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A Methodology for Performing Effects-Based Assessments

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THESIS

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Abstract

In order to bring the doctrine of Effects-Based Operations (EBO) into a fully operational capability, Effects-Based Assessment (EBA) must provide relevant insight to the commander and his planning staff. Assessments of an effects-based plan and execution must include an assessment of the effects of a campaign on the enemy in addition to an assessment of the accomplishment of friendly actions taken to achieve the desired effects. Determining the effects of a campaign requires an analysis of the dynamics of the enemy systems. EBA must be able to recognize the states of the enemy's systems as the system states change over time. This research advances the application of EBA by defining anticipated states of enemy systems, developing indicators to determine those states, and applying progress functions to the states in order to quantify attainment of the commander's objectives. The methodology describes a process for assessing combat and stability operations. The results indicate that the EBA methodology developed in this research works best where the systems of interest cannot be assessed directly.

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DEDICATION

In loving memory of my grandmother.

Acknowledgments

I would like to thank my advisor, Lt Col Dave Denhard, for his guidance and patience. Thanks too, to my reader, Lt Col Jeff Weir, for his time. I'd like to thank my mother for her life-long support in all my endeavors. I'd also like to thank the members of Left-Null Space, the best Ultimate team at AFIT. Special thanks to Capt Jason Gastelum for his sense of humor, mistrust of the establishment, and unceasing distractions from academia. I extend extra special thanks to my dear friend *R*, whose friendship and loving support transcend mortal experience. Most importantly, I thank the Lord Jesus Christ for all the blessings in my life. If I have done any good in my thesis, my career, my life, it is only because of His grace and love. For that, I am thankful.

Benjamin A. Thoele

Table of Contents

Page

List of Figures

Page

Page

List of Tables

Page

Page

Page

A METHODOLOGY FOR PERFORMING EFFECTS-BASED ASSESSMENTS

1 Introduction

1.1 Background

In his 2005 *Phalanx* article, "Re-Operationalizing Analysis for the Warfighter," Air Force Chief of Staff and former Combined Forces Air Component Commander (CFACC) for Operations ENDURING FREEDOM and IRAQI FREEDOM, General T. Michael Moseley emphasizes the importance of an operations assessment capability for support to the CFACC: "We need to focus on whether we are creating the effect we want . . . We must also ensure the understanding of the 2nd and 3rd order effects we are having on the battlespace and our enemies . . . " (Moseley, 2005:8, 9). The Chief's statements embody the essence of Effects-Based Operations (EBO) and the necessity for commanders, strategists, planners, and assessors to gain useful knowledge of the effects military actions achieve during combat operations.

As a CFACC, General Moseley saw first-hand the challenges of executing EBO and the necessity of a robust assessment capability. Across the Air Force, the operational and analytical communities alike have developed new doctrine, technologies, and processes to meet these challenges and bring the EBO concept into a fully operational capability. The thesis develops a new methodology for performing Effects-Based Assessment that incorporates the lessons learned from past assessment efforts and concepts from recent doctrine, technology, and analytical methods.

Chapter 1 summarizes the definition of EBO and presents how the assessments team under General Moseley implemented an effects-based assessment effort in

Operation IRAQI FREEDOM and the challenges the assessment team encountered. These challenges illustrate well the problems with the current assessment methodology. The chapter continues with a detailed problem statement and the objectives of this thesis. The chapter concludes with an overview of the rest of the document.

1.1.1 *Effects-Based Operations Defined.*

Several definitions for EBO exist and many differ only in their jargon. The United States Joint Forces Command Joint Warfighting Center Joint Doctrine Series Pamphlet 7 (JWFC Pam 7) offers the most comprehensive definition of EBO:

> Operations that are planned, executed, assessed, and adapted based on a holistic understanding of the operational environment in order to influence or change system behavior or capabilities using the integrated application of selected instruments of power to achieve directed policy aims. (JWFC Doctrine Pam 7, 2004:2)

JWFC Pam 7 extends this definition by decomposing EBO into four major components: System-of-Systems Analysis, Effects-Based Planning, Effects-Based Execution, and Effects-Based Assessment.

A System-of-Systems Analysis (SoSA) model provides the holistic understanding of the operational environment by characterizing the complex organization, relationships, and key characteristics of an enemy political, military, economic, social, information, and infrastructure (PMESII) network. The SoSA recognizes the multifarious linkages across the enemy PMESII system and describes the system using network topology. In the SoSA model, the key components of the system are represented by nodes, and the connections between the components are represented by arcs, as shown in Figure 1.1 (JWFC Doctrine Pam 7, 2004:10).

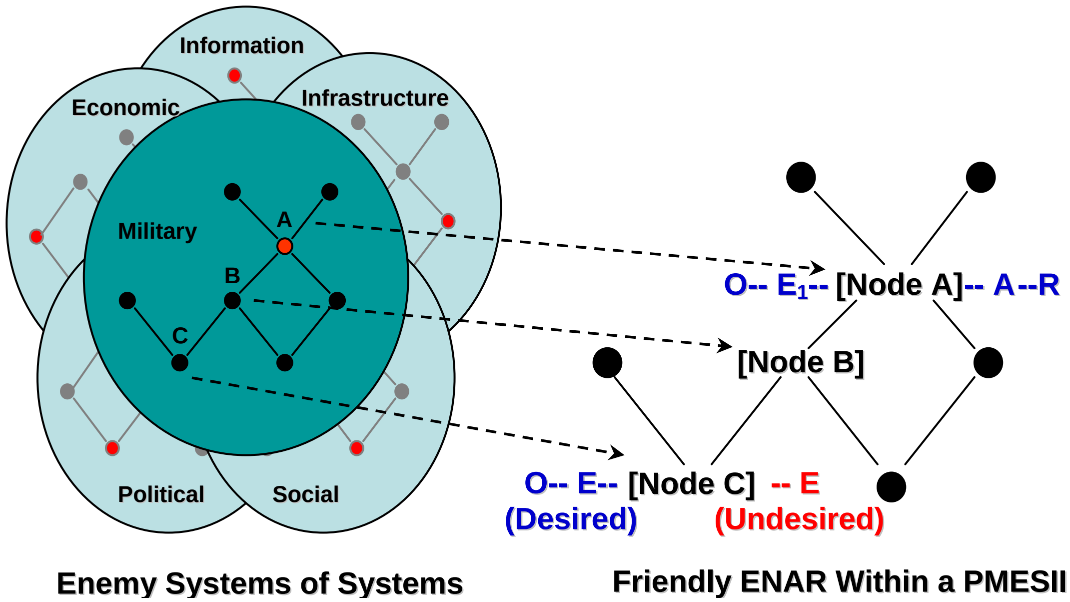


Figure 1.1 System-of-Systems Model and O-E-N-A-R Chains

Effects-Based Planning (EBP) develops the integrated application of selected instruments of power. EBP considers all domestic, information, military, and economic (DIME) actions available to commanders in order to influence or change enemy system behavior or capabilities to achieve directed policy aims. EBP begins when the planners clarify commanders' policy aims and goals and translate them into objectives. Then, based on the enemy SoSA model, planners determine the enemy system behaviors and capabilities that need to be influenced or changed. The desired enemy behaviors and capabilities are described as a set of effects required to attain the objectives. Essentially, an effect is *a change in the state of an enemy system*. Planners look to change the state of the enemy system by changing the state of enough system nodes. Planners target the system nodes with a set of DIME actions to produce the desired effects (i.e., desired change in system behavior). Then planners couple available resources to the actions based on force structure. The combination of the objectives, effects, nodes, actions, and resources forms O-E-N-A-R chains. These O-E-N-A-R chains are the basis of Effects-Based Courses of Action (COAs) available to commanders. In addition to the desired effects, planners also consider the secondary and unintended effects that may result from changes in the state of other enemy system nodes. Planners can then change the COA to accommodate these indirect effects (JWFC Doctrine Pam 7, 2004:10-12).

Effects-Based Execution (EBE) implements the actions set forth in EBP. The subordinate military commanders and units execute the military actions from the EBP, which are translated as tasks via orders from the higher commanders. Other supporting agencies and departments are tasked via the interagency process to perform tasks that accomplish the diplomatic, infrastructure, and economic actions of DIME (JWFC Doctrine Pam 7, 2004:16).

