOG01 (Phase 1) is 0.850, the group consensus for LOG01 is:

$$(1/3)x(0.850) + (2/3)x(0.756) = 0.787$$

Therefore, the impact of the proponents' priority is applied fairly through the weighted decision matrix used by the experts and the weighting of the Phase 1 proponent lists in the final consensus calculation.

Steps 5 (Formulating the base list)and 6 (Formulating the strawman list) are unchanged from the the procedure described in Section 4.3.

4.5 <u>Numerical Example</u>

This numerical example uses the same parameters (total deficiencies, number of experts) in the hypothetical example presented in Section 2.3. Phase 1 and Phase 2 are outlined for this example using the evolutionary MCDM approach described in the previous sections of this chapter. There are two separate parts (and solutions) to the example. In part I, the proponents' priority is not considered as a criteria. In part II, proponents' priority is used as a criteria, and the procedure of Section 4.4 is followed.

PART I. (Proponents' priority is not criteria)

a. PHASE 1 (Proponent prioritization of deficiencies)

Step 1 - (Determine criteria) For this example, five criteria are selected (X1 - X5) by the Army staff and TRADOC. The first four criteria are benefit criteria and the fifth, X5, is a cost criteria ($ millions). The criteria are:

X1 - Criticality to battlefield success
X2 - Gap between current capability and mission standard
X3 - Impact on key operational capabilities
X4 - Previous BDP priority
X5 - Cost of corrective action

The scale used to assign the qualitative attributes (X1, X2, X3) to a quantitative 10 point scale is shown in Figure 4.4 below:

For Cost Attributes			For benefit attributes
	0	0	
very high	1.0	1.0	very low
high	3.0	3.0	low
average	5.0	5.0	average
low	7.0	7.0	high
very low	9.0	9.0	very high
	10.0	10.0	

Figure 4.4 Assignment of values to an interval scale Hwang and Yoon, Ref. 4, p. 28)

Additionally, TRADOC imposes the following limitations on the weighting of criteria:

- Each criteria must be weighted at least .05
- No one criteria can receive a weight of more than .40

<u>Step 2 - (Proponents develop decision matrices)</u>. In this step, the proponents evaluate mission area deficiencies identified in the MAA process against the established criteria. In this example, the decision matrix prepared by each proponent will consist of m deficiencies and n = 5 criteria.

The decision matrices prepared by CAA, LOG, and AVN mission area proponents are shown on the following page:

		X1	X2	X3	X4	X5
MA1 (CAA)	CAA 01	9.00	9.00	9.00	8.00	250.00
	CAA 02	6.00	7.00	6.00	6.00	125.00
	CAA 03	8.00	7.00	9.00	5.00	289.00
	CAA 04	5.00	5.00	5.00	7.00	200.00
	CAA 05	9.00	7.00	7.00	9.00	550.00
	CAA 06	6.00	7.00	5.00	5.00	260.00
	CAA 07	7.00	9.00	9.00	6.00	600.00
	CAA 08	5.00	3.00	4.00	2.00	55.00
	CAA 09	6.00	3.00	3.00	3.00	156.00
	CAA 10	9.00	6.00	7.00	0.00	800.00

		X1	X2	X3	X4	X5
MA2 (LOG)	LOG 01	9.00	9.00	9.00	8.00	300.00
	LOG 02	7.00	9.00	4.00	9.00	250.00
	LOG 03	8.00	8.00	8.00	3.00	75.00
	LOG 04	7.00	8.00	9.00	4.00	125.00
	LOG 05	9.00	9.00	9.00	9.00	534.00
	LOG 06	7.00	7.00	7.00	7.00	235.00
	LOG 07	8.00	7.00	6.00	9.00	385.00
	LOG 08	5.00	8.00	8.00	7.00	100.00
	LOG 09	8.00	5.00	5.00	5.00	59.00
	LOG 10	7.00	7.00	5.00	5.00	215.00
	LOG 11	6.00	6.00	7.00	5.00	55.00
	LOG 12	5.00	6.00	9.00	5.00	200.00
	LOG 13	5.00	6.00	5.00	4.00	85.00
	LOG 14	6.00	3.00	7.00	5.00	90.00
	LOG 15	8.00	4.00	3.00	5.00	400.00
	LOG 16	6.00	3.00	8.00	4.00	39.00
	LOG 17	7.00	5.00	5.00	0.00	215.00
	LOG 18	4.00	4.00	9.00	0.00	25.00
	LOG 19	4.00	4.00	4.00	4.00	90.00

		X1	X2	X3	X4	X5
MA3 (AVN)	AVN 01	9.00	8.00	9.00	9.00	300.00
	AVN 02	9.00	7.00	7.00	9.00	450.00
	AVN 03	8.00	7.00	8.00	7.00	325.00
	AVN 04	7.00	6.00	6.00	6.00	125.00
	AVN 05	8.00	5.00	5.00	7.00	450.00
	AVN 06	6.00	7.00	8.00	7.00	590.00
	AVN 07	6.00	6.00	9.00	5.00	150.00
	AVN 08	7.00	4.00	7.00	0.00	150.00
	AVN 09	7.00	4.00	3.00	3.00	75.00
	AVN 10	4.00	7.00	7.00	5.00	250.00
	AVN 11	5.00	5.00	8.00	0.00	100.00
	AVN 12	5.00	5.00	5.00	5.00	175.00

Step 3 - (Panel validates proponent decision matrices) This step is critical in the BDP process. For the purposes of the numerical example, however, it is assumed that the data (scoring) of the decision matrices submitted are accurate. Therefore, the panel validates each matrix as an accurate rating of deficiencies against the criteria.

Step 4 - (Proponents submit prioritized mission area lists) Using the restrictions for weighting established by TRADOC, each proponent determines the weighting scheme to be used to evaluate their respective decision matrices. Any method of weighting can be used. The Saaty eigenvector approximation method is suitable and is easily programmed for use on the computer. The weighting schemes determined by the three proponents for this example are shown below:

	X1	X2	X3	X4	X5
CAA	0.20	0.20	0.20	0.20	0.20
LOG	0.34	0.26	0.15	0.15	0.10
AVN	0.40	0.28	0.19	0.08	0.05

Using these weights, each proponent decision matrix is solved using the TOPSIS subroutine. With the computer, the TOPSIS rank ordering of deficiencies is almost immediate, providing the decision maker(s) the opportunity to see the impact of their criteria weighting and adjust it to obtain a final solution as they see fit. For simplicity, the decision matrix data for this example was set up so that the rank ordering solution would match the numerical order of the proponents deficiencies. This will make it easier to follow the proponents deficiencies through Phase 1 and Phase 2. The prioritized lists are shown in Table 4.1 for each proponent. These rankings by the proponents will be considered as another criteria to be applied later in the formulation of the strawman list.

b. Phase 2: (Developing the strawman list)

Step 1 - (Sampling procedure) Sampling the top 60% and the bottom 5% of deficiencies from each proponent prioritized lists determines the deficiencies to be used in the Phase 2 general officer evaluations. This sample of 28 deficiencies is shown below:

MA 1	MA 2	MA 3
CAA 01	LOG 01	AVN 01
CAA 02	LOG 02	AVN 02
CAA 03	LOG 03	AVN 03
CAA 04	LOG 04	AVN 04
CAA 05	LOG 05	AVN 05
CAA 06	LOG 06	AVN 06
CAA 10	LOG 07	AVN 07
	LOG 08	AVN 12
	LOG 09	
	LOG 10	
	LOG 11	
	LOG 12	
	LOG 19	

Step 2 - (Assignment of deficiencies) Since there is no concern that any group of experts would be assigned more than 50 deficiencies for this example, the number of groups to be used can be arbitrarily set. For this example, the group of 14 experts is split into three subgroups -- A, B, and C. Groups A and B have five experts each, while group C has only four

Table 4.1 Proponents Prioritized Lists (Example)

Rank	Deficiency	Cardinal Value
1	CAA 01	0.82
2	CAA 02	0.71
3	CAA 03	0.67
4	CAA 05	0.64
5	CAA 05	0.60
6	CAA 06	0.60
7	CAA 07	0.54
8	CAA 08	0.52
9	CAA 09	0.50
10	CAA 10	0.27
1	LOG 01	0.78
2	LOG 02	0.69
3	LOG 03	0.68
4	LOG 04	0.67
5	LOG 05	0.66
6	LOG 06	0.65
7	LOG 07	0.65
8	LOG 08	0.62
9	LOG 09	0.60
10	LOG 10	0.59
11	LOG 11	0.58
12	LOG 12	0.50
13	LOG 13	0.48
14	LOG 14	0.47
15	LOG 15	0.45
16	LOG 16	0.44
17	LOG 17	0.41
18	LOG 18	0.40
19	LOG 19	0.38
1	AVN 01	0.92
2	AVN 02	0.79
3	AVN 03	0.77
4	AVN 04	0.58
5	AVN 05	0.57
6	AVN 06	0.55
7	AVN 07	0.54
8	AVN 08	0.46
9	AVN 09	0.41
10	AVN 10	0.39
11	AVN 11	0.37
12	AVN 12	0.31

experts. Each group is randomly assigned 10 deficiencies, one of which (LOG 06) is a control deficiency. This is the only deficiency common to each group. The assignment of the 28 deficiencies to the three groups is shown in Table 4.2.

Table 4.2 Assignment of deficiencies - Phase 2

GROUP A	GROUP B	GROUP C
CAA 01	CAA 02	CAA 03
CAA 05	CAA 04	CAA 06
LOG 04	CAA 10	LOG 02
LOG 06 *	LOG 01	LOG 05
LOG 08	LOG 03	LOG 06 *
LOG 11	LOG 06 *	LOG 09
LOG 19	LOG 07	LOG 12
AVN 02	LOG 10	AVN 01
AVN 06	AVN 04	AVN 03
AVN 07	AVN 05	AVN 12

* Control deficiency

<u>Step 3 - (General officer expert evaluations)</u> Using the scoring provided by each proponent, TRADOC prepares the decision matrices for each group of general officers. Along with the fact-sheets on the assigned deficiencies, each expert is provided the percentile ranking of each deficiency by the mission proponent.

Each general officer expert determines the criteria weights (X1 - X5) and then the decision matrix can be calculated. At this point, the expert can review the prioritized list of 10 deficiencies, and if not satisfied, revises the weighting of criteria to obtain a different solution. In this example, only the decision matrix, criteria weights, and prioritized list for each of the four experts in <u>group C</u> are shown to demonstrate the group merging procedure.

(Group C Decision Matrix)

CAA 03	8.00	7.00	9.00	5.00	289.00
CAA 06	6.00	7.00	5.00	5.00	260.00
LOG 02	7.00	9.00	4.00	9.00	250.00
LOG 05	9.00	9.00	9.00	9.00	534.00
LOG 06	7.00	7.00	7.00	7.00	235.00
LOG 09	8.00	5.00	5.00	5.00	59.00
LOG 12	5.00	6.00	9.00	5.00	200.00
AVN 01	9.00	8.00	9.00	9.00	300.00
AVN 03	8.00	7.00	8.00	7.00	325.00
AVN 12	5.00	5.00	5.00	5.00	175.00

(Criteria Weights)

Expert	X1	X2	X3	X4	X5
1	0.20	0.20	0.20	0.20	0.20
2	0.40	0.30	0.20	0.05	0.05
3	0.35	0.25	0.25	0.05	0.10
4	0.25	0.35	0.24	0.10	0.05

(TOPSIS Results for Group C)

Expert	1		2		3		4	
	LOG 09	0.63	AVN 01	0.83	AVN 01	0.76	AVN 01	0.81
	AVN 01	0.62	LOG 05	0.79	CAA 03	0.67	LOG 05	0.78
	LOG 06	0.60	CAA 03	0.68	LOG 05	0.64	CAA 03	0.64
	LOG 12	0.57	AVN 03	0.66	AVN 03	0.63	AVN 03	0.62
	LOG 02	0.57	LOG 02	0.54	LOG 05	0.56	LOG 02	0.54
	CAA 03	0.54	LOG 06	0.53	LOG 09	0.52	LOG 06	0.54
	AVN 12	0.52	LOG 09	0.47	LOG 02	0.49	LOG 12	0.47
	AVN 03	0.51	LOG 12	0.38	LOG 12	0.48	CAA 06	0.36
	CAA 06	0.46	CAA 06	0.34	CAA 06	0.37	LOG 09	0.35
	LOG 05	0.42	AVN 12	0.19	AVN 12	0.32	AVN 12	0.20

Step 4 - (Determining consensus within groups) To obtain the consensus of the four experts in group C, the average cardinal value for each deficiency is calculated. Three significant digits are used in the remainder of the example. The resulting prioritized list for group C is:

(Group C)

Rank	Deficiency	Value
1	AVN 01	0.755
2	LOG 05	0.658
3	CAA 03	0.633
4	AVN 03	0.605
5	LOG 06 *	0.558
6	LOG 02	0.535
7	LOG 09	0.493
8	LOG 12	0.475
9	CAA 06	0.383
10	AVN 12	0.305

----

*Control deficiency

Similarly, the prioritized lists for groups A and B are calculated:

(Group A)

Rank	Deficiency	Value
1	CAA 01	0.775
2	CAA 05	0.768
3	AVN 02	0.738
4	AVN 06	0.623
5	LOG 04	0.570
6	LOG 06 *	0.545
7	LOG 08	0.458
8	AVN 07	0.443
9	LOG 11	0.363
10	LOG 19	0.025

(Group B)

Rank	Deficiency	Value
1	LOG 01	0.853
2	LOG 03	0.720
3	LOG 06 *	0.610
4	LOG 07	0.593
5	AVN 04	0.540
6	CAA 02	0.535
7	LOG 10	0.518
8	AVN 05	0.440
9	CAA 04	0.400
10	CAA 10	0.398

----

*Control deficiency

Step 5 - (Formulating the base list) Lists from groups A, B, and C are now merged to formulate the base list. Using the merging formulation in Appendix E, one of the lists (C in this case) is selected as a base for the merging of the other two lists. Two constants must be determined to transform the values in list A and B. The constant for

the first merge is $a = \frac{.558}{.545} = 1.024$ and for

the second merge is $a = \frac{.558}{.610} = 0.915.$

Multiplying the values in lists A and B by the first and second constants respectively transforms the values of these lists and permits the combination and ranking with the list from group C. The resulting base list is shown in Table 4.3.