Effects-Based Assessment (EBA) aims to identify progress towards the attainment of commander's objectives as the campaign and EBE progresses. EBA forms the basis and justification for changes in the plan and future execution. EBA tracks both the accomplishment of the COA actions and the effects of those actions on the enemy. In this manner, EBA assesses the overall campaign helping to identify trends affecting future operations. EBA assesses the overall campaign and compares the current battlespace picture with the desired battlespace conditions at a given point in time. When a delta exists between the current picture and desired conditions, further analysis is necessary to reveal the cause. If the execution has followed the plan, then changes to the plan maybe required. Conversely, if the execution has not followed the plan, then further analysis must reveal the cause, and the commander may redirect resources to remedy the situation. The results of EBA then feedback into EBP (JWFC Doctrine Pam 7, 2004:16-17).

To implement the whole of EBO, the process must include a SoSA model, EBP, EBE, and EBA. The bulk of the EBO tools and literature created thus far contribute most to the SoSA and EBP efforts. However, EBA methodologies remain mostly doctrinal. While doctrinal definitions provide a framework for conceptualizing EBA, they offer little in the way of operational implementation with regard to actually assessing the actions and effects in EBO.

1.1.2 *Effects-Based Assessment in OPERATION IRAQI FREEDOM.*

The most recent large-scale air campaign assessment effort occurred in 2003 during the first days of OPERATION IRAQI FREEDOM (OIF). In OIF, planners attempted to implement EBA into the operational assessment process, however, the current EBA construct was not conducive to the rapid pace, short duration, highly dynamic nature of OIF (Allen, 2005:v).

At the height of air operations, the Operational Assessment (OA) team, who was responsible for conducting EBA, consisted of 17 members. Their mission was to track the progress of the CFACC's ten Operational Objectives broken into over 200 Tactical Tasks with nearly 300 Measures of Effectiveness (MOEs) and Success Indicators (SIs). MOEs measured the progress of the tactical tasks assigned to the flying units; though called MOEs, the metrics actually tracked coalition actions and not effects. SIs measured progress towards operational objectives and provided broad qualitative guidance for operational assessment. The SIs were independent of the MOEs and provided evidence of effects of coalition actions on the enemy. The OAT tracked the MOEs and SIs daily, updating the metrics iteratively as necessary. Figure 1.2 depicts the basic strategy-to-task hierarchy used for the Joint Air Operations Plan of OIF (Thoele, DiSebastain, and Garcia, 2004; Allen, 2005:19).

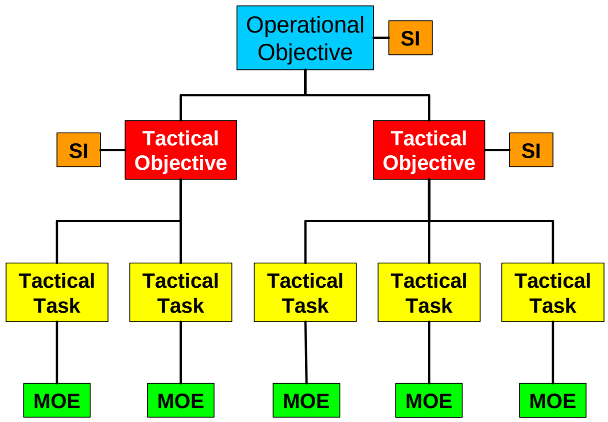


Figure 1.2 Strategy-to-Task Hierarchy used in OIF (Thoele, DiSebastian, and Garcia, 2004)

This process, however, failed to answer the questions of the CFACC and did not successfully guide and steer the air strategy (Thoele, 2004a; Allen, 2005:22). In his 2005 School of Advanced Air and Space Studies (SAASS) thesis, Major Neil Allen pinpoints the reasons for the shortcomings in the OA team process: "In a short, fast-paced war like OIF . . . the EBA construct is difficult if not impossible to achieve given the doctrine, organizational structure, and technology within the CAOC" (Allen, 2005:3).

The organization problems that hampered the EBA efforts, as Allen describes them, are stove-piped, hierarchical structures and insufficient manning levels inside the CAOC, along with conflicting interests and prioritizations outside the CAOC. Allen also points out that the EBA doctrine was lacking, insufficient, or not conducive in guiding and instructing assessors in the EBA process. While the doctrine described what to do, it fell short of explaining how to do it. Without a defined EBA process to guide them, OA team assessors were poorly equipped to accomplish EBA during OIF (Allen, 2005:24, 38, 41).

Therein lies the biggest problem facing the analytical community with regards to EBA: no proven assessment methodology exists that provides insight to the commander and helps guide the air strategy. Valid complaints of the current EBA methodology include that it is too complex, too time consuming, and too dependent on intangible assessment inputs to adapt to a war like OIF. In order to guide the commander's strategy, assessments need to be timely, accurate, and actionable. Any new EBA constructs must be operationally useful and efficient in a war as fast, short, and dynamic as OIF. Put another way, an EBA construct must be useful to the CFACC, and the benefits gained from accomplishing EBA remain greater than or equal to the overall expenditure of effort, resources, or human life. The challenge then is to formulate an EBA construct that is timely, accurate, actionable, efficient, simple, quantifiable, adaptable, and most importantly, provides relevant insight to the CFACC and military planners (Allen, 2005:9, 75-78).

1.2 Problem Statement

To provide relevant insight to the CFACC and Strategy Division in a Combined Air Operations Center (CAOC) environment, the assessment of an EBO plan and execution must include an assessment of the effects of the air campaign on the enemy in addition to an assessment of the accomplishment of friendly actions taken to achieve the desired effects. Determining the effects of the air campaign requires an analysis of the dynamics of the enemy systems. EBA must be able to recognize the state of the enemy systems as the system states change over time. This thesis advances the application of EBA by defining anticipated states of enemy systems, developing indicators to determine the state of enemy systems, and applying progress functions to the anticipated and desired states of the enemy systems in order to describe progress of the campaign towards attainment of the commander's objectives.

1.3 Research Objective

The objective of this thesis is to establish a an EBA construct that supports the EBO process by providing timely, actionable information to the CFACC and CAOC staff. The construct will be flexible to changes in the operational environment, complex enough to provide accurate information, simple enough to be performed on existing CAOC tools, and efficient in the use of CAOC resources. In addition, this thesis defines the necessary phases of an EBA process and the methods to be applied, setting the stage for future research into more robust stochastic methods and the development of future tools.

1.4 Research Scope

This thesis focuses on the assessment of an air campaign at the operational level of warfare. The methodology is described from the viewpoint of an OA team within a CAOC. This methodology assesses three elements of EBO: the accomplishment of CFACC actions, the achievement of CFACC desired effects, and the progress towards the attainment of CFACC operational objectives. The methodology implicitly considers the constraints of time and personnel on an OA team, and therefore is designed to be applied to one or two high-priority commander objectives. The methodology explicitly describes a process for assessing combat operations, though the methodology is intended to be general enough to enable its application to stability operations as well.

1.5 Assumptions

The methodology developed in this thesis makes the following key assumptions about pre-conflict analysis of the enemy and data availability during conflict:

- A SoSA model exists for the enemy in some form, and this model is used by the planners to develop the courses of action examined in EBP. Though SoSA models are discussed in Chapter 2, this thesis does not include development of a SoSA in the methodology.
- All data necessary to perform the assessments described in this methodology are available to the assessors. Many of the problems described by Allen and Thoele *et al* deal specifically with data collection, compilation, and dissemination within the CAOC. This thesis views these issues as organizational constraints, which require procedural solutions, and are therefore outside of the scope of this thesis. For further analysis and research on procedural solutions to data availability for CAOC operations, see Allen (2005) and Air Combat Command (2004).

Other assumptions made in this thesis will be described in the appropriate position within the methodology.

1.6 Overview and Format

This thesis is divided into five chapters: Chapter 1, Introduction; Chapter 2, Literature Review; Chapter 3, Methodology; Chapter 4, Results and Analysis; and

Chapter 5, Discussion. Chapter 2 presents an overview of EBO and discusses in detail a formal definition of *effects*, including different types and levels of effects as they apply to warfare. Chapter 2 also presents some historical examples of the application of EBA and then reviews relevant methods from the fields of medicine, risk analysis, quality control, and decision theory.

Chapter 3 describes the mathematical construct of EBA and presents a seven phase methodology for performing EBA. Chapter 4 applies the EBA methodology to two examples. The first example is a combat operations scenario example based on conflicts the United States Air Force has been involved in over the last two decades. The second example is a stability operations scenario based on the operations involved in nation building such as with those associated with OIF. Chapter 5 then discusses the limitations and contributions of the methodology, as well as areas for future research.

2 Literature Review

2.1 Introduction

Chapter 2 reviews existing research and publications relevant to the analysis methods described in the methodology of Chapter 3. Chapter 2 first looks at the definition and components of Effects-Based Operations (EBO) and a formal definition of *effects*. Next, the chapter investigates the major components of EBO, namely Operational Net Assessment (which is the formal Joint process that performs System-of-Systems Analysis), Effects-Based Planning (EBP), Effects-Based Execution (EBE), and Effects-Based Assessments (EBA). Then Chapter 2 reviews the contributions of Operation IRAQI FREEDOM, the most recent large-scale assessments effort of an air campaign. Chapter 2 next discusses a new model for EBA based on the Jones Criteria for diagnosing rheumatic fever. The Jones Criteria model leads to a discussion of measures, indicators, and criteria for good indicators of system capability and behavior. Next, Chapter 2 presents tools for the development and use of indicators that includes cause-and-effect diagrams (fishbone charts), operational experience, and Powell's 40-70 principle for decision making with incomplete information. The chapter concludes with a discussion of the contributions of risk analysis and decision theory, and the subtle differences between value functions and the *progress functions* introduced in Chapter 3.

2.2 EBO Defined

Several definitions for EBO exist. Virtually every document written on EBO contains a definition with a flavor unique to the publication, however, each definition of

EBO contains the same general concepts. This thesis draws primarily from the United States Joint Forces Command Joint Warfighting Center Joint Doctrine Series Pamphlet 7; Mann, Endersby, and Searle; and Smith to describe EBO and its components. This thesis begins with the definition of EBO prescribed by the United States Joint Forces Warfare Center Doctrine Series Pamphlet 7:

> Operations that are planned, executed, assessed, and adapted based on a holistic understanding of the operational environment in order to influence or change system behavior or capabilities using the integrated application of selected instruments of power to achieve directed policy aims. (JWFC Doctrine Pam 7, 2004:2)

This thesis considers the *operational environment* to be a composite of all elements, conditions, and influences that affect the employment of resources and capabilities that bear on the decisions of the Combined Forces Air Component Commander (CFACC). In addition, the operational environment is comprised of political, military, economic, social, infrastructure, and information (PMESII) systems. Analysis of these systems and their interrelationships provides the "holistic understanding" mentioned in the definition (JWFC Doctrine Pam 7, 2004:2).

A *system* is defined as a functionally, physically, and/or behaviorally related group of elements that interact together as a whole (JWFC Doctrine Pam 7, 2004:2). This thesis will refer to *enemy systems* that will change behavior or capabilities. When the systems being described belong to the United States or coalition allies, they will be denoted as *friendly systems*.

Instruments of power can include diplomatic, informational, military, economic (DIME), and other means available to national leaders to influence the operational environment. This thesis is concerned only with instruments within the primary control of the CFACC, that is military and informational means. Likewise, *directed policy aims* refer to the objectives of the CFACC and the Combined Forces Commander (CFC) that comprise the desired operational end state relevant to the operation at hand (JWFC Doctrine Pam 7, 2004:3).

In summary, for the purpose of this thesis, EBO is the set of operations planned, executed, assessed, and adapted based on a holistic understanding of the operational environment in order to influence or change enemy system behavior or capabilities using the integrated application of selected instruments of power (military and informational) to achieve CFACC and CFC objectives.

2.3 Effects

The above definition of EBO speaks of influencing or changing enemy systems. These changes to enemy systems embody the essence of *effects.* Mann *et al* describe an effect as the "full range of outcomes, events, or consequences that result from a specific action" (Mann, Endersby, and Searle, 2002:31). Similarly, JWFC Pamphlet 7 describes an effect as "the physical and/or behavioral state of a system that results from a military and nonmilitary action or set of actions" (JWFC Doctrine Pam 7, 2004:2). The key elements of an effect for this thesis are as follows:

1. A system of interest exists in an initial state.
2. The system transitions to a different state as a result of an action. (To be clear, in this thesis, "do nothing" can be an action.)
3. The resulting change in the state of the system is the *effect.*

2.3.1 *First, Second, and Third Order Effects.*

Effects can be broken down into direct and indirect effects. Direct effects are immediate and easily recognizable. Indirect effects are often the cumulative result of many direct effects. *First-order* effects are direct effects, which result immediately from an action. In the case of kinetic operations, results of the action are directly attributable to military attack on a target (Mann, Endersby, and Searle, 2002:31-32).

Second and third-order effects are indirect effects. These effects result from one or two intermediate effects or mechanisms, thereby producing a final outcome. A second-order effect has one intermediate effect, the first-order effect; while a third-order effect has two intermediate effects, the first and second-order effects. Second and third-order effects tend to be delayed and are typically more difficult to recognize than direct effects (Mann, Endersby, and Searle, 2002:32-33).

2.3.2 *Cumulative and Cascading Effects.*

Cumulative effects result from the aggregate of many direct or indirect effects. Cumulative effects generally occur at the operational and strategic levels of warfare, although they may occur at the tactical level. Cumulative effects can be considered the "roll-up" of multiple first, second, and third-order effects. Cascading effects occur when indirect effects flow from higher levels to lower levels of employment (Mann, Endersby, and Searle, 2002:34). Cascading effects can be considered the distribution of second and third-order effects created by a direct or first-order effect on an a large highly connected system.

2.3.3 *Collateral Effects.*

An effect is the resulting state of a system due to an action. Depending on the nature of the system state and whether the system is enemy or friendly, the effect can be positive or negative. *Collateral effects* are defined as any outcome (or resulting state of a system) other than what was intended, whether positive or negative. In EBO, collateral effects should be a major, deliberate consideration in planning, executing, and assessing military actions (Mann, Endersby, and Searle, 2002:35-36).

2.3.4 *Types of Effects on a System.*

The nature of the system and the action applied to the system will dictate the resulting state of the system. How the system is changed by the action can be described by four different types of effects on a system: physical effects, functional effects, systemic effects, and psychological effects.

Physical effects are direct, first-order effects. Their primary purpose is to "damage, disrupt, or neutralize a target or group of targets through the application of military force" (Mann, Endersby, and Searle, 2002:37). Physical effects result in a physical alteration of the system. *Functional Effects* are direct or indirect effects of actions on the ability of a target or system to function properly and perform its mission. *Systemic effects* are effects that are aimed at disrupting the operation of a specific system or set of systems. *Psychological effects* are the results of actions that influence emotions, motives, objective reasoning, and ultimately the behavior of individuals, groups, organizations, and foreign governments (Mann, Endersby, and Searle, 2002:37-38).

2.3.5 *Effects at Different Levels of Warfare.*

Changes in a system behavior or capability can occur at any of the strategic, operational, and tactical levels of warfare. Both the nature of the system and the action applied to it can determine the level of the effect. Strategic effects contribute to affecting an enemy's overall political, military, and economic capacities as well as its psychological stability. Strategic actions are activities associated with the campaign effort as a whole. Operational level actions are activities that affect an entire theater of operations. The focus of operational actions is on the war-making potential of the enemy within the theater of operations. Tactical effects are the result of an action or actions at the individual unit level. Tactical effects generally occur on a localized basis and are immediate and short in duration (Mann, Endersby, and Searle, 2002:40-41).

The focus of this thesis is determining the impact of military operations at the operational level. Generally speaking, operational effects can be direct effects and indirect effects of tactical effects. Operational effects can also result from cumulative effects from tactical actions and other operational effects as well as cascading effects from strategic actions.

2.3.6 *Precisely Defining Effects.*

Gallagher *et al* describe the necessity of precisely defined effects for the proper execution of EBO. Gallagher *et al* state that analysts must be able to identify elemental effects that lend themselves to analytical modeling and analysis in order for analytical methods to be applied to EBO. Furthermore, a bottom-up approach for EBO planning and assessment requires careful definition of these elemental effects such that they achieve exhaustive coverage, mutual exclusivity, and independence from the means of achievement of the effects (Gallagher, True, and Whiteman, 2004:9).