Table 4.3 Phase 2 Base List

Rank	Deficiency	Value
1	CAA 01	0.794
2	CAA 05	0.786
3	LOG 01	0.780
4	AVN 02	0.756
5	AVN 01	0.755
6	LOG 03	0.659
7	LOG 05	0.658
8	AVN 06	0.638
9	CAA 03	0.633
10	AVN 03	0.605
11	LOG 04	0.584
12	LOG 06	0.558
13	LOG 07	0.543
14	LOG 02	0.535
15	AVN 04	0.494
16	LOG 09	0.493
17	CAA 02	0.489
18	LOG 12	0.475
19	LOG 10	0.474
20	LOG 08	0.469
21	AVN 07	0.454
22	AVN 05	0.403
23	CAA 06	0.383
24	LOG 11	0.372
25	CAA 04	0.366
26	CAA 10	0.364
27	AVN 12	0.305
28	LOG 19	0.026

Step 6 - (Formulating the strawman list) Using the piece-wise linear transformation explained in Appendix F and demonstrated in Section 2.3, the deficiencies that were not sampled in Phase 2 (a total of 13) are integrated into the base list to obtain the strawman list (Table 4.4).

Table 4.4 Phase 2 Strawman List

Rank	Deficiency	Value	Rank	Deficiency	Value
1	CAA 01	0.794	22	AVN 05	0.403
2	CAA 05	0.786	23	AVN 08	0.402
3	LOG 01	0.780	24	LOG 13	0.400
4	AVN 02	0.756	25	CAA 06	0.383
5	AVN 01	0.755	26	CAA 07	0.380
6	LOG 03	0.659	27	CAA 08	0.379
7	LOG 05	0.658	28	CAA 09	0.378
8	AVN 06	0.638	29	LOG 11	0.372
9	CAA 03	0.633	30	AVN 09	0.370
10	AVN 03	0.605	31	CAA 04	0.366
11	LOG 04	0.584	32	CAA 10	0.364
12	LOG 06	0.558	33	LOG 14	0.363
13	LOG 07	0.543	34	AVN 10	0.357
14	LOG 02	0.535	35	AVN 11	0.344
15	AVN 04	0.494	36	AVN 12	0.305
16	LOG 09	0.493	37	LOG 15	0.288
17	CAA 02	0.489	38	LOG 16	0.251
18	LOG 12	0.475	39	LOG 17	0.138
19	LOG 10	0.474	40	LOG 18	0.101
20	LOG 08	0.469	41	LOG 19	0.026
21	AVN 07	0.454			

The strawman list is sent to each mission area proponent for review and comment to complete Phase 2.

PART II. Using the Proponents' Priority as a Criteria

a. Phase 1 (Proponent prioritization of deficiencies)

The procedures of Phase 1 in Part II of this numerical example follows the same calculations presented in Part I, so these steps will not be repeated here. The decision matrices, proponent weights, and prioritized lists (Table 4.1) are identical to those shown in Part I.

b. Phase 2 (Developing the strawman list)

Step 1 (Sampling procedure) and Step 2 (Assignment of deficiencies) are conducted in an identical manner as in Part I. In this example, the three groups of experts (A, B, and C) receive the same deficiencies for evaluation (See Table 4.2). Now, a new step is introduced - the preparation of weighted decision matrices.

Step 2a - (Prepare weighted decision matrices) In this step, the proponent decision matrices are revised by multiplying each column of the matrices by the corresponding criteria weight, obtaining weighted decision matrices for each proponent. These weighted matrices are shown in Table 4.5. The information (values) contained in weighted matrices is used to prepare the general officer expert matrices for their evaluations.

Table 4.5 Weighted Decision Matrices

	X1	X2	X3	X4	X6
CAA 01	1.80	1.80	1.80	1.60	50.00
CAA 02	1.20	1.40	1.20	1.20	24.00
CAA 03	1.60	1.40	1.80	1.00	57.80
CAA 04	1.00	1.00	1.00	1.40	40.00
CAA 05	1.80	1.40	1.40	1.80	110.00
CAA 06	1.20	1.40	1.00	1.00	52.00
CAA 07	1.40	1.80	1.80	1.20	120.00
CAA 08	1.00	0.60	0.80	0.40	11.00
CAA 09	1.20	0.60	0.60	0.60	31.20
CAA 10	1.80	1.20	1.40	0.00	160.00
LOG 01	3.06	2.34	1.35	1.20	30.00
LOG 02	2.38	2.34	0.60	1.35	25.00
LOG 03	2.72	2.08	1.20	0.45	7.50
LOG 04	2.38	2.08	1.35	0.60	12.50
LOG 05	3.06	2.34	1.35	1.35	53.40
LOG 06	2.38	1.82	1.05	1.05	23.50
LOG 07	2.72	1.82	0.90	1.35	38.50
LOG 08	1.70	2.08	1.20	1.05	10.00
LOG 09	2.72	1.30	0.75	0.75	5.90
LOG 10	2.38	1.82	0.75	0.75	21.50
LOG 11	2.04	1.56	1.05	0.75	5.50
LOG 12	1.70	1.56	1.35	0.75	20.00
LOG 13	1.70	1.56	0.75	0.60	8.50
LOG 14	2.04	0.78	1.05	0.75	9.00
LOG 15	1.70	0.78	1.20	0.60	3.90
LOG 16	2.72	1.04	0.45	0.75	40.00
LOG 17	2.38	1.30	0.75	0.00	21.50
LOG 18	1.36	1.04	1.35	0.00	2.50
LOG 19	1.36	1.04	0.60	0.60	9.00
AVN 01	3.60	2.24	1.71	0.72	15.00
AVN 02	3.60	1.96	1.33	0.72	22.50
AVN 03	3.20	1.96	1.52	0.56	16.25
AVN 04	2.80	1.68	1.14	0.48	6.25
AVN 05	3.20	1.40	0.95	0.56	22.50
AVN 06	2.40	1.96	1.52	0.56	29.50
AVN 07	2.40	1.68	1.71	0.40	7.50
AVN 08	2.80	1.12	1.33	0.00	7.50
AVN 09	2.80	1.12	0.57	0.24	3.75
AVN 10	1.60	1.96	1.33	0.40	12.50
AVN 11	2.00	1.40	1.52	0.00	5.00
AVN 12	2.00	1.40	0.95	0.40	8.75

<u>Step 3 - (General Officer Expert Evaluations)</u> As demonstrated in Part I, only the evaluations for Group C are shown

in detail here. The decision matrix of the selected deficiencies to be evaluated by the four experts in Group C is:

D =

	X1	X2	X3	X4	X5
CAA 03	1.60	1.40	1.80	1.00	57.81
CAA 06	1.20	1.40	1.00	1.00	52.00
LOG 02	2.38	2.34	0.60	1.35	25.00
LOG 05	3.06	2.34	1.35	1.35	53.40
LOG 06	2.38	1.82	1.05	1.05	23.50
LOG 09	2.27	1.30	0.75	0.75	5.90
LOG 12	1.70	1.56	1.35	0.75	20.00
AVN 01	3.60	2.24	1.71	0.72	15.00
AVN 03	3.20	1.96	1.52	0.56	16.25
AVN 12	2.00	1.40	0.95	0.40	8.75

The criteria weights established by the experts are:

Expert	X1	X2	X3	X4	X5
1	0.20	0.20	0.20	0.20	0.20
2	0.40	0.30	0.20	0.05	0.05
3	0.35	0.25	0.25	0.05	0.10
4	0.25	0.35	0.24	0.10	0.05

The ordered solution (solved using TOPSIS) for each expert is:

Expert 1		2		3		4	
AVN 01	0.73	AVN 01	0.92	AVN 01	0.90	AVN 01	0.84
AVN 03	0.64	AVN 03	0.77	AVN 03	0.77	LOG 05	0.72
LOG 09	0.58	LOG 05	0.73	LOG 05	0.65	AVN 03	0.70
LOG 06	0.58	LOG 02	0.49	LOG 09	0.49	LOG 02	0.50
LOG 02	0.57	LOG 06	0.48	LOG 06	0.48	LOG 06	0.48
LOG 12	0.53	LOG 09	0.48	LOG 02	0.45	CAA 03	0.46
AVN 12	0.51	CAA 03	0.36	CAA 03	0.41	LOG 12	0.39
LOG 05	0.50	AVN 12	0.32	LOG 12	0.40	LOG 09	0.37
CAA 03	0.38	LOG 12	0.32	AVN 12	0.39	AVN 12	0.30
CAA 06	0.28	CAA 06	0.14	CAA 06	0.17	CAA 06	0.23

<u>Step 4 - (Determining consensus within groups)</u> The consensus <u>within</u> groups is a revised procedure from that shown in Part I. First, the average cardinal value for each .pa

deficiency is calculated. This list of average values for Group C is:

Rank	Deficiency	Value
1	AVN 01	0.848
2	AVN 03	0.720
3	LOG 05	0.650
4	LOG 06 *	0.505
5	LOG 02	0.502
6	LOG 09	0.480
7	LOG 12	0.410
8	CAA 03	0.402
9	AVN 12	0.380
10	CAA 06	0.205

*control deficiency

Similarly, the prioritized lists for Groups A and B are calculated as:

(Group A)

Rank	Deficiency	Value
1	AVN 02	0.603
2	CAA 05	0.525
3	CAA 01	0.503
4	LOG 06 *	0.483
5	AVN 06	0.480
6	LOG 04	0.448
7	AVN 07	0.440
8	LOG 08	0.363
9	LOG 11	0.250
10	LOG 19	0.040

(Group B)

Rank	Deficiciency	Value
1	LOG 01	0.903
2	LOG 03	0.758
3	LOG 07	0.700
4	AVN 04	0.698
5	LOG 06 *	0.685
6	AVN 05	0.650
7	LOG 10	0.623
8	CAA 02	0.483
9	CAA 04	0.400
10	CAA 10	0.293

*control deficiency

To determine the consensus for each group, the original proponents' cardinal value and the averages for deficiencies just calculated are weighted and combined. The weight for the proponents' prioritization (Table 4.1) is set at 1/3 and the expert (Group) lists at 2/3. Calculation of the consensus for deficiency AVN 03 is:

$$(1/3)\times(.770) + (2/3)\times(.720) = .736$$

In this manner, the consensus for each deficiency within each group is calculated. The consensus for each group is shown in Table 4.6.

Table 4.6 Ordered Group Consensus List
(using proponents' priority)

	Deficiency	Value
(Group A)	AVN 02	0.672
	CAA 01	0.608
	CAA 05	0.550
	LOG 06 *	0.538
	LOG 04	0.522
	AVN 06	0.503
	AVN 07	0.473
	LOG 08	0.448
	LOG 11	0.360
	LOG 19	0.153
(Group B)	LOG 01	0.862
	LOG 03	0.732
	LOG 07	0.683
	LOG 06 *	0.673
	AVN 04	0.658
	AVN 05	0.623
	LOG 10	0.612
	CAA 02	0.558
	CAA 04	0.480
	CAA 10	0.285
(Group C)	AVN 01	0.872
	AVN 03	0.736
	LOG 05	0.653
	LOG 02	0.564
	LOG 06 *	0.553
	LOG 09	0.520
	CAA 03	0.491
	LOG 12	0.440
	AVN 12	0.357
	CAA 06	0.336

Step 5 - (Formulating the base list) This step is conducted using the same procedure shown in Part I. The three group lists are merged to formulate the base list. The consensus list from Group C is used as the base to merge the other two lists. The constants determined for the mergings are:

$$\text{(List A merge)} \quad a = \frac{.553}{.538} = 0.991$$

$$\text{(List B merge)} \quad a = \frac{.553}{.673} = 0.822$$

The base list (Table 4.7) is determined by ordering the three groups of deficiencies after the transformation of Group A and Group B values. This baselist can be compared with the base list shown in Table 4.3 to observe the effect of using the proponents' priority as a criteria.

Table 4.7 Phase 2 Base List
(using proponents' priority)

Rank	Deficiency	Value
1	AVN 01	0.872
2	AVN 03	0.736
3	LOG 01	0.709
4	AVN 02	0.666
5	LOG 05	0.653
6	CAA 01	0.603
7	LOG 03	0.602
8	LOG 02	0.564
9	LOG 07	0.561
10	LOG 06	0.553
11	CAA 05	0.545
12	AVN 04	0.541
13	LOG 09	0.520
14	LOG 04	0.517
15	AVN 05	0.512
16	LOG 10	0.503
17	AVN 06	0.498
18	CAA 03	0.491
19	AVN 07	0.469
20	CAA 02	0.459
21	LOG 08	0.444
22	LOG 12	0.440
23	CAA 04	0.395
24	CAA 06	0.357
25	AVN 12	0.357
26	LOG 11	0.357
27	CAA 10	0.234
28	LOG 19	0.152

Step 6 - (Formulating the strawman list) The strawman list is constructed in the same manner used in Part I (Step 6), using piecewise linear transformation. The strawman list formulated using the original five criteria and the proponents' priority as a separate criteria is shown in Table 4.8. This list can be compared with Table 4.5 to observe the effect of using the proponents' priority as a separate criteria.

Table 4.8 Phase 2 Strawman List
(using proponents' priority)

Rank	Deficiency	Value	Rank	Deficiency	Value
1	AVN 01	0.872	21	LOG 08	0.444
2	AVN 03	0.736	22	LOG 12	0.440
3	LOG 01	0.709	23	AVN 08	0.430
4	AVN 02	0.666	24	AVN 09	0.406
5	LOG 05	0.653	25	AVN 10	0.396
6	CAA 01	0.603	26	CAA 04	0.395
7	LOG 03	0.602	27	LOG 13	0.392
8	LOG 02	0.564	28	AVN 11	0.386
9	LOG 07	0.561	29	LOG 14	0.368
10	LOG 06	0.553	30	LOG 11	0.357
11	CAA 05	0.545	31	CAA 06	0.357
12	AVN 04	0.541	32	AVN 12	0.357
13	LOG 09	0.520	33	CAA 07	0.334
14	LOG 04	0.517	34	CAA 08	0.327
15	AVN 05	0.512	35	LOG 15	0.320
16	LOG 10	0.503	36	CAA 09	0.319
17	AVN 06	0.498	37	LOG 16	0.296
18	CAA 03	0.491	38	CAA 10	0.234
10	AVN 07	0.469	39	LOG 17	0.224
20	CAA 02	0.459	40	LOG 18	0.200
			41	LOG 19	0.152

Chapter 5

A REFORMED APPROACH USING MULTIPLE CRITERIA DECISION MAKING

5.1 Introduction

The alternative presented in this chapter also uses the tools and techniques of MCDM. However, the framework of the current BDP process is more thoroughly changed in this approach. The technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is selected again as the MADM method to cardinally rank order the battlefield deficiencies identified by the mission area proponents. The most significant modification from the evolutionary MCDM approach is the absence of the Phase 2 sampling process. Instead, the Phase 2 experts evaluate all deficiencies using TOPSIS and an averaging process is used to obtain the consensus of the experts. The proponents weighting and priorities for deficiencies serve as a criteria so that their evaluations impact on the formulation of the strawman list (similar to Part II, Section 4.4).

The reformed approach is a straight forward, scientific procedure. The application of this approach relies on the use of computers at every stage. The reformed approach is a structured process that can be adapted easily to the changing battlefield criteria which influence the prioritization of battlefield deficiencies.

5.2 Description of the Reformed Approach

Since Phase 3 is unchanged from the BDP-85 process, the reformed approach is described here by the activities of Phase 1 and Phase 2. The flow diagram of the reformed approach is shown at Figure 5.1.

a. Phase 1 (Proponent prioritization of deficiencies)

The steps of Phase 1 are identifical to the evolutionary approach described in Section 4.3. They are:

1) Determine criteria
2) Proponents develop decision matrices
3) Panel validates proponent decision matrices
4) Proponents submit prioritized mission area lists

There are no differences in the procedure for Phase 1 between the evolutionary and reformed approaches. Each method relies on the accurate development of decision matrices by the mission area proponents and the validation of this information by the appropriate integrating center panel. Proponent decision makers determine criteria weights to formulate their own prioritized mission area deficiency lists. Refer to Section 4.3 for a detailed description of Phase 1.

b. Phase 2 (Developing the "strawman list")

There are four main steps in formulating the Phase 2 strawman list using the reformed approach:

1) Prepare weighted decision matrix
2) General officer expert evaluations
3) Determine the consensus of experts
4) Formulating the strawman list

Step 1 - (Prepare weighted decision matrix) TRADOC analysts review the criteria weighting used by the mission area proponents and develop one weighted decision matrix which contains all mission area deficiencies. This is similar to the method of Section 4.4, Part II, Step 2a. Refer to Table 4.5 for an example of the weighted decision matrix.

Step 2 - (General officer expert evaluations) Since each proponent has evaluated deficiencies based on the same criteria, TRADOC can construct a single weighted decision matrix containing all of the identified deficiencies. The general officer experts receive an evaluation package that includes fact sheets for each deficiency, the weighted decision matrix, and an explanation of the criteria to be used. Additionally, the experts are aware of each deficiencies percentile ranking established by the proponent.

At this step, the separate general officer experts evaluate the criteria to determine a preference for weighting within any restrictions imposed by TRADOC. After establishing a weighting scheme, each expert can solve the MADM problem using the TOPSIS program. This computer aided process allows the decision maker to view the resulting cardinal value ranking of each deficiency. The decision maker retains the choice of adjusting the weights of the criteria and resolving the decision matrix. When the expert is satisfied with the prioritized listing, his output is forwarded to TRADOC to be used in the next step.

Step 3 - (Determining the consensus of the experts) To determine the consensus of the general officer experts, the cardinal values determined by TOPSIS are totaled for each deficiency, then divided by the number of experts to obtain the average cardinal values. This averaging process results in one ordered list that includes all mission deficiencies. The values of this list are used in the final step, formulating the strawman list.

Step 4 - (Formulating the strawman list) The values from the proponents' prioritized lists of Phase 1 and the consensus of general officer experts are used to construct the strawman list in the reformed approach. TRADOC will specify the weighting (importance) of each value. If for instance the weight for the proponents' priority is established as 1/3, then the proponents' cardinal value for a particular deficiency is multipled by 1/3 and the cardinal value established by the general officer experts is multiplied by the remaining 2/3. These two values are added to determine the actual strawman value for the deficiency.

After the strawman list is formulated, it is sent out to the mission proponents for review and comment. Phase 3 of this approach follows the same procedure that is currently in effect at TRADOC.

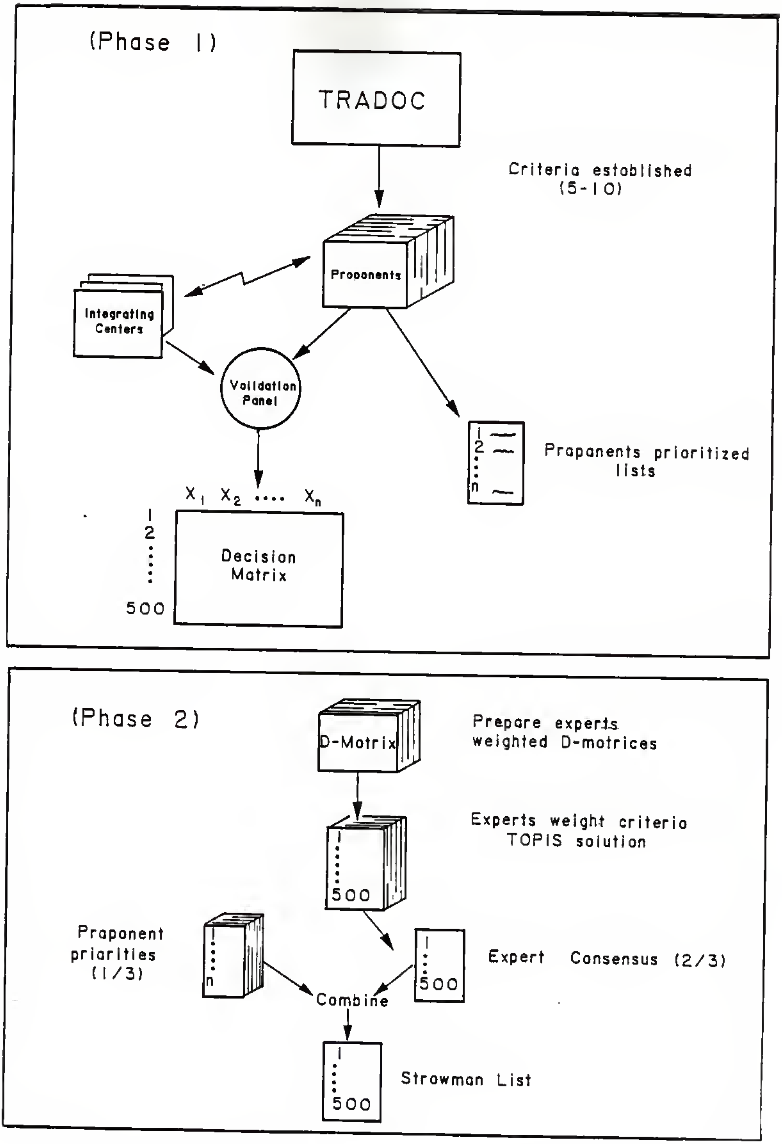


Figure 5.1 Flow Diagram of Reformed Approach

5.3 Numerical Example

This numerical example employs the same parameters as used in example presented in Sections 2.3 and 4.5. Phase 1 and Phase 2 are described in this example using the reformed MCDM approach.

a. Phase 1 (Proponent prioritization of deficiencies)

Steps 1-4 of Phase 1 are performed in the same manner as the evolutionary approach of Section 4.5. The same five criteria are used and the proponents develop their decision matrices according to the criteria. Proponent prioritized lists are determined using TOPSIS after a weighting scheme for the criteria has been established. The proponents' prioritized lists are shown in Table 5.1 (same as Table 4.1).

b. Phase 2 (Developing the strawman list)

Step 1 - (Prepare weighted decision matrix) In this step, TRADOC weights the BDP deficiencies according to the criteria weights established by the respective proponents in Phase 1. This is the same step used in Part II of Section 4.5. This weighted matrix with the 41 deficiencies is shown in Table 5.2.