A problem, however, is that the current EBO taxonomy focuses on a set of verbs to describe effects (a consequence of a particular action). Few of the proposed EBO verb sets provide detailed definitions. In fact, most effects implied by the verb sets (terms) are less than precise, are not mutually exclusive, and often imply kinetic means to achieve the effect. That is, the use of these terms to describe effects lacks the rigor and precision required for mathematical analysis (Gallagher, True, and Whiteman, 2004:9). Therefore, Gallagher *et al* state that effects should not be defined in terms of verbs, but rather should be defined as an impact on a single functional capability or behavior with four specifications (Gallagher, True, and Whiteman, 2004:9):

- Range (a capability-range is the affected area, such as target, city, region or state, whereas behavior-range is the affected individual, group or nation);
- Extent (specifies the resulting level of capability or behavior whether it is decreased, maintained or increased);
- Start time;
- End time.

This thesis uses the specifications for precisely defining effects outlined by Gallagher *et al* as the initial step in a comprehensive EBA methodology. Chapter 3 describes how well-defined desired effects are used to direct the EBA process. With regards to the analytical requirements of the effects definition (exhaustive coverage, mutually exclusivity, and independence from the means of achievement), this thesis discusses neither the need for the effects to be independent from the means of achievement nor the need for mutual exclusivity. While exhaustive coverage directly supports the EBA method through the assessment of the higher objectives, independence from the means of achievement primarily supports the planning process to determine actions. Likewise, mutually exclusivity of effects is an invalid assumption when effects are viewed through the interconnected system-of-systems model. Achieving one effect may aid or deter the achievement of other effects, and therefore effects are not mutually exclusive.

Desired effects may be defined in terms of two different sets of consequences: those to be achieved and those to be avoided (Gallagher, True, and Whiteman, 2004:15). JWFC Pamphlet 7 states that a "specified effect describes desired or undesired conditions . . . that results form a set of actions (JWFC Doctrine Pam 7, 2004:12)." Therefore, planners must consider both types of effects and the systems they involve when decomposing the commander's objectives into a set of effects. This thesis considers the contributions of undesired and collateral effects in the overall assessment methodology.

2.4 Components of EBO

An EBO methodology is a means for planning, executing, and assessing operations designed to attain the effects required to achieve desired national security outcomes (Mann, Endersby, and Searle, 2002:46). An EBO methodology relies heavily on a comprehensive system-of-systems understanding of the operational environment. Therefore, the EBO process begins with a complete system-of-systems understanding of the enemy and proceeds with three highly interdependent and overlapping major components: effects-based planning, effects-based execution, and effects-based assessment (JWFC Doctrine Pam 7, 2004:8-9).

2.4.1 *Operational Net Assessment and System-of-Systems Analysis.*

Virtually no part of a target system or its infrastructure is isolated, therefore it is important to develop a better understanding of inherent relationships of effects to incorporate understanding into planning, execution, and assessment of EBO (Mann, Endersby, and Searle, 2002:34, 39). In order to build a holistic knowledge base of the operational environment, EBO begins with a System-of–Systems Analysis (SoSA) of the enemy PMESII systems. Operational Net Assessment (ONA) is the organizational process that performs the SoSA and develops the SoSA model (JWFC Doctrine Pam 7, 2004:9).

United States Joint Forces Command defines ONA as "the integration of people, processes, and tools that use multiple information sources and collaborative analysis to enhance command decision-making." The aim of ONA is to produce a coherent, relevant and shared knowledge environment for planners and decision makers. In doing so, ONA uses link analysis, network analysis and structured augmentation to assess an adversary's PMESII systems, thus producing a SoSA model. The SoSA model reveals critical nodes and vulnerabilities that may be used in EBO. In order to create the SoSA model, ONA integrates military, national agencies, coalition governments, nongovernmental organizations and other partners who have information to contribute. ONA is a continuous and dynamic process that operates through peacetime and conflict. ONA enables commanders to avoid conflict by engaging opponents in influence and deter methods; likewise, ONA offers defeat mechanisms to accomplish commanders' objectives during times of conflict. In this manner, ONA provides the first crucial piece of EBO, the SoSA model of enemy systems (USJFCOM, 2006).

A SoSA model provides a framework for understanding the battlespace by characterizing the complex organization, relationships, and key characteristics of an enemy PMESII network. SoSA recognizes the linkages across the various areas of an enemy system and describes the connections and key components of the entire system. A SoSA model decomposes the system of interest into a network of *nodes* and *links* (Figure 2.1). A node can be a person, place, or any physical thing that is a fundamental component of the system. Links represent the behavioral, physical, or functional relationship between the nodes. These links, are the basis for the *causal linkages*, which describe why planners think the proposed actions will achieve the desired effects. A SoSA model increases the understanding of how actions taken against one element of the system can affect the entire system as well as other elements of the system. (JWFC Doctrine Pam 7, 2004:10; Mann, Endersby, and Searle, 2002:49)

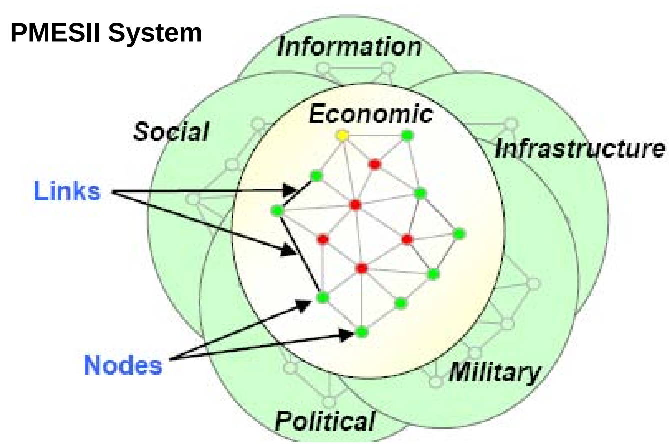


Figure 2.1 System of Systems Model of a PMESII System

2.4.2 *Example SoSA Models.*

Building SoSA models brings additional analytical challenges to the operational implementation of EBO. Several authors have offered techniques and tools to facilitate the building of a SoSA model. This thesis examines briefly two SoSA methods for building models, one by Lee and Kupersmith and the other by Goodwinan and Lee. Lee and Kupersmith describe a hierarchical structure for a SoSA model based on their Objectives to Metrics Methodology (OMM); Goodwin and Lee describe a more robust version of a SoSA model, the Net-Centric Effects-Based Operations Model (NEMO), which is based on existing engineering models of infrastructure networks. Together these methods represent the broad spectrum of complexity of SoSA models, with OMM being a simpler form of a SoSA model and NEMO being a more complex form. In this thesis models that represent a system on the basis of topology alone are considered to be simple; models that require engineering-level detail to represent the system are considered to be complex.

Lee and Kupersmith base their SoSA frameworks on two broad conditions under which desired effects can be achieved: 1) the enemy "can't" achieve their own desired objectives; 2) the enemy "won't" perform activities in support of their objectives. "Can't" speaks to the enemy's capability. "Won't" speaks to the enemy's will. These conditions are a crucial part of the Objectives to Metrics Methodology (OMM). OMM is a five step process designed to link a desired effect to a measurable set of metrics (Lee and Kupersmith, 2002:4-5).

In OMM, planners first identify the objective based on the Commander's Intent Statement for a given operation, which is generally used to describe the end-state of an operation. Second, planners define the effect using doctrinal definitions, because these definitions provide a formal common frame of reference. Third, planners frame the effect in quantifiable terms that help determine if the effects are being accomplished or not. To do this, the intent of an effect is reformed into a question to facilitate the establishment of metrics against an objective. For example, for the objective *Air Superiority*, the desired effect is *freedom of movement in area of interest*. The question then would be phrased as "Can BLUE conduct air ops without interference from RED?" Fourth, planners assign target sets to the effect, decomposing each of the *can't* and *won't* ideas into details from which vulnerabilities and interactions can be identified and prioritized for attack. It is here that Lee and Kupersmith utilize their framework structure of a SoSA model (Lee and Kupersmith, 2002:4-8).

The Lee and Kupersmith model (Figure 2.2) consists of elements comprising each effect. This structure helps to visualize the interrelationships of the various factors that contribute to an effect while simultaneously accounting for key factors. In addition, the model helps the planner determine potential vulnerabilities for attaining a desired effect with acceptable consumption of resources. This model looks at effects from both the *can't* and *won't* conditions to gain insight into key linkages between the sides of the framework. It is important that the resulting tree structure be sufficiently detailed to define targets and actions (kinetic or non-kinetic) associated with neutralizing them (Lee and Kupersmith, 2002:10).

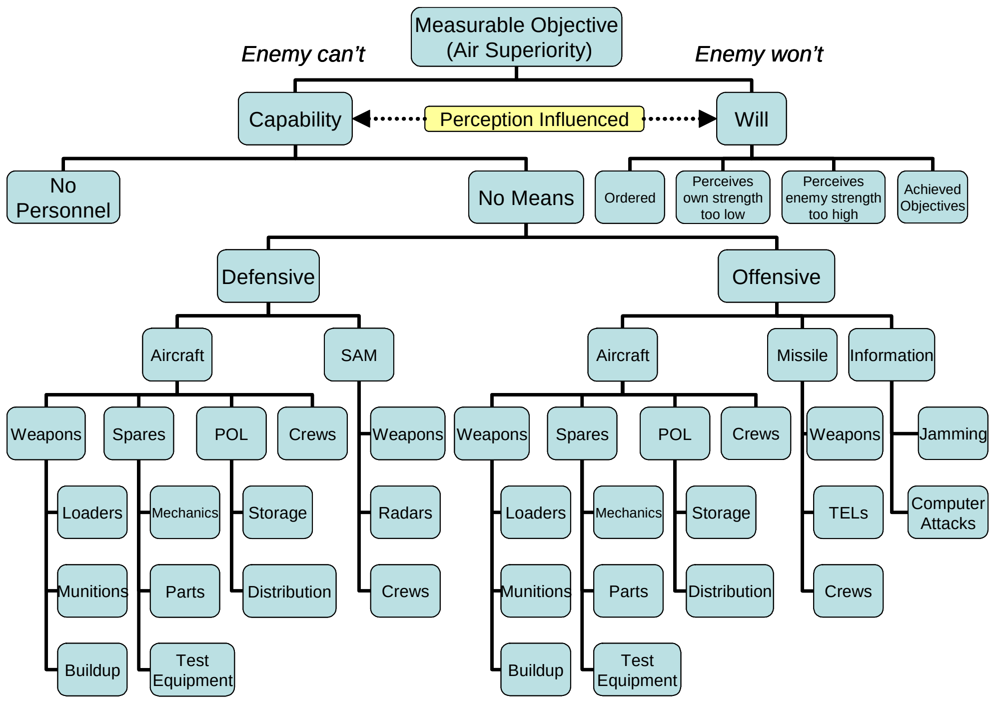


Figure 2.2 Enemy Systems Framework (Lee and Kupersmith, 2002:10)

The fifth and final step of OMM is to establish metrics to measure achievement of the effect. The metrics should be considered synergistically in order to measure progress in achieving an effect (Lee and Kupersmith, 2002:8). This thesis views the culmination of effects to be a non-linear function, and agrees with Lee and Kupersmith that the effects should be viewed synergistically.

Goodwin and Lee describe an automated approach for performing SoSA that leverages existing, commercially available software models—the Net-Centric Effects-Based Operations Model (NEMO). NEMO provides analysts with the means for defining relationships between multiple infrastructure networks within a single user interface. NEMO has the capability to model interactions across electrical power, water, gas, and road networks using "on/off interaction behavior" between the components of the different networks. In this way NEMO provides a basic capability for performing effects-based planning and analysis for operations against an opponent's physical infrastructure network (Goodwin and Lee, 2005:4-5, 13, 15).

NEMO enables planners to consider a target as a component of the network (regardless of the target type) by providing a framework to model an opponent's PMESII network as well as their interdependencies. Specifically, NEMO integrates infrastructure models such as lines of communication, electrical power, gas pipelines, and water pipelines. NEMO can help identify nodal intersections between system layers using a geospatial database; intersections are where different infrastructure layers lie within a user-specified distance from each other. In this way, planners can understand how a particular element of one network relies on the elements of one or more other networks thus providing a basis for analyzing cascading effects. Understanding and quantifying the nature of these relationships is the key to performing effects-based analysis (Goodwin and Lee, 2005:5, 7-8).

An example of NEMO use is the analyzing the effect of bringing down electrical power on the travel time between points A and B in Figure 2.3. The dashed line represents the shortest path. Taking the power down at point D affects the draw bridge at point C on the graph. As a result, the shortest path has changed as represented by the dashed yellow line in Figure 2.4.

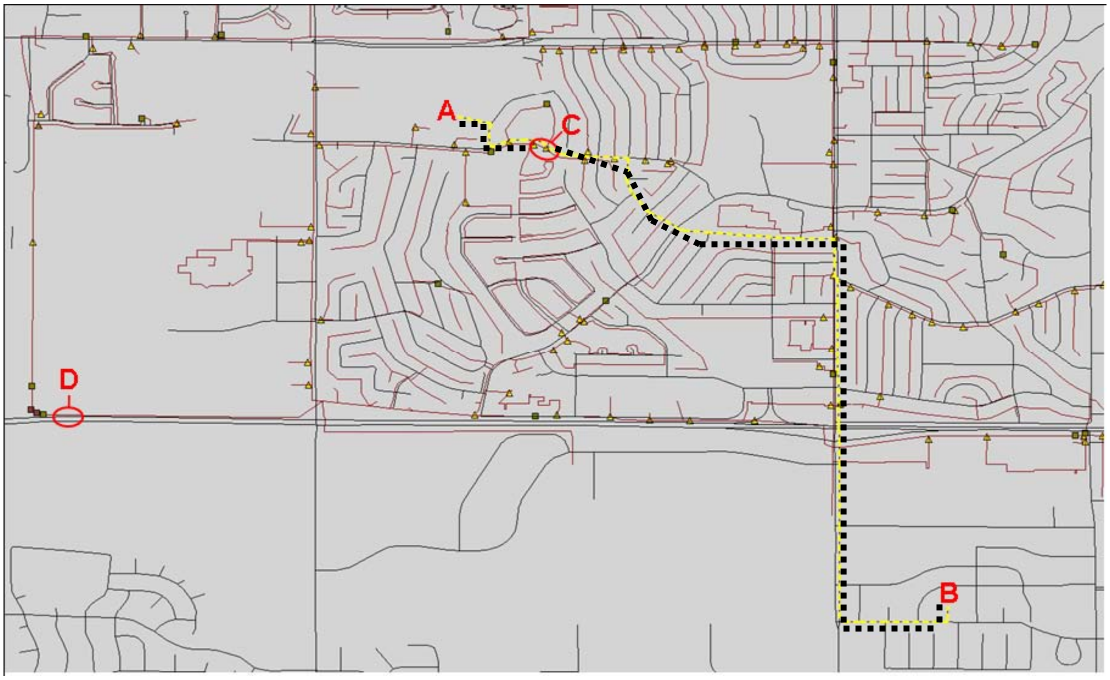


Figure 2.3. NEMO Analysis of Electrical Outage Impact on Travel Time (Goodwin and Lee, 2005:11)

One drawback of NEMO is that it uses highly detailed physical engineering models, which require users with a significant amount of domain experience and knowledge of the infrastructure being modeled. Knowing only the general network topology of a network is not sufficient to support the highly detailed modeling of NEMO. However, for use in EBO a SoSA model may not require engineering level detail (Goodwin and Lee, 2005:12).

The search for other methods of creating SoSA models includes those methods as complex and detail specific as NEMO and those that are more simplified as with OMM. Umstead offers a literature review of operations research methods to aid the analysis and building of SoSA models. These methods include Bayesian networks, influence diagrams and networks, social networks, game theory, complexity theory and others (Umstead, 2005, 56-69).