Table 5.1 Proponents Prioritized Lists (Example)

Rank	Deficiency	Cardinal Value
1	CAA 01	0.82
2	CAA 02	0.71
3	CAA 03	0.67
4	CAA 04	0.64
5	CAA 05	0.60
6	CAA 06	0.60
7	CAA 07	0.54
8	CAA 08	0.52
9	CAA 09	0.50
10	CAA 10	0.27
1	LOG 01	0.78
2	LOG 02	0.69
3	LOG 03	0.68
4	LOG 04	0.67
5	LOG 05	0.66
6	LOG 06	0.65
7	LOG 07	0.65
8	LOG 08	0.62
9	LOG 09	0.60
10	LOG 10	0.59
11	LOG 11	0.58
12	LOG 12	0.50
13	LOG 13	0.48
14	LOG 14	0.47
15	LOG 15	0.45
16	LOG 16	0.44
17	LOG 17	0.41
18	LOG 18	0.40
19	LOG 19	0.38
1	AVN 01	0.92
2	AVN 02	0.79
3	AVN 03	0.77
4	AVN 04	0.58
5	AVN 05	0.57
6	AVN 06	0.55
7	AVN 07	0.54
8	AVN 08	0.46
9	AVN 09	0.41
10	AVN 10	0.39
11	AVN 11	0.37
12	AVN 12	0.31

Table 5.2 Weighted Decision Matrix

	X1	X2	X3	X4	X5
CAA 01	1.80	1.80	1.80	1.60	50.00
CAA 02	1.20	1.40	1.20	1.20	25.00
CAA 03	1.60	1.40	1.80	1.00	57.80
CAA 04	1.00	1.00	1.00	1.40	40.00
CAA 05	1.80	1.40	1.40	1.80	110.00
CAA 06	1.20	1.40	1.00	1.00	52.00
CAA 07	1.40	1.80	1.80	1.20	120.00
CAA 08	1.00	0.60	0.80	0.40	11.00
CAA 09	1.20	0.60	0.60	0.60	31.20
CAA 10	1.80	1.20	1.40	0.00	160.00
LOG 01	3.06	2.34	1.35	1.20	30.00
LOG 02	2.38	2.34	0.60	1.35	25.00
LOG 03	2.72	2.08	1.20	0.45	7.50
LOG 04	2.38	2.08	1.35	0.60	12.50
LOG 05	3.06	2.34	1.35	1.35	53.40
LOG 06	2.38	1.82	1.05	1.05	23.50
LOG 07	2.72	1.82	0.90	1.35	38.50
LOG 08	1.70	2.08	1.20	1.05	10.00
LOG 09	2.72	1.30	0.75	0.75	5.90
LOG 10	2.38	1.82	0.75	0.75	21.50
LOG 11	2.04	1.56	1.05	0.75	5.50
LOG 12	1.70	1.56	1.35	0.75	20.00
LOG 13	1.70	1.56	0.75	0.60	8.50
LOG 14	2.04	0.78	1.05	0.75	9.00
LOG 15	1.70	0.78	1.20	0.60	3.90
LOG 16	2.72	1.04	0.45	0.75	40.00
LOG 17	2.38	1.30	0.75	0.00	21.50
LOG 18	1.36	1.04	1.35	0.00	2.50
LOG 19	1.36	1.04	0.60	0.60	9.00
AVN 01	3.60	2.24	1.71	0.72	15.00
AVN 02	3.60	1.96	1.33	0.72	22.50
AVN 03	3.20	1.96	1.52	0.56	16.25
AVN 04	2.80	1.68	1.14	0.48	6.25
AVN 05	3.20	1.40	0.95	0.56	22.50
AVN 06	2.40	1.96	1.52	0.56	29.50
AVN 07	2.40	1.68	1.71	0.40	7.50
AVN 08	2.80	1.12	1.33	0.00	7.50
AVN 09	2.80	1.12	0.57	0.24	3.75
AVN 10	1.60	1.96	1.33	0.40	12.50
AVN 11	2.00	1.40	1.52	0.00	5.00
AVN 12	2.00	1.40	0.95	0.40	8.75

Step 2 - (General officer expert evaluations Each general officer in Phase 2 receives the weighted decision matrix containing all deficiencies. The experts individually evaluate the criteria and determine weighting scheme (within any restrictions imposed). In this example, only four separate weighting schemes are considered for the 14 experts as shown in Table 5.3.

	Criteria				
Expert	X1	X2	X3	X4	X5
1-2	0.20	0.20	0.20	0.20	0.20
3-6	0.40	0.30	0.20	0.05	0.05
7-10	0.35	0.25	0.25	0.05	0.10
11-14	0.25	0.35	0.24	0.10	0.05

Using TOPSIS (according to the four different weighting schemes), four separate prioritized lists are computed and shown in Table 5.4.

Table 5.4 TOPSIS Results for Experts

Deficiency	Experts 1-2	3-6	7-10	11-14
LOG 01	0.78	0.81	0.79	0.80
LOG 02	0.73	0.60	0.60	0.63
LOG 03	0.69	0.69	0.72	0.66
LOG 04	0.70	0.64	0.69	0.66
LOG 05	0.72	0.79	0.75	0.80
LOG 06	0.73	0.59	0.63	0.61
LOG 07	0.72	0.63	0.63	0.62
LOG 08	0.74	0.51	0.59	0.62
LOG 09	0.69	0.55	0.60	0.48
LOG 10	0.67	0.56	0.59	0.55
LOG 11	0.70	0.49	0.58	0.52
LOG 12	0.68	0.45	0.55	0.52
LOG 13	0.66	0.41	0.51	0.45
LOG 14	0.67	0.40	0.52	0.38
LOG 15	0.66	0.36	0.50	0.37
LOG 16	0.59	0.48	0.50	0.39
LOG 17	0.57	0.48	0.54	0.41
LOG 18	0.60	0.35	0.50	0.39
LOG 19	0.63	0.29	0.43	0.32
CAA 01	0.71	0.53	0.59	0.65
CAA 02	0.69	0.36	0.47	0.46
CAA 03	0.61	0.44	0.52	0.53
CAA 04	0.64	0.27	0.39	0.37
CAA 05	0.49	0.42	0.43	0.52
CAA 06	0.58	0.32	0.41	0.41
CAA 07	0.42	0.44	0.45	0.57
CAA 08	0.59	0.24	0.40	0.26
CAA 09	0.56	0.22	0.36	0.24
CAA 10	0.18	0.35	0.33	0.36
AVN 01	0.75	0.90	0.90	0.81
AVN 02	0.72	0.82	0.81	0.73
AVN 03	0.71	0.80	0.81	0.72
AVN 04	0.69	0.65	0.69	0.59
AVN 05	0.66	0.65	0.66	0.54
AVN 06	0.67	0.64	0.68	0.66
AVN 07	0.68	0.62	0.69	0.62
AVN 08	0.62	0.57	0.65	0.48
AVN 09	0.62	0.52	0.57	0.41
AVN 10	0.65	0.49	0.57	0.57
AVN 11	0.62	0.49	0.60	0.50
AVN 12	0.64	0.45	0.55	0.45

Step 3 - (Determining the consensus of the experts) The four cardinal values for each deficiency in Table 5.5 are totaled and divided by four to determine the average cardinal value or consensus of the experts. This prioritized consensus list is shown in Table 5.6.

Table 5.6 General Officer Experts' Consensus (prioritized)

Rank	Deficiency	Value	Rank	Deficiency	Value
1	AVN 01	0.840	23	LOG 12	0.550
2	LOG 01	0.795	24	AVN 09	0.530
3	AVN 02	0.770	25	CAA 03	0.525
4	LOG 05	0.763	26	AVN 12	0.523
5	AVN 03	0.760	27	LOG 13	0.508
6	LOG 03	0.690	28	LOG 17	0.500
7	LOG 04	0.673	29	CAA 02	0.495
8	AVN 06	0.663	30	LOG 14	0.493
9	AVN 04	0.655	31	LOG 16	0.490
10	AVN 07	0.653	32	LOG 15	0.473
11	LOG 07	0.650	33	CAA 07	0.470
12	LOG 02	0.640	34	CAA 05	0.465
13	LOG 06	0.640	35	LOG 18	0.460
14	AVN 05	0.628	36	CAA 06	0.430
15	CAA 01	0.620	37	CAA 04	0.418
16	LOG 08	0.615	38	LOG 19	0.418
17	LOG 10	0.593	39	CAA 08	0.373
18	AVN 08	0.580	40	CAA 09	0.345
19	LOG 09	0.580	41	CAA 10	0.305
20	LOG 11	0.573			
21	AVN 10	0.570			
22	AVN 11	0.553			

Step 4 - (Formulating the strawman list) Like the example of Section 4.5 (Part II), TRADOC specifies a 1/3 weight for the proponents' prioritized list and 2/3 weighting for the general officer consensus just constructed in Step 3. The calculation for AVN 01 is:

$$(1/3)(.92) + (2/3)(.840) = 0.866$$

The final strawman list for the reformed approach is shown in Table 5.7.

Table 5.7 Strawman List

Rank	Deficiency	Value	Rank	Deficiency	Value
1	AVN 01	0.866	22	AVN 08	0.540
2	LOG 01	0.790	23	LOG 12	0.533
3	AVN 02	0.776	24	CAA 05	0.521
4	AVN 03	0.763	25	AVN 10	0.501
5	LOG 05	0.728	26	LOG 13	0.499
6	LOG 03	0.686	27	CAA 07	0.493
7	CAA 01	0.686	28	AVN 11	0.492
8	LOG 04	0.672	29	CAA 04	0.491
9	LOG 02	0.656	30	AVN 09	0.490
10	LOG 07	0.650	31	CAA 06	0.486
11	LOG 06	0.643	32	LOG 14	0.485
12	AVN 04	0.630	33	LOG 16	0.473
13	AVN 06	0.625	34	LOG 17	0.470
14	LOG 08	0.616	35	LOG 15	0.465
15	AVN 07	0.615	36	AVN 12	0.452
16	LOG 08	0.608	37	LOG 18	0.440
17	LOG 10	0.592	38	CAA 08	0.422
18	LOG 09	0.586	39	LOG 19	0.405
19	LOG 11	0.575	40	CAA 09	0.397
20	CAA 03	0.573	41	CAA 10	0.293
21	CAA 02	0.566			

Chapter 6

CONCLUSIONS

The thesis analyzed the TRADOC prioritization problem and proposed two alternative methods to solve the BDP problem using multiple criteria decision making. Despite lacking a working knowledge of the BDP process, a solid understanding of the problem and TRADOC procedure was obtained through personal contacts and literature study. It is clear that the use of multiple criteria decision making in the annual prioritization of battlefield deficiencies is sensible.

Analysis of the BDP-85 process revealed certain strengths, but also significant weaknesses. The current pairwise comparison of deficiencies is inadequate for determining priorities based on the many criteria relating to battlefield deficiencies. For Army planners to focus priority properly on mission area deficiencies, they must evaluate each deficiency on these multiple criteria, not simply on one or two criteria or their intuition. The BDP process is complex and although important improvements have occurred over the past few years, the process is not directly linked to the Army's objectives and it remains inflexible to battlefield scenario changes.

The multiple criteria decision making structure and solution of the BDP problem is understandable, flexible, and auditable. Two approaches using TOPSIS, a multiple attribute decision making technique were presented. Both alternatives broadened the scope of information used in the prioritization of battlefield deficiencies.

The evolutionary approach retains some features of the BDP-85 process, but it is based on the development and validation of mission area decision matrices. The validation panel proposed is vital to the acceptance and efficiency of the method. The TOPSIS program prioritizes the mission deficiencies according to the decision matrices and the criteria weighting determined by the decision makers. Two separate procedures are described for this approach depending on the selection of the mission proponents' priority as a separate criteria.

The reformed approach is even more scientifically oriented. Multiple attribute decision making remains the basis for this method in which decision makers evaluate all BDP deficiencies to formulate the strawman list.

Both alternative methods present a procedure based on the establishment of multiple criteria which influence the importance of battlefield missions and deficiencies. These structured approaches reduce the burden on decision makers and shorten the overall time required to complete the BDP.

The BDP is a critically important document with extensive influence in Army planning and development. The BDP merits the best possible prioritization procedure, one that absorbs all of the information regarding the problem. To be effective, the procedure must specify requirements in terms of quantities, time, and resources. The criteria that dominate the present and future battlefield and relate to enhancement of the Army's key operational capabilities must be the framework of the prioritization process.

The approaches presented require further refinement and analysis before they could be implemented. However, the main ideas of each method can be captured and adapted to the Army's benefit. It is strongly recommended that TRADOC research the advantages of instituting a multiple criteria approach to solve the BDP prioritization problem.

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Appendix A

(Reprint from Ref. 6)

DEFICIENCY REQUIREMENTS

In the most recent BDP processes, TRADOC has asked the various mission area proponents to submit an unconstrained prioritized list of specific mission deficiencies. In the past, the broad general nature of deficiencies made it possible to permit many material programs to be associated as potential corrective actions to high priority deficiencies. This caused difficulty in establishing an accurate linkage between BDP deficiencies and the corrective actions (many of which are LRRDAP material programs) (8). The solution to this problem was to improve the specificity of BDP deficiencies in guiding the material developer (AMC) and private industry to gauge the forecast of their developmental programs. The deficiency fact sheets (TRADOC form 870-R) are provided to identify these deficiencies and the corrective action necessary to reduce or eliminate them.

The Department of the Army (DA) has outlined certain requirements and considerations for identifying and prioritizing mission area deficiencies. These qualifications should be carefully followed in order to obtain a BDP that warrants DA visibility for action.

Qualifications for Specific MA Deficiencies

- Correction essential to AirLand Battle. Submit only those deficiencies which require visibility at the DA level to influence the allocation of resources (RDTE and procurement funds, manpower, force structure) or which have an impact on combined arms doctrine and training. This includes combat, combat support, and combat service support issues.

- Deficiency should be derived from an MAA or other analytical study efforts.
- Deficiency may include the POM programs.
- Deficiency is a statement of a proponent's inability or inadequacy to perform a cited task or subtask.
    - Inability: Lacks the capability to perform the task.
    - Inadequacy: Possesses some capability to perform the task; however, not to the required standard.

<u>Considerations for Prioritizing MA Deficiencies</u>

- How critical is the accomplishment of this task/subtask to the success of the AirLand Battle?
- To what degree does this deficiency currently exist on the battlefield? What is the gap between requirements to execute the task and the capability to execute it?
- The BDP deficiency priority influences the priority of programs in the TRADOC/AMC Long Range Research, Development, and Acquisition Plan (LRRDAP). Therefore, if the program needs to come out high in the LRRDAP, it should also be prioritized high in the BDP list of MA deficiencies.

Mission area deficiencies are broadly categorized by the proponents according to the Four Pillars of Defense. These categories provide a common language to evaluate service programs and allocate resources to correct Army deficiencies. Definitions for the Four Pillars of Defense are shown below.

<u>Force Structure</u>. The number and type of units in the force and their Authorized Levels of Organization (ALO).

<u>Readiness</u>. Ability of units to deliver design outputs (includes manning, equipping, and training of the force and the ability to deploy and employ) for successful outcome of initial missions ("initial" means first two weeks of war). It includes peacetime training and distribution of equipment and manpower to early deploying units. Mobilizing and deploying (including

lift, POMCUS, and overseas stationing) are also aspects of readiness.

Modernization. Capability improvements of units, weapons systems, and equipment (includes relatively long-term improvements through research, development, and acquisition programs, and near-term fielding of new equipment and structure).

Sustainability. The staying power of units and equipment beyond the first two weeks of war (includes adequacy of days of supply, tactical support units, and uncommitted personnel). Includes mechanisms (to include continuing mobilization), equipment, and facilities necessary to produce and deliver people and things over prolonged periods. It includes supply, repair, replacement of losses, support systems, and facilities necessary to employ resources and to distribute equipment and manpower to later deploying units.

Deficiencies are further defined according to functional packages. One or more of these packages will apply to each Army deficiency as annotated on each TRADOC fact sheet.

MAA Deficiency Functional Packages

Pkg. No.	
1	Target Acquisition: Deficiencies in the ability of the force to acquire close in and deep battle targets (cue/focus, acquire, identify, locate, and nominate).
2	Target Destruction: Deficiencies in the ability of the force to defeat a target.
3	Target Assessment: Deficiencies in the ability of the force to assess battle damage (cue assets, observe targets, BDA, determine if desired criteria is met, and feedback, decision).
4	Training Support: Pertains to ranges, training areas, training ammunition, targets, simulations, and related development and sustainment programs.
5	Deep Attack: Deficiencies related to the capability of the programmed force to conduct the deep battle (see, shoot, and maneuver deep).
6	Personnel Survivability: Ability of personnel to survive a conventional or integrated battle.

7 Equipment Survivability: Ability of equipment to survive a conventional or integrated battle.

8 Command and Control: Includes all command and control, communications, and computer programs for commanders to exercise and provide the direction for assigned forces at the strategic, operational, and tactical levels of war.

9 Surveillance/Fusion: Pertains to data gathering/receipt, intelligence preparation of the battlefield, location of emitters, collection, processing, locating, classifying, tracking, and projecting of enemy forces. Includes friendly vulnerabilities, recommended countermeasures, and support deception.

10 Deployability: Deficiencies related to capability to deploy critical systems to theater of operations in a timely manner. Movement of personnel, equipment, and supplies from present locations into the theater of operations (includes POMCUS).

11 Mobilization: Includes requirements for the mobilized force from receipt of the mobilization order until departure from mobilization stations. Includes industrial base development planning and construction.

12 Combined Arms Doctrine: Deficiencies due primarily to the absence of doctrine covering particular tasks.

13 Transport: Deficiencies in our ability to move personnel, supplies, and equipment within the theater.

14 Field Services: Includes laundry, bath, clothing exchange, bakery, salvage, decontamination, graves registration, and clothing renovation.

15 Personnel Services: Includes personnel automatic data processing support and services, personnel services to maintain unit strength, and see to the morale and welfare of the troops.

16 Tactical Communications: Communication deficiencies at corps and below.

17 Theater Communications: Communication deficiencies above corps level.

18 NBC: Deficiencies pertaining to the ability of forces to execute assigned missions on an integrated battlefield.

19 <u>Continuous Operations</u>: Ability of personnel and equipment to sustain military operations on a 24-hour basis.

20 <u>Resupply</u>: Pertains to the issue, receipt, relocation, and handling of spare parts, ammunition, and other classes of supply.

21 <u>Recovery/Repair</u>: Ability to locate, diagnose, recover, repair, and evacuate damaged or faulty equipment.

22 <u>Medical Support</u>: Ability to collect patients, conduct triage, treatment, and evacuation/disposition.

23 <u>Rear Area Operations</u>: Deficiencies in the ability to protect units, lines of communcations, installations, and facilities within the rear area.

24 <u>Missile, Munitions, EOD</u>: Deficiencies in systems, procedures, or availability.

25 <u>EMP</u>: Deficiencies in the ability to protect C3I systems from the disabling effects of electromagnetic pulse.

26 <u>Mobility/Countermobility</u>: Pertains to the inability to reduce obstacles or to improve movement of maneuver/weapon systems and supplies to and from operation areas.

27 <u>Directed Energy</u>: Deficiencies associated with directed energy weapon systems and operations.

28 <u>Light Forces</u>: Pertains to deficiencies in the antiarmor and light forces weapon systems, and support for the light forces.

29 <u>Heavy Forces</u>: Deficiencies in heavy forces to counter the projected threat.

Appendix B

(Reprint from Ref. 6)

MAJOR ARMY VECTORS AND KEY OPERATIONAL CAPABILITIES

A. Major Army Vectors. The Army's transition from planning to fielding a force capable of meeting 21st Century requirements will proceed along major complementary vectors that provide focus for incorporating change in future planning. These vectors are:

- Provide quality soldiers in the Active and Reserve components by focusing on technical and combat proficiency, strong ethical leaders, strong and healthy supporting families, quality of life programs, and personal and professional excellence.

- Fight and sustain as part of joint and combined forces by emphasizing joint and combined warfighting concepts and doctrine; improving joint support planning, rationalization, standardization, and interoperability; planning host nation support and the military assistance of other nations; and ensuring multi-service/national use of selected systems.

- Field a flexible, sustainable, balanced modernized force across the conflict spectrum by organizing appropriate heavy, light, and special operations forces with support capability for the Total Army; strengthening forward deployment; complementing allied land forces; providing optimal combat power with improved sustainability, enhancing Reserve Component capabilities, building unit cohesion, continuing to field modernize systems, and applying high leverage product improvements.

- Exploit operational and tactical dimensions of AirLand Battle Doctrine across the conflict spectrum under all climatic conditions. AirLand Battle Doctrine will be further updated by incorporating advanced operational concepts and technology to improve capabilities to execute doctrine; executing operations faster than the enemy; defeating the projected threat; and evolving to 21st Century warfighting capabilities. Efforts will continue to link training to doctrinal imperatives and pursue the Army's proper role in space.

- Develop and exploit high technology and productivity enhancements by increasing soldier day/night combat performance; developing more effective individual and unit training; fielding smaller, more lethal combat units; developing deep operations capabilities; developing more effective individual and unit training; and building more efficient facilities.

- Improve tactical and strategic deployability by lightening and downsizing the force, prepositioning stocks, planning thruput logistics, participating in joint initiatives for advanced Air Force-Navy combat developments in air and sea system capabilities, readiness and availability of Reserve Components, developing direct deployment procedures for Reserve Component units, and developing new concepts for Army mobilization.

B. Critical Tasks. As the Army moves along these vectors into the 21st Century, it will need to perform numerous tasks. Listed below are Critical Tasks the Army must accomplish to enhance its warfighting capabilities and ensure its success in combat during the long-range planning period. The most potential for accomplishing these Critical Tasks lies in the military application of the high technology and industrial advantages available to the U.S. and the melding of these advantages with the operational concepts of AirLand Battle to generate combat power. Accomplishing these Critical Tasks will also enable the Army to field a more effective fighting force before it can be countered by potential opponents. The Critical Tasks are:

- Enhance the performance of individual soldiers and battlefield leaders.
- Enhance joint and combined operational capabilities.
- Enhance the productivity of units.
- Achieve synchronization of the battlefield.
- Field a deep attack capability.
- Field a capability to defeat advanced Soviet armor.

- Achieve modernized battlefield sustainment capability.

C. Essential Tasks. The Army also needs to accomplish a number of other <u>essential tasks</u>, which, while not directly related to the battlefield, are necessary to the achievement of overall Army effectiveness. These essential tasks include:

- Develop an enhanced capability to reconstitute, reorganize, and redistribute forces after large losses on the AirLand Battlefield.

- Develop further and fully implement the Concept Based Requirements System for integrating doctrinal, structural, and equipment changes in the Army.

- Develop a significantly enhanced capability to provide security assistance worldwide.

- Reduce bulk energy and supply consumption of operational forces and the sustaining base.

- Develop means to apply advanced technology (e.g., Strategic Defense Initiatives) to land warfare.

- Develop more efficient methods for base operations support.

- Shorten the hardware acquisition cycle to allow timely incorporation of technological improvements to the force before threat countermeasures are produced or the technology is superceded by follow-on generations.

- Develop a material acquisition strategy that seeks and encourages military application of civil technology and accommodates technology progression (e.g., high leverage product improvements) during the procurement cycle and fielded life of hardware and software systems.

- Improve the interaction among industrialists, combat developers, and hardware users.

- Emphasize industrial community automation of the domestic production base for production of high technology weapon systems.

- Develop a strategic reserve of high technology components which complements an established stockpile of essential materials focused on the rapid replacement of damaged combat systems of the AirLand Battlefield.

- Improve capabilities to survive, recover, and reconstitute following strategic and tactical nuclear and chemical attacks.

D. Key Operational Capabilities. These major vectors and supporting tasks encompass many areas; however, the more important are those which enable the Army to translate AirLand Battle operational concepts into combat power. It is essential that Army planners focus priority on those specific enhancements which lead to <u>Key Operational Capabilities</u> -- Command, Control, and Communications (C3); Reconnaissance, Surveillance, and Target Acquisition (RSTA); Battlefield Lethality; Battlefield Sustainment; and Soldier and Unit Performance Enhancement (SUPE). Cutting across each of the five Key Operational Capabilities is the requirement to consider the concept of <u>lightness</u>. It applies to all developments and is multi-faceted. Lightness includes reducing the weight of equipment, creating smaller more effective units without reducing fire power, improving deployability and agility, and developing new approaches for doing more with less. It is more specific items or the sum of those items. It is a state of mind. Achieving these Key Operational Capabilities will enable the Army to execute the Critical Tasks and realize the order to magnitude improvement in warfighting capability necessary for optimal execution of AirLand Battle doctrine.

These capabilities will provide the means of maintaining balance between an ever evolving doctrine and technological progress while permitting the Army to accomplish the Critical

Tasks. Objectives, tasks, and defining systems, programs, and technology challenges have been determined for each Key Operational Capability.

E. Key Operational Capability Objectives. Objectives for each Key Operational Capability to enhance Army warfighting capabilities, and execution of Critical Tasks are described below:

1. Command, Control, and Communications.

- Objective 1: Improve ability of Commanders to effect a favorable outcome of the AirLand Battle.
  - Task 1: Provide an advanced voice, data, and image common user combat network.
  - Task 2: Provide integrated battle management systems necessary to synchronize the AirLand Battlefield.
  - Task 3: Provide extremely high frequency, high data capacity satellite terminals for joint, combined, strategic, and tactical operations.
- Objective 2: Enhance continuity of C3 function on the AirLand Battlefield.
  - Task 1: Provide Secure C3 systems with reduced signature.
  - Task 2: Develop follow-on information architecture and planning systems.
- Objective 3: Increase combat effectiveness of personnel involved in C3 functions on the AirLand Battlefield.
  - Task 1: Provide highly mobile, self-contained C3 vehicle that integrates power, antenna, and NBC protection.
  - Task 2: Provide follow-on systems that facilitate peace to war transition.
  - Task 3: Provide unmanned expendable communication systems.
  - Task 4: Provide expert systems for automated trouble shooting and frequency and C3 planning.

- Task 5: Provide fault tolerant information systems with integrated test diagnostic, and training simulations.

2. Reconnaissance, Surveillance, and Target Acquisition.

- Objective 1: Field an enhanced order of battlefield intelligence in support of the AirLand Battle.

  - Task 1: Provide all weather, day/night reconnaissance systems capable of providing the commander multidisciplined information to the limits of his area of interest.

  - Task 2: Provide tactical fusion systems at division, corps, and EAC to rapidly integrate, correlate, fuse, and disseminate pertinent RSTA information to the appropriate commander.

  - Task 3: Provide a tactical environment assessment system in support of corps and below.

  - Task 4: Provide a digital topographic support system.

- Objective 2: Develop enhanced munitions vectoring capability for AirLand Battlefield weapons.

  - Task 1: Provide advanced sensors capable of autonomous target detection, recognition, identification, and classification with location accuracy sufficient for attack with precision guided munitions.