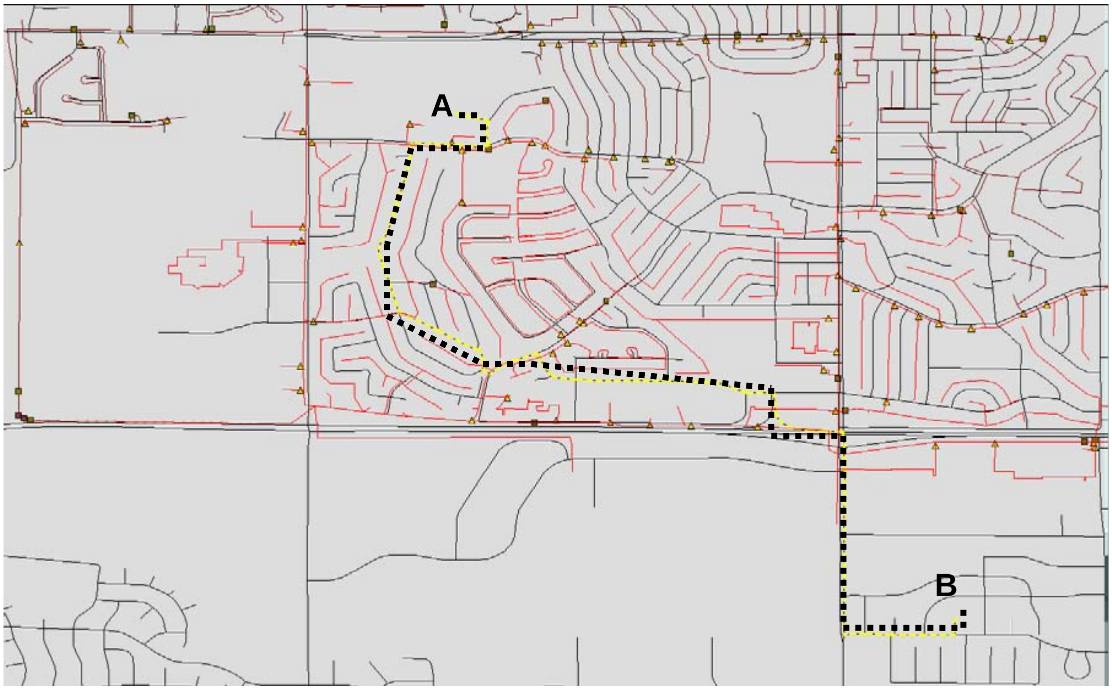


Figure 2.4. Resulting Time Delays in New Route Due to Power Outage (Goodwin and Lee, 2005:12)

These examples of SoSA models and analytical methods offer a wide variety of starting points for developing a descriptive model of the adversary and an improved understanding of the relationships and linkages between components of the adversary system (Umstead, 2005:21). However, performing SoSA and developing a SoSA model is outside the scope of this thesis. For the purposes of the assessment methodology presented in Chapter 3, this thesis assumes that a SoSA model exists in some form prior to the start of the assessment process. In Chapter 4, the examples presented are based on a simpler form of the SoSA models. This thesis views a simpler SoSA model as appropriate at the operational level because the simpler form of the model requires less lead time to build and still maintains the fidelity that is required at the operational level.

2.4.3 *Effects-Based Planning.*

The goal of Effects-Based Planning (EBP) is to produce an executable course of action (COA). The COAs decompose into five critical components: objectives, effects, nodes, actions, and resources. The combination of the objectives, effects, nodes, actions, and resources forms O-E-N-A-R chains. These O-E-N-A-R chains from the basis of the COAs available to commanders. The EPB process results in a set of COAs which includes measures for determining success as well as the traditional task, purpose, and desired end state, which have been traditionally used in operational planning (JWFC Doctrine Pam 7, 2004:8, 10, 12).

EBP begins when strategists and planners clarify commanders' goals and *objectives*. Objectives define an end state that actions are designed to achieve. The objectives are the first crucial piece of the COA. The objectives are then further defined by a set of conditions or *desired effects* that must be created to achieve each objective. These desired effects require foreknowledge of specific achievable conditions believed necessary for attaining the objectives. For each objective in EBP, planners determine the set of effects that are required to attain the objective. Here, the SoSA model helps determine what PMESII behaviors or capabilities (effects) are required to achieve objectives. Effects are the second piece of the O-E-N-A-R chains. (JWFC Doctrine Pam 7, 2004:7, 10-12; Mann, Endersby, and Searle, 2002: 44)

The third link in the O-E-N-A-R chain is a *node*. Using the SoSA model, planners determine which nodes of the enemy system apply to the effects. Planners also consider the secondary and unintended effects that may result from changes in the state of the nodes (JWFC Doctrine Pam 7, 2004:10-12). When planners carefully consider the desired effects that must be established to achieve objectives and the underlying causal linkages between nodes, they may find that potential negative collateral effects outweigh the positive intended effects (Mann, Endersby, and Searle, 2002:44).

For each node, planners can apply a set of *actions* to achieve the desired effects. EBP considers all DIME actions available to commanders in order to create desired effects that will achieve the commanders' objectives. Planners aim to harmonize DIME actions to influence PMESII systems in order to achieve desired effects, which leads to attainment of operational objectives (JWFC Doctrine Pam 7, 2004:8). Analysis of the causal-linkages, which describe why an action will achieve an effect, can help in understanding the potential contribution of a particular action towards attaining objectives (Mann, Endersby, and Searle, 2002:49). Finally, planners couple the actions to available *resources* and forces (JWFC Doctrine Pam 7, 2004:10-12), thus completing the O-E-N-A-R chain of a COA. This thesis does not discuss the constraint of resources. The assumption is that the strategists and planners have all necessary resources available to them in order to execute a chosen COA.

2.4.4 ***Effects-Based Execution.***

Effects-Based Execution (EBE) implements the actions set forth in EBP. The subordinate military commanders and units execute the actions from the EBP, which are translated as tasks via orders from the higher commanders. In the case of an air campaign, the CFACC produces the Air Tasking Order (ATO), which orders the subordinate units to execute the actions. All data necessary to assess a combat operations will be generated by EBE. This data includes but is not limited to mission reports

(MISREPS), Battle Damage Assessments (BDA), order battle charts, message traffic, intelligence summaries (INTSUMs), etc. All of these sources of data will aid the assessment of the execution of military and information actions and the effects those actions create.

2.4.5 *Effects-Based Assessment.*

Effects Based Assessment (EBA) aims to identify progress towards attainment of commander's objectives as the campaign and EBE progresses. EBA forms the basis and justification for changes in the plan and execution. EBA compares the current battlespace picture with the desired battlespace conditions at any point in time. When a delta exists between the current picture and desired conditions, further analysis reveals the cause. If the execution has followed the plan, then changes to the plan maybe required. Conversely, if the execution has not followed the plan, then further analysis must reveal the cause, and the commander may redirect resources to remedy the situation (JWFC Doctrine Pam 7, 2004:16-17). Each piece of the EBA process will contribute to the methodology presented in Chapter 3 of this thesis.

Several types of assessment exist to aid EBA, including physical assessment, target system assessment, performance assessment, and psychological assessment. Physical assessment of an individual target looks at the direct, first-order effect of a kinetic military action. Physical assessment is a necessary component of EBA and focuses on specific, enumerable critical nodes. Physical assessment determines which nodes of the system are still functioning to ensure the desired effect of the system is achieved (Smith, 2002:358). Physical assessments are then used to perform target system assessment; the physical assessment information is fused with functional damage to a target system and an evaluation is made of the overall impact on the system's capabilities (Mann, Endersby, and Searle, 2002:38).

Performance assessment involves monitoring the physical performance of a system over time and comparing the baseline performance to the performance post-action. Performance assessment is largely quantifiable. System performance metrics look at the culmination of indirect physical effects planners hoped would grow from destruction of the key nodes in the system. The critical element in performance assessment is less the collection of new data on the system than it is the availability of a data or knowledge base from which to calculate change (Smith, 2002:358-359, 366).

When dealing with large systems, the effects will cross over into the psychological domain, which is considered in psychological assessment. Psychological assessment operates on two levels: physical indicators (point indicators) and indirect psychological effects determined by intuition and mental models of decision makers and subject-matter experts. Psychological effects are extremely difficult to measure accurately, although performance assessment can be used to assess behavioral changes, which could indicate psychological effects (Smith, 2002:367, 370-372; Mann, Endersby, and Searle, 2002:39).

The EBA methodology of Chapter 3 does not specifically dictate a process for performing the above listed assessments, however these assessments are very important to the completion of the methodology. To perform EBA, each of these assessments plays a vital role in determining the status of the enemy systems under consideration in EBO. The methodology presented in this thesis views the actual assessment of the enemy systems as a function of the Intelligence, Surveillance, and Reconnaissance Division within the CAOC. The methodology then uses these assessments as data to perform an overall effects assessment.