  - Task 2: Provide a capability to detect, recognize, locate, and exploit advanced signals (LPI, target designators, millimeter wave, etc.).

- Objective 3: Enhance the combat effectiveness of soldiers and units engaged in IEW operations on the AirLand Battlefield.

  - Task 1: Provide advanced computer based techniques for automatic collection, analysis, and dissemination of RSTA information.

3. Battlefield Sustainment.

- Objective 1: Balanced prepositioned war reserve stocks to meet defense guidance objectives.

- Task 1: Use advanced simulation to accurately determine requirements for critical munitions, major end items, and secondary items.

- Task 2: Procure selected critical munitions and secondary items for modernized systems to meet defense.

- Objective 2: Protect and optimize use of critical industrial base resources and encourage expansion of industrial facilities necessary to support wartime surge.

  - Task 1: Correct shortfalls in the industrial base in order to support the AirLand Battle.

  - Task 2: Identify innovative means to rapidly fill equipment shortfalls in the event of mobilization.

- Objective 3: Increase productivity of logistic support to AirLand Battle.

  - Task 1: Reduce weapon system life cycle support cost significantly.

  - Task 2: Develop responsive and survivable supply, distribution, and maintenance systems from industrial base to the AirLand Battlefield.

  - Task 3: Develop advanced power generation with reduced signature and logistical requirements.

- Objective 4: Enhance battlefield casualty management and optimize soldier return to duty.

  - Task 1: Improve flexibility, mobility, and sustainability of field medical units on the AirLand Battlefield.

  - Task 2: Exploit medical technologies to improve casualty treatment and survivability.

4. Battlefield Lethality.

- Objective 1: Develop deep attack capability for AirLand Battlefield.

  - Task 1: Provide deep attack systems with precision munitions.

  - Task 2: Provide enhanced chemical weapons.

- Task 3: Provide anti-tactical missile systems and advanced air defense weapons.

- Objective 2: Develop anti-armor leap ahead for close combat on the AirLand Battlefield.

    - Task 1: Provide advanced propellants and attack concepts.

    - Task 2: Field integrated family (light to heavy) of direct fire anti-tank weapons and indirect fire munitions capable of defeating the future soviet tank.

    - Task 3: Field advanced anti-tank barriers and mines.

- Objective 3: Achieve capability to neutralize or suppress enemy indirect fire systems and air defense weapons on the AirLand Battlefield.

    - Task 1: Provide enhanced area suppression with longer range field artillery, wide area attack, and overpressure munitions.

- Objective 4: Ensure survivability of forces on the AirLand Battlefield.

    - Task 1: Provide advanced anti-mine/obstacle clearing.

    - Task 2: Provide enhanced collective/unit protection in NBC environment.

    - Task 3: Provide advanced countermeasures for ground combat vehicles.

    - Task 4: Provide advanced combat fortifications capability.

- Objective 5: Enhance offensive EW capability of forces engaged in the AirLand Battle.

    - Task 1: Provide advanced battlefield deception for forces.

    - Task 2: Provide enhanced jamming capability.

- Objective 6: Develop a survivable, logistically supportable light helicopter family.

5. Soldier and Unit Performance Enhancement.

- Objective 1: Maximize soldier combat capability in the AirLand Battle environment.

  - Task 1: Provide and maintain a high level of soldier skills.

  - Task 2: Provide maximum soldier physical and mental endurance.

- Objective 2: Enhance soldier combat survivability on the AirLand Battlefield.

  - Task 1: Provide maximum protection for individual soldiers on an NBC contaminated battlefield.

  - Task 2: Provide maximum protection for individual soldiers from wound/injury producing mechanisms and environmental health hazards.

- Objective 3: Develop battlefield leaders.

  - Task 1: Provide leaders with AirLand Battle leader skills.

  - Task 2: Achieve improved decision making on the AirLand Battlefield.

- Objective 4: Increase unit productivity in the AirLand Battle.

  - Task 1: Provide units with the best battlefield leaders.

  - Task 2: Provide units with the best soldiers.

  - Task 3: Provide cohesive units trained to perform their mission.

Appendix C

(Extracted from Ref.2)

PAIRWISE COMPARISON AND SAATY EIGENVECTOR APPROXIMATION METHOD

A. Pairwise Comparison

Pairwise comparison is the predominant methodology recommended for use by the proponents and experts in the BDP-85 process. In a pairwise manner (using a half matrix format) deficiencies are compared to determine the importance of one versus the other. The evaluation scale used by TRADOC for this evaluation process is shown in Table C.1 below.

Table C.1 Evaluation Scale

Definition	Intensity of Importance	Explanation
A. Equal importance	1	Two deficiencies contribute equally
C. Weak importance	3	Experience and judgment slightly favor one deficiency over another
E. Strong importance of one over another	5	Experience and judgment strongly favor one deficiency over another
G. Very strong or demonstrated importance	7	A deficiency is favored very strongly over another; its dominance demonstrated in practice
B, D, F. Intermediate values between adjacent scale values	2, 4, 6	When compromise is needed

The pairwise comparisons of deficiencies are evaluated using the eigenvalue/eigenvector methodology. Either an exact eigenvector or a simplified approximation method (Saaty's Approximation Method (9)) can be used. Saaty's Eigenvector Approximation Method is used by TRADOC and is described later in this appendix.

In filling out the half matrix, mission area expert A (for example) uses the recommended scale (Table C.1). He should start with deficiency 1 vs. 2 in the upper left-hand cell of his half matrix. In this case, expert A strongly prefers deficiency 2 over deficiency 1. Therefore placing an E in the lower half-cell closest to the number 2 for deficiency 2 (Figure C.1).

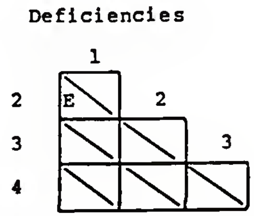

Figure C.1 Half matrix for expert A

Next, expert A pairwise compares deficiency 1 vs. 3 in the cell (3,1), row 3 and column 1. In this case, expert A makes a judgment of weakly preferring deficiency 3 over deficiency 1. Therefore, placing a C in the lower half-cell closest to the number 3 for deficiency 3. The final pairwise comparison example is comparing MA deficiency 1 vs. 4. In this case, MA expert A judges that deficiency 1 is equal to deficiency 4.

Therefore, placing an A in the upper half-cell closes to the number 1 for deficiency 1. The placement of the letter (A, B, C, D, E, F and G) in either the upper or lower half-cell of the half-matrix indicates which deficiency is the preferred deficiency of the two.

The completed half-matrix is shown in Figure C.2.

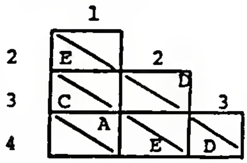

Figure C.2 Completed half matrix for expert A

This completed half-matrix is now translated into the positive reciprocal matrix with the aid of the scale below:

Letter	Numerical Scale Intensity
A	1
B	2
C	3
D	4
E	5
F	6
G	7

The resulting matrix for MA expert A is shown below:

Positive Reciprocal Matrix

Deficiencies	1	2	3	4
1	1	1/5	1/3	1
2	5	1	4	1/5
3	3	1/4	1	1/4
4	1	5	4	1

This positive reciprocal matrix has the properties that all diagonal elements, $a_{ii} = 1$, are equal to 1, and all other elements, $a_{ii} \geq 0$, are non-negative.

In the absence of a computer program to solve the positive reciprocal matrix, eigenvalue and eigenvector, an estimate of the eigenvector can be obtained using Saaty's Approximation Method explained below.

B. <u>Saaty's Eigenvector Approximation Method</u> (9).

The method involves dividing each column element by the sum of that column, then summing the resulting rows and dividing by the number of elements in the row. The process is averaging over the normalized column.

Using the previous example, we will obtain the estimated solution:

<u>Step 1</u>. Sum the columns, then determine the normalized matrix by dividing each element by the respective column sum.

Row	1	2	3	4
1	1	1/5	1/3	1
2	5	1	4	1/5
3	3	1/4	1	1/4
4	1	5	4	1
	---	---	---	---
Col. Sum.	10.00	6.45	9.33	2.45

Normalized Matrix

(Deficiencies)

Row	1	2	3	4	Row Sum
1	0.10	0.03	0.04	0.41	0.58
2	0.50	0.16	0.43	0.08	1.17
3	0.30	0.04	0.11	0.10	0.55
4	0.10	0.78	0.43	0.41	1.72

Step 2. Determine the row sums of the normalized matrix, then divide them by the number of row elements to obtain the estimated solution. Comparison with the exact solution is shown:

Estimated Solution (Row sum/4)	Exact Solution
0.14	0.13
0.29	0.28
0.13	0.12
0.43	0.46

This method gives a good estimate of the actual solution and is consistent. We can also estimate the consistency index (C.I.) by multiplying the original matrix by the estimated solution (0.14, 0.29, 0.13, 0.43), then dividing by the solution vector (eignvector), and take the average.

Using the exact eigenvector method, the consistency index and consistency ratio are defined as:

*C.I. - Consistency Index = $(\ _{max} - n)/(n-1)$;
$(5.42 - 4)/(4-1) = 0.47$

**C.R. - Consistency Ratio = C.I./R.I. where R.I. is the random index and C.I. is the consistency index. C.R. = (0.47/0.90) = 0.52.

The consistency index (C.I.) is a measure of consistency in the judgments made by each expert in developing the positive reciprocal matrix. In general, if this number is less than 0.1, the judgments are satisfactory (consistent. The smaller the index the better is the consistency.

On the other hand, the consistency ratio (C.R.) is a measure of consistency when a random degree of expected inconsistency (noise) is considered due to the size of the matrix. Oak Ridge National Laboratory and the Wharton School, University of Pennsylvania, have generated a random index (R.I.) to consider this effect. A consistency ratio of 0.10 or less is acceptable.

The eigenvector/eigenvalue approach to pairwise comparisons provides a method for establishing a numerical (cardinal) scale, particularly in areas where measurements and quantitative comparisons do not exist. The consistency index and consistency ratio enables one to monitor judgments during the priority process.

Appendix D

(Reprint from Ref. 2)

BALANCED INCOMPLETE BLOCK DESIGN

In BDP-85 HQ TRADOC tasked each mission area (MA) proponent to prioritize specific mission area analysis (MAA) deficiencies rather than continue with the broader, more general Battlefield Development Plan (BDP) deficiencies as in the past. Because of the large number of specific MA deficiencies (from a low of 28 deficiencies for COM to a high of 432 deficiencies for CSS), MA proponents will require a method to prioritize a greater number of deficiencies. The balanced incomplete block design (BIBD) will allow the MA proponent to subdivide the total number of specific MA deficiencies into smaller subsets for prioritization. This will reduce the burden placed on each individual and allow for a greater number of specific MA deficiencies to be prioritized within each of the mission areas. This decrease in burden is demonstrated in the following table where the number of paired comparisons geometrically increases with the number of deficiencies.

Table D.1 Paired Comparison Sample

No. of MA Deficiencies	No. of Paired Comparisons Required
20	190
25	300
30	435
35	595
40	780
45	990
50	1225

Each MA proponent will have to make a judgment as to what is an acceptable number of paired comparisons for each individual. Table D.2 demonstrates how beneficial it would be if 60 deficiencies were subdivided into three subsets of 20 deficiencies each.

Table D.2

No. of MA Deficiencies	No. of Paired Comparisons Required
60	1,770
3 subsets of 20 deficiencies	190 Total of 570

If the number of specific MA deficiencies are small in number (30 or less), then each individual should evaluate the complete set. If the number is larger (greater than 30), each MA expert should evaluate a selected subset of the total number of specific MA deficiencies within the respective MA. Whatever the technique chosen (optimal for each MA proponent), each specific MA deficiency has to be given an equal opportunity of becoming the top or bottom ranked deficiency. In order for this to happen, each specific MA deficiency must appear the same number of times. Also, the deficiencies should be evaluated against each of the other deficiencies an equal number of times during the evaluation.