2.5 EBA in OPERATION IRAQI FREEDOM

The assessment methodology used during the air war of OPERATION IRAQI FREEDOM (OIF) is the most recent example of a large-scale assessment of an air campaign at the operational level. The methodology used in OIF offers a starting point for developing future methods such as the one in this thesis. The methodology used in OIF implemented many but not all of the items listed previously in this chapter. The Joint Air Operations Plan (JAOP) was based on a Strategy-to-Task hierarchy developed by the strategic planners with input from assessors. The Strategy-to-Task hierarchy consisted of Operational Objectives, Tactical Objectives, Tactical Tasks, Success Indicators (SI), Focus of Effort, Desired Effects, and MOEs (Figure 2.5). The JAOP contained ten Operational Objectives that were decomposed into 200+ Tactical Tasks.

The assessors planned to assess the entire JAOP on a daily basis. To handle the workload associated with assessing a campaign of that magnitude, the assessors assigned Offices of Primary Responsibility (OPR) and Subject Matter Experts (SME) in all sections of the CAOC. The OPRs and SMEs helped to develop the Tactical Tasks and MOEs as well as provide the data needed to assess their accomplishment. At the task level, assessors defined quantitative MOEs to determine the task accomplishment and the achievement of first-order desired effects.

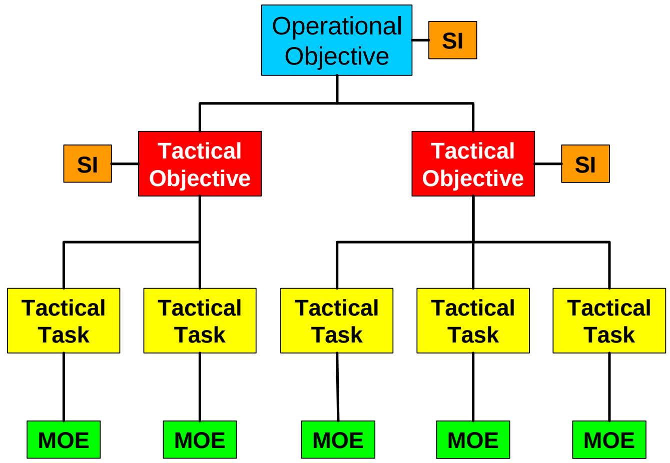


Figure 2.5 Example Strategy-to-Task Hierarchy used in OIF (Thoele, DiSebastian, and Garcia, 2004)

At the objective level, assessors defined SIs that represented evidence of effects and the attainment of objectives. The SIs were a more subjective assessment than MOEs and were assessed independently of the MOEs. The assessors along with planners, OPRs, and SMEs developed over 300 MOEs and SIs. The Focus of Effort and Desired Effects (not pictured) were planning tools used to guide the Air Tasking Order cycle and were not used in the assessment process (Thoele, DiSebastian, and Garcia, 2004).

To assess the overall campaign, the assessors and planners applied weights to each level of the hierarchy. As the OPRs provided data, the assessors calculated the MOE scores along with the hierarchy weights in an additive value function. The result was a normalized rating between 0 and 1; 0 being the lowest rating and 1 being the highest. This mathematical rating along with a subjective assessment was then translated into a stoplight-chart assessment for the Tactical and Operational Objectives (Figure 2.6). As the campaign progressed, however, this assessment process and methodology had to be put aside in order to solve other CAOC issues and provide the CFACC with answers to other pressing questions (Thoele, DiSebastian, and Garcia, 2004).

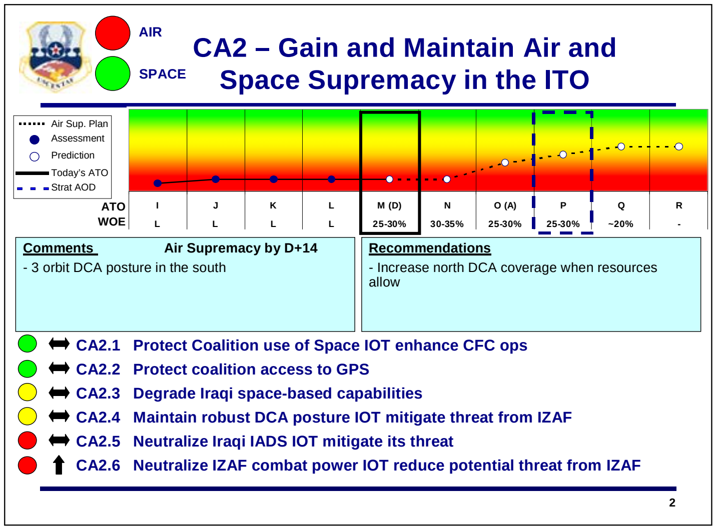


Figure 2.6 Example Assessment from OIF (Thoele, DiSebastian, and Garcia, 2004)

Assessing the JAOP each day required assessors to make determinations on the CFACC's top 100 prioritized Tactical Tasks. This equated to gathering data for 150 to 200 MOEs and SIs daily. Even with SMEs and OPRs throughout the CAOC, and a robust in-house database created by the OA team specifically for their mission, the 17-member OA team could not keep up with all of the metrics. The number of metrics to be tracked was just too great for the OA team to track comprehensively on a daily basis. The number of metrics (approximately 150) provides this thesis with an upper bound for the number of metrics and indicators capable of being tracked in practice. The methodology presented in Chapter 3 states the tractable number of indicators to be tracked is 50 to 60, based on the recommendations of Thoele et al (Thoele, DiSebastian, and Garcia, 2004).

Though called "Measures of Effectiveness," the MOEs actually tracked coalition efforts and not effects. Of the 200 tasks there were only five distinct types of tasks, each with a corresponding type of MOE. Table 2.1 summarizes the tasks and MOEs used to assess the air campaign. This thesis uses the MOE structure from OIF to aid actions assessment as a part of the overall EBA methodology. The methodology presented in Chapter 3 designates measures of performance (MOP) for tracking friendly actions. These MOPs are based upon the format of four of the MOEs outlined in the OIF methodology (Thoele, DiSebastian, and Garcia, 2004).

Table 2.1 Example Tasks and MOEs used in OIF (Thoele, DiSebastian, and Garcia, 2004)

Task	MOE
Degrade/disrupt/destroy/neutralize the enemy.	Percentage of the enemy degraded/disrupted/ destroyed/neutralized.
Influence the enemy.	Enemy behaves as desired.
Locate, monitor, and track enemy units.	Percentage of *known* enemy units located/monitored/tracked.
Detect and identify specific enemy capabilities (GPS jamming, etc.)	Number of occurrences of enemy capability detected and identified.
Maintain 24-hour coverage/specific capability.	Percentage of coverage/capability maintained.

2.6 Jones Criteria as a Model for EBA

This thesis now takes a turn towards another way of thinking about assessing effects, borrowing a model methodology from the field of medicine. In 1944, Dr T. Duckett Jones published a set of criteria for the diagnosis of rheumatic fever (Table 2.2). The modified Jones Criteria form the basis for the diagnosis criteria that are still used today. Rheumatic fever is known to be related to previous infection with group A β-hemolytic streptococci, but how the disease operates in the patient, or its mechanism, is unknown. No specific laboratory diagnostic test exists, and distinguishing the disease from other diseases is sometimes impossible. Therefore, the diagnosis of rheumatic fever must be arbitrary and empirical (Rutstein et al, 1956; Rheumatic Fever, 2005).

Jones proposed a list of criteria divided into major and minor categories. Categorization of the criteria depended on their relative occurrence in rheumatic fever and their relative occurrence in other disease syndromes, which need to be differentiated from rheumatic fever. For example, chorea is included in the major criteria, while fever, a symptom common to many diseases, is included in the minor criteria (Rutstein et al, 1956).