The BIBD has these characteristics; every pair of deficiencies occurs together the same number of times, allowing each deficiency an equal chance of being the top ranked deficiency in the set of specific MA deficiencies. The actual design will depend upon the number of specific deficiencies, the number of MA experts (individuals), and the degree of discrimination required to gain consensus. Some degree of replication will be required. Hence, each pair of deficiencies should be evaluated by a number of MA experts so that adequate representation is placed on each specific deficiency. The following is the mathematical formulation for a BIBD (see references for more detail). The following notation is used:

N = Number of total observations
t = Number of deficiencies
r = Number of replications of each deficiency
b = Number of mission area experts (evaluators)
k = Number of deficiencies evaluated by each evaluator
  = Number of times two specific deficiencies are evaluated

The following relationships must be satisfied

$$\frac{r(k-1)}{t-1} = \frac{N(k-1)}{t(t-1)} = \qquad (1)$$

$$N = tr = bk \qquad (2)$$

Not all BIBD are symmetrical. A necessary and sufficient condition for a symmetrical design is that b = t, i.e., the number of evaluators must equal the number of deficiencies; consequently, k = r. In order to utilize these relationships (1 and 2) a number of these variables (t, r, b, k, and) must first be fixed before solving for the others. An example is given where we first subdivide the total number of deficiencies and then apply the BIBD to the subsets. If one subdivides the total, then a control MA deficiency is required in each BIBD. This control MA deficiency is required to integrate the individual subsets into one list. This example has a small number of deficiencies in order to communicate the basic idea. Suppose 28 specific MA deficiencies needed to be prioritized by the MA proponent this year. This would require each expert to perform 378 paired comparisons in order to prioritize all 28 deficiencies. On the other hand, if we utilize the BIBD and subdivide the 28 deficiencies into four subsets of equal size, seven deficiencies plus a control deficiency for a total of eight, then each MA expert would be required to evaluate four sets of four deficiencies each. (See Figure D.1, a design to evaluate eleven specific deficiencies.) This would require a total of 24 paired comparisons as compared to 378, a major reduction in the required level of effort.

MISSION AREA DEFICIENCIES

GENERAL OFFICERS	A	B	C	D	E	F	G	H	I	J	K
GO 1		X	X		X				X	X	X
GO 2	X		X	X		X				X	X
GO 3	X	X		X	X		X				X
GO 4	X	X	X		X	X		X			
GO 5		X	X	X		X	X		X		
GO 6			X	X	X		X	X		X	
GO 7				X	X	X		X	X		X
GO 8	X				X	X	X		X	X	
GO 9		X				X	X	X		X	X
GO 10	X		X				X	X	X		X
GO 11	X	X		X				X	X	X	

Figure D.1 Balanced Incomplete Block Design

This design is not symmetrical. That is, the number of deficiencies is not equal to the number of evaluators (experts). In this case, one deficiency, picked at random is placed in each of the four subset of deficiencies. This control (standard) deficiency is used to integrate-gauge the four subsets of eight deficiencies into one cardinally ranked (prioritized) list. In the above BIBD each deficiency is evaluated seven times by the 14 evaluators (experts) and each pair appears three times, e.g., deficiencies 1 and 2 occur in A, B and I half-matrix, and deficiencies 1 and 3 occur in A, C, and J half-matrix, and so on. Hence, this BIBD satisfies the requirement that every pair occurs together the same number of times (λ = 3). Once the BIBD is chosen, a half-matrix is prepared for each of the evaluators (MA expert) tasked to pairwise compare the specific MA deficiencies.

APPENDIX E

(Extracted from Ref. 5)

MERGING FORMULATION

In Phase 2, up to 30 general officer experts are asked to pairwise compare subsets of deficiencies to determine the relative ranking of deficiencies from different mission areas. After TRADOC calculates the half matrices for each expert, the result is prioritized lists for each expert. The number of lists depends on the number of subsets (half matrices) for each expert. To obtain a single list, the experts his/her separate lists must be merged.

To begin, one of each expert lists is considered a base list. This base list should have the control deficiency ranked as close to the center as possible. The next step is to determine a constant that will be used to transform the cardinal values of the list(s) to be merged.

$$\underset{\text{(constant)}}{a} = \frac{\text{(control cardinal value from base list)}}{\text{(control cardinal value from merging list)}}$$

The new value for the base list is determined as follows:

(new value for base list) = a * (value from merging list)

A demonstration of merging list 2 into list 1 (base list) is as follows:

List 1 (Deficiency)	Cardinal Value (Eigenvector)	List 2 (Deficiency)	Cardinal Value (Eigenvector)
6	(0.220)	11	(0.220)
3	(0.187)	9	(0.165)
2	(0.140)	5	(0.140)*
8	(0.128)	15	(0.135)
5	(0.125)*	14	(0.120)
1	(0.100)	10	(0.100)
4	(0.080)	12	(0.070)
7	(0.020)	13	(0.050)
TOTAL	1.00		1.00

Deficiency (5) * is the control deficiency common to both subsets. The merging transformation is:

(merged cardinal value) = a * (old cardinal value):

where a = (0.125)/(0.140) = 0.8928

The actual merge is shown below:

a = 0.8928 (constant)

List 2	Transformed Value	("Base list") Merged List of List 1 and 2
11 (0.220) * (0.8928) =	(0.196)	6 (0.220)
		11 (0.196)
9 (0.165) * (0.8928) =	(0.147)	3 (0.187)
		9 (0.147)
*5 (0.265) * (0.8928) =	(0.125)	2 (0.140)
		8 (0.128)
		*5 (0.125)
15 (0.135) * (0.8928) =	(0.121)	15 (0.121)
14 (0.120) * (0.8928) =	(0.107)	14 (0.107)
10 (0.100) * (0.8928) =	(0.089)	1 (0.100)
		10 (0.089)
12 (0.070) * (0.8928) =	(0.062)	4 (0.080)
		12 (0.062)
13 (0.050) * (0.8928) =	(0.045)	13 (0.045)
		7 (0.020)

Appendix F

(Extracted from Ref. 5)

PIECEWISE LINEAR TRANSFORMATION

The results of the pairwise evaluations performed by the general officer experts in Phase 2 is a cardinally ranked list of deficiencies across all mission areas. This "base list" represents the consensus of the general officer experts. It will be used as a reference to merge the original 13 mission proponent lists to obtain a strawman list that contains all mission area deficiencies.

Since the base list of selected deficiencies contains specific deficiencies from each of the 13 mission areas, a unique piecewise linear transformation can be formulated to integrate all deficiencies. Each original mission proponent list must be merged into the base list, one at a time, to accomplish this integration.

The reference points (deficiencies in the base list) common to the proponent lists will establish the coefficients for the piecewise linear transformation that will merge the remaining specific deficiencies into the base list. The number of reference points is based on the percentage of deficiencies that was sampled from the total list.

Figure F.1 illustrates the linear merging of one proponent list into the base list to obtain the resulting strawman list.

The linear equation $y = a x + b$ is used to determine the exact cardinal value for the strawman list. The deficiencies

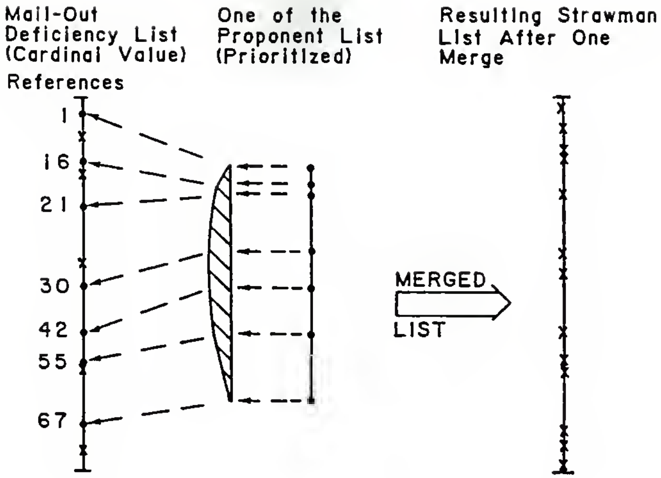

Figure F.1 Linear Transformation

in the proponent lists that are also represented in the base list, assume the base list values in the strawman. The slope (a) and intercept (b) are determined using the values of two reference points that bound the value of the deficiency to be merged. The cardinal value of this deficiency assigned by the proponent represents "x" in the equation. Now the new cardinal value, "y", can be calculated.

This technique will preserve the mission area proponents cardinal relationship between specific mission area deficiencies and insure that consensus with the experts mail-out package is maintained. The above procedure will produce the strawman list of prioritized deficiencies for BDP-85.

Appendix G

(Extracted from Ref. 3,4)

SUMMARY OF MULTIPLE CRITERIA DECISION MAKING

Multiple Criteria Decision Making (MCDM) refers to making decisions in the presence of multiple and often conflicting criteria. MCDM is a new specialization of mathematical programming, and it applies to real-world decision making problems.

The problems of MCDM can be broadly classified into two categories: Multiple Objective Decision Making (MODM) and Multiple Attribute Decision Making (MADM). MODM problems design the best alternative and are characterized by an infinite number of solutions or planning alternatives. MADM problems select the best alternative from a predefined finite number of alternatives. Decision making processes can be carried out by a single decision maker or multiple decision makers (group decision making).

Moving from a single decision maker to a multiple decision maker setting introduces a great deal of complexity into the analysis. The Group Decision Making under Multiple Criteria (GDMMC) problem is now no longer concerned with the selection of the most preferred alternative among the nondominated solutions according a single decision maker's preference structure, as the analysis must be extended to account for the conflicts among different interest groups who have different objectives and goals.

GDMMC are quite diverse and includes such diversely interconnected fields as preference analysis, utility theory, social choice theory, committee decision theory, theory of voting, general game theory, expert evaluation analysis, aggregation of qualitative factors, economic equilibrium theory, etc.

Some simple examples are presented here to illustrate the distinction between MODM, MADM, and GDMMC problems.

For example, a MODM nutrition problem is to determine the quantities of six foods that should be eaten to meet certain nutritional requirements so as to satisfy the following three objectives:

(i) minimize cost
(ii) minimize cholesterol intake
(iii) maximize carbohydrate intake

The problem constraints include meeting the daily nutritional requirements, and setting upper limits on daily intake of individual foods. Information on six foods is given in the following Table G.1:

Table G.1 MODM Problem Constraints

	Milk (pint)	Beef (pound)	Eggs (dozen)	Bread (ounce)	Lettuce salad (ounce)	Orange juice (pint)	Recommended daily allowance for adults
Vitamin A (i.u.)	720	107	7080	0	134	1000	5000
Food energy (calories)	344	1460	1040	75	17.4	240	2500
Cholesterol (unit)	10	20	120	0	0	0	
Protein (g)	18	151	78	2.5	0.2	4	63
Carbohydrate (g)	24	27	0	15	1.1	52	
Iron (mg)	0.2	10.1	13.2	0.75	0.15	1.2	12.5
Cost ($)	0.225	2.2	0.8	0.1	0.05	0.26	

Mathematically, this MODM problem can be represented as:

$$\text{Min } [f_1(\underline{x}), f_2(\underline{x})]$$

$$\text{Max } f_3(\underline{x})$$

Subject to constraints:

where $x = \{\underline{x} \;\; a\, \underline{x} \leq \underline{b},\; \underline{x} \geq \underline{0}, \underline{x} \leq \underline{u}\}$ and $\underline{x}$ is a decision vector representing the daily diet requirements of milk, beef, eggs, bread, lettuce, salad, and orange juice. Therefore, a solution of the MODM problem is one from an infinite number of solutions.

An example of a MADM problem is a fighter aircraft selection problem as follows: A country decides to purchase a fleet of jet fighters from the U.S. Pentagon officials offer the characteristic information of four models which may be sold to that country. The Air Force analyst team of that country agreed that six characteristics (attributes) should be considered. They are: maximum speed (X_1), ferry range (X_2), maximum payload (X_3), purchasing cost (X_4), reliability (X_5), and maneuverability (X_6). The values of the six attributes for each model (alternative) are given in the following table:

Table G.2 MADM Decision Matrix

Alternatives (A_i)	Attributes (X_j) Maximum speed (Mach)	Ferry range (NM)	Maximum payload (pounds)	Acquisition cost ($\$ \times 10^6$)	Reliability (high-low)	Maneuverability (high-low)
A_1	2.0	1500	20000	5.5	average	very high
A_2	2.5	2700	18000	6.5	low	average
A_3	1.8	2000	21000	4.5	high	high
A_4	2.2	1800	20000	5.0	average	average

The above table forms a decision matrix, and upon it the selection procedure is applied. The solution to this MADM problem is to select one alternative from the predefined four candidates, subject to six conflicting attributes (criteria).

The problems of group decision making under multiple criteria are widely varied. However, even the range of different problems which are considered here share some common characteristics such as multiple criteria/objectives/attributes, and conflict among criteria.

An example of GDMMC involves expert judgment as discussed below:

<u>Experts judgment/group participation</u>. The problem of group decision making can be broadly classified into two categories in this field: experts judgment and group participation. The experts judgment process entails making a

decision by inventing a new alternative. Specifically, it is concerned with forecasting and involves constructing supplemental objects which may be new designs or new technical solutions. On the other hand, the group participation process entails groups which have common interests, such as a community or an organization, making a decision.

Numerical Example.

Let us use examples to illustrate the expert judgment and the group participation processes.

First, NASA's Marine Jupiter/Saturn 1977 (MJS 77) project was to launch two MJS 77 spacecrafts on a pair of trajectories. Before launching, they needed to design the two trajectories, and determine the kinds of experiments to be carried out. There was no past experience on which to rely. Therefore, 80 leading scientists (experts) were asked to participate in the decision process. They were divided into eleven science teams, each with different purpose and objective.

Through idea generation activities, they initially generated 2,624 trajectories pairs. Then the team leaders and NASA engineers, through systematic structuring analysis activities, reduced the trajectories to 24 pairs. Through further structuring analysis, these same 11 team leaders and NASA engineers determined the best trajectory pairs. Finally, the project was put into action which had needed certain planning and controlling to accomplish it. In this procedure, the methods of generating ideas, systematic structuring, simulation, and implementing and controlling were used.

Appendix H

(Extracted from Ref. 4, pp. 128-134)

TOPSIS

Hwang and Yoon (4) developed the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) based upon the concept that the chosen alternative should have the shortest distance from the ideal solution and the farthest from the negative-ideal solution.

Assume that each attribute takes the monotonically increasing (or decreasing) utility; then it is easy to locate the "ideal" solution which is composed of all best attribute values attainable, and the "negative-ideal" solution composed of all worst attribute values attainable. One approach is to take an alternative which has the (weighted) minimum Euclidean distance to the ideal solution in a geometrical sense. It is argued that this alternative should be farthest from the negative-ideal solution at the same time. Sometimes the chosen alternative, which has the minimum Euclidean distance from the ideal solution, has the shorter distance (to the negative-ideal) than the other alternative(s). For example, in Fig. H-1, an alternative A_1 has shorter distances (both to ideal solution A^* and to the negative-ideal solution A^-) than the other alternative A_2. Then it is very difficult to justify the selection of A_1. TOPSIS considers the distances to both the ideal and the negative-ideal solutions simultaneously by taking the relative closeness to the ideal solution. This method is simple and yields an indisputable preference order of solution.

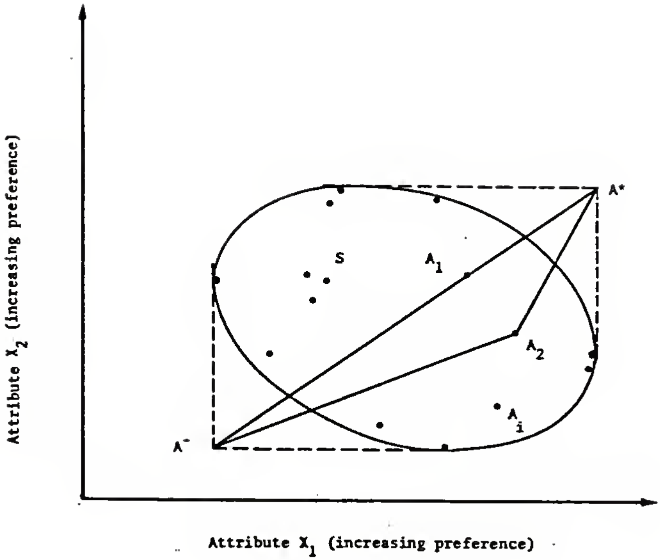

Figure H.1 Euclidean distances to the ideal and negative-ideal solutions in two dimensional space (Yoon and Hwang).

The Algorithm

The TOPSIS method evaluates the following decision matrix which contains m alternatives associated with n attributes (or criteria):

$$
D = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_i \\ \vdots \\ A_m \end{array}
\begin{array}{c} \begin{array}{cccccc} x_1 & x_2 & & x_j & & x_n \end{array} \\
\left[\begin{array}{cccccc}
x_{11} & x_{12} & \cdots & x_{1j} & \cdots & x_{1n} \\
x_{21} & x_{22} & \cdots & x_{2j} & \cdots & x_{2n} \\
\vdots & \vdots & & \vdots & & \vdots \\
x_{i1} & x_{i1} & \cdots & x_{ij} & \cdots & x_{in} \\
\vdots & \vdots & & \vdots & & \vdots \\
xm1 & x_{m2} & \cdots & x_{mj} & \cdots & x_{mn}
\end{array}\right] \end{array}
$$

where

A_i = the i^{th} alternative considered,

x_{ij} = the numerical outcome of the i^{th} alternative with respect to the j^{th} criterion.

TOPSIS assumes that each attribute in the decision matrix takes either monotonically increasing or monotonically decreasing utility. In other words, the larger the attribute outcomes, the greater the preference for the "benefit" criteria and the less the preference for the "cost" criteria. Further, any outcome which is expressed in a nonnumerical way should be quantified through the appropriate scaling technique. Since all criteria cannot be assumed to be of equal importance, the method receives a set of weights from the decision maker. For the sake of simplicity, the proposed method will be presented as a series of successive steps.

<u>Step 1. Construct the normalized decision matrix</u>: This process tries to transform the various attribute dimensions into nondimensional attributes, which allows comparison across the attributes. One way is to take the outcome of each criterion divided by the norm of the total outcome vector of the criterion at hand. An element r_{ij} of the normalized decision matrix R can be calculated as

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

Consequently, each attribute has the same unit length of vector.

<u>Step 2. Construct the weighted normalized decision Matrix</u>: A set of weights $\underline{w} = (w_1, w_2, \ldots, w_j, \ldots, w_n)$ $\sum_{j=1}^{n} w_j = 1$, from the decision maker is accommodated to the decision matrix in this step. This matrix can be calculated by multiplying each column of the matrix R with its associated weight w_j. Therefore, the weighted normalized decision matrix V is equal to:

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

<u>Step 3. Determine ideal and negative-ideal solutions</u>: Let the two artificial alternatives A^* and A^- be defined as

$$A^* = \{(\max_i v_{ij} | j \in J), (\min_i v_{ij} | j \in J') | i = 1,2,\ldots,m\}$$

$$= \{v_1^*, v_2^*, \ldots, v_j^*, \ldots, v_n^*\} \qquad (3.44)$$

$$A^- = \{(\min_i v_{ij} | j \in J), (\max v_{ij} | j \in J') | i = 1,2,\ldots,m\}$$

$$= \{v_1^-, v_2^-, \ldots, v_j^-, \ldots, v_n^-\} \qquad (3.45)$$

where $J = \{j = 1,2,\ldots,n | j$ associated with benefit criteria$\}$

$J' = \{j = 1,2,\ldots,n | j$ associated with cost criteria$\}$

Then it is certain that the two created alternatives A^* and A^- indicate the most preferable alternative (ideal solution) and the least preferable alternative (negative-ideal solution), respectively.

<u>Step 4. Calculate the separation measure</u>: The separation between each alternative can be measured by the n-dimensional

Euclidean distance. The separation of each alternative from the ideal one is then given by

$$S_{i*} = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^*)^2}, \qquad i = 1,2,\ldots,m \qquad (3.46)$$

Similarly, the separation from the negative-ideal one is given by

$$S_{i-} = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2}, \qquad i = 1,2,\ldots,m \qquad (3.47)$$

<u>Step 5. Calculate the relative closeness to the ideal solution</u>: The relative closeness of A_i with respect to A^* is defined as

$$C_{i*} = S_{i-}/(S_{i*} + S_{i-}), \qquad 0 < C_{i*} < 1,$$

$$i = 1,2,\ldots,m \qquad (3.48)$$

It is clear that $C_{i*} = 1$ if $A_i = A^*$ and $C_{i*} = 0$ if $A_i = A^-$. An alternative A_i is closer to A^* as C_{i*} approaches to 1.

<u>Step 6. Rank the preference order</u>: A set of alternatives can now be preference ranked according to the descending order of C_{i*}.

<u>Numerical Example</u> (The Fighter Aircraft Decision Problem)

The decision matrix of a fighter aircraft selection problem after the quantification of nonnumerical attributes of x_5 and x_6 is:

$$
D = \begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ A_4 \end{array}
\begin{array}{c}
\begin{array}{cccccc} x_1 & x_2 & x_3 & x_4 & x_5 & x_6 \end{array} \\
\begin{bmatrix}
2.0 & 1500 & 20000 & 5.5 & 5 & 9 \\
2.5 & 2700 & 18000 & 6.5 & 3 & 5 \\
1.8 & 2000 & 21000 & 4.5 & 7 & 7 \\
2.2 & 1800 & 20000 & 5.0 & 5 & 5
\end{bmatrix}
\end{array}
$$

(Note all attributes except x_4 are the benefit criteria.)

1. <u>Calculate the normalized decision matrix</u>:

$$
R = \begin{bmatrix}
.4671 & .3662 & .5056 & .5069 & .4811 & .6708 \\
.5839 & .6591 & .4550 & .5990 & .2887 & .3727 \\
.4204 & .4882 & .5308 & .4147 & .6736 & .5217 \\
.5139 & .4392 & .5056 & .4607 & .4811 & .3727
\end{bmatrix}
$$

2. <u>Calculate the weighted decision matrix</u>: Assume that the relative importance of attributes is given by the decision maker as $\underline{w} = (w_1, w_2, w_3, \ldots, w_6) = (.2, .1, .1, .1, .2, .3)$. The weighted decision matrix is then

$$
V = \begin{bmatrix}
.0934 & .0366 & .0506 & .0506 & .0962 & .2012 \\
.1168 & .0659 & .0455 & .0598 & .0577 & .1118 \\
.0841 & .0488 & .0531 & .0414 & .1347 & .1565 \\
.1028 & .0439 & .0506 & .0460 & .0962 & .1118
\end{bmatrix}
$$

3. <u>Determine the ideal and negative-ideal solutions</u>:

$$
A^* = (\max_i v_{i1}, \max_i v_{i2}, \max_i v_{i3}, \min_i v_{i4}, \max_i v_{i5}, \max_i v_{i6})
$$

$$
= (.1168, \; .0659, \; .0531, \; .0414, \; .1347, \; .2012)
$$

$$A^- = (\min_i v_{i1}, \min_i v_{i2}, \min_i v_{i3}, \max_i v_{i4}, \min_i v_{i5}, \min_i v_{i6})$$

$$= (.0841, \quad .0366, \quad .0455, \quad .0598, \quad .0577, \quad .1118)$$

4. <u>Calculate the separation measures</u>:

$$S_{i*} = \sqrt{\sum_{j=1}^{6} (v_{ij} - v_j^*)^2}, \qquad i = 1,2,3,4$$

$S_{1*} = .0545 \qquad S_{2*} = .1197$

$S_{3*} = .0580 \qquad S_{4*} = .1009$

$$S_{i-} = \sqrt{\sum_{j=1}^{6} (v_{ij} - v_j^-)^2}, \qquad i = 1,2,3,4$$

$S_{1-} = .0983 \qquad S_{2-} = .0439$

$S_{3-} = .0920 \qquad S_{4-} = .0458$

5. <u>Calculate the relative closeness to the ideal solution</u>:

$C_{1*} = S_{1-}/(S_{1*} + S_{1-}) = .643, \qquad C_{2*} = .268,$

$C_{3*} = .613, \; C_{4*} = .312$

6. <u>Rank the preference order</u>: According to the descending order C_{i*}, the preference order is:

A_1, A_3, A_4, A_2

MULTIPLE CRITERIA DECISION MAKING APPROACHES
TO THE TRADOC BATTLEFIELD DEVELOPMENT PLAN

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ABSTRACT

The United States Army Training and Doctrine Command (TRADOC) represents the battlefield user in developing doctrine, training, force structure, and material requirements for the future. Guidance for developing these requirements comes mainly from two sources: critical tasks outlined by the Army staff and the detailed mission area analysis (MAA) of each TRADOC mission area. Under this direction, each of 13 TRADOC centers or schools must prioritize specific deficiencies existing within their own mission area. The particular problem for TRADOC is to integrate and prioritize these 13 prioritized lists into a single ordered list of deficiencies - the Battlefield Development Plan (BDP).

Formulation of the BDP is a yearly process. When finalized, it greatly influences the development of programs and the allocation of resources toward correcting deficiencies in order of their importance. Over the past few years, the development of a rigorous and understandable prioritization methodology has changed dramatically. Evaluating a sample of the deficiencies using pairwise comparison is the prioritization logic of the current process.

This thesis presents two alternative approaches to solving the BDP problem. In each approach, a multiple criteria decision making structure is developed. Using TOPSIS, a multiple attribute decision making method, the prioritization process is simplified and properly driven by the criteria critical to battlefield victory. An evolutionary procedure is

presented first. It can be fully automated while the consequences are easily grasped by the decision maker. Two separate procedures are described for this approach, depending on the criteria established by TRADOC . The second MCDM approach scrubs the current BDP framework in favor of a more scientific structure and evaluation process.

Both methods offer several advantages including user-friendly automation, weighting, and consistency. Most importantly, these alternatives are directly linked to the multiple criteria the Army provides for guiding the selection and determining the importance of battlefield deficiencies across all mission areas. These methods merit consideration by TRADOC for application in future BDP formulations.