Table 2.2 Jones Criteria for Diagnosis of Rheumatic Fever (Rutstein et al, 1956)

Major Criteria	**Minor Criteria**
I. Carditis	I. Fever
II. Polyarthritis	II. Arthalgia
III. Chorea	III. Prolonged P-R Interval in the Electrocardiogram
IV. Subcutaneous Nodules	IV. Increased Erythrocyte Sedimentation Rate, Presence of C-reactive Protein or Leukocytosis
V. Erythema Marginatum	V. Evidence of Preceding Beta-hemolytic Streptococcal Infection
	VI. Previous History of Rheumatic Fever or the Presence of Inactive Rheumatic Heart Disease

The use of the criteria dictates that "the presence of two major criteria or one major and two minor criteria indicates a high probability of the presence of rheumatic fever" (Rutstein et al, 1956). Additionally, the criteria are not meant to substitute the judgment, wisdom, and experience of the physician. The criteria are designed only to guide the diagnosis of the disease (Rutstein et al, 1956).

The diagnosis of rheumatic fever presents challenges similar to EBA. Assessors look to define the current state of enemy and coalition systems in order to determine progress towards desired effects and objectives. Often, assessors know a cause or condition related to the desired end state but have no direct indicator to determine the current state of a system. Also, how a system moves from state to state is often unknown. Likewise, distinguishing one state from another can be difficult and even impossible, and, similar to diagnosing rheumatic fever, determining a state of a given system must be arbitrary and empirical. Therefore, developing a set of criteria or indicators appropriately weighted based on the relative likelihood of occurrence of a system state may also be useful in performing EBA. The methodology presented in Chapter 3 develops this idea further, describing means to define system states and likely indicators of those states.

2.7 Measures and Indicators

The key question of EBA asks "How do assessors know if the effect has been achieved?" Measures and indicators are the tools used to answer this question. In this thesis, *measures* denote the actual numerical value associated with the assessment. This thesis will also refer to measures as *metrics*. *Indicators* denote the event that is to be described by a measure. For example, an indicator of an effect might be "the enemy daily sortie rate decreases." Then, the actual number or percentage decrease of sorties would be the measure—say "25% decrease" or "30 sorties" for example. Two typical measures in EBO and assessment literature are Measures of Performance and Measures of Effectiveness. Timmerman adds to these a Measure of Interaction, discussed in Section 2.72..

2.7.1 *Measures of Performance and Effectiveness.*

Two types of measures are used in practice to aid EBA—Measures of Performance (MOPs) and Measures of Effectiveness (MOEs). MOPs exist to track task accomplishment. MOPs serve as a metric for the level of completion of the planned actions. MOEs exist to track the effects of actions taken on the enemy. MOEs measure changes in the PMESII system, or SoSA model. MOEs focus on effects achievement. MOEs are also key measures of progress towards the change in system behavior. Combined together, MOPs and MOEs provide an assessment of current operations performance and help to identify trends affecting future operations (JWFC Doctrine Pam 7, 2004:12, 17). This thesis will discuss methods of using and combining MOPs and MOEs in order to perform campaign assessment.

2.7.2 *Timmerman's Three Measures.*

Timmerman defines three types of measures using Col John Boyd's Observer, Orient, Decide, Act (OODA) loop model. Timmerman's EBA process views combat operations as two interlocking OODA loops—one for BLUE forces and one for RED forces (Figure 2.7). Timmerman's measures for EBA follow directly from this model. The first of Timmerman's measures is the Measure of Effort. This corresponds to the MOP defined earlier. As Timmerman puts it, "the [C]FACC has to know the present capabilities of his forces and the actions they are currently carrying out." The second of Timmerman's measures is the Measure of Interaction (MOI). An MOI is the measure of "the immediate results of [coalition] actions and their interaction with enemy efforts and the environment." Timmerman's third measure is identical to the MOE previously defined. An MOE, according to Timmerman, measures the "emerging consequences of those results on the enemy's capabilities and decisions" (Timmerman, 2003:32-34).

The addition of MOIs does not significantly change the methodology of this thesis. The methodology presented in Chapter 3 is indicator based. Since measures of all types refer to the quantitative portions of the indicators used in this thesis, MOEs, MOPs, and MOIs will all be used, though not explicitly by name. MOPs, however, are used by name when tracking the progress of friendly actions taken by the coalition forces.

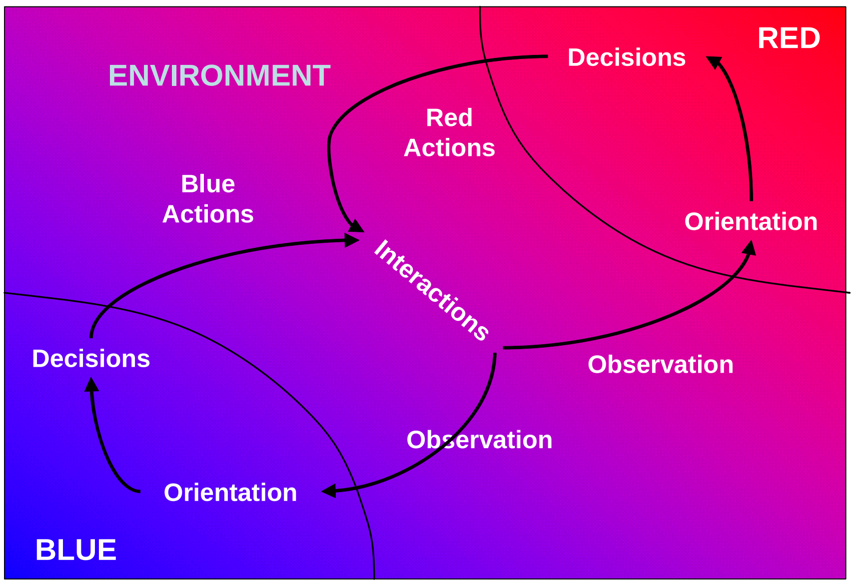


Figure 2.7 Interacting OODA Loops (Timmerman, 2003:33)

Timmerman's description of assessing stability operations differs slightly from his description of assessing combat operations. Timmerman states that operations that are non-combat in nature such as humanitarian and mobility missions can be viewed similarly to combat operations but with a single OODA loop. The actions in stability operations interact only with the environment. Therefore, Timmerman asserts, only Measures of Effort and Measures of Interaction matter since there is no opponent whose decisions are being affected (Timmerman, 2003:39). In the stability operations example in Chapter 4, the EBA methodology does not address the use or lack of use of any type of measure.

2.7.3 *Early Warning Indicators.*

Smith states that assessing effects can resemble the indications and warning intelligence methods developed during the Cold War to determine when the enemy is preparing an attack. The methodology Smith describes serves as a skeleton for the methodology presented in Chapter 3. The methodology will flesh out this skeleton to develop and apply indicators of the states of enemy systems. The Cold War methodology Smith describes was comprised of the following (Smith, 2002:382):

- development of extensive list of indicators based on postulated actions the enemy might take;
- indicators are made into intelligence collection priorities and regularly tracked and reported;
- observable indicators are weighted for their significance and for the place they occupied in the sequence of preparing an attack;
- weighted indicators are aggregated and placed into an algorithm to determine overall probability of attack;
- a fundamental criterion of an indicator is that it must be in some way observable.

2.7.4 *Criteria for good indicators.*

To perform EBA, this thesis recognizes the necessity of developing good indicators of the effects friendly actions have on the enemy. This section reviews the criteria of indicators that can serve this purpose.

A good indicator is one that provides insight to the state of an enemy system. In order to provide insight, indicators must be both observable and relevant. An observable indicator is one that can be found, fixed, and tracked by coalition ISR assets, to include ELINT, HUMINT, MASINT, etc. Indicators may also be observed through open source means of intelligence. Indicators provide the data for any EBA model, and as such must be observable to provide any input into a model. Put simply, analysts cannot assess what they cannot see. The most revealing set of metrics provides no value if no observable data exists to apply to the metrics. That said, there are certain things that are not directly observable such as the internal workings of the enemy's mind or the enemy's decision making process. In order to determine the state of the system, assessors must rely on the aspects of the emerging behavior of the enemy system (Smith, 2002:383, 386).

To be relevant, an indicator must connote the actions taken by coalition forces and the effects those actions are designed to achieve. That is, an indicator must be connected via a causal linkage to a coalition action and a desired effect. In as much, an indicator should reflect the state of the system after the coalition action has been executed. Similarly, an indicator must relate somehow to the system in order to serve as evidence for a state change of the system. Though coalition assets can track many potential indicators of the state of enemy systems, only those indicators linked to coalition action and the system of interest can provide insight. Therefore, the indicator assessors seek is observable evidence of a behavioral change that occurs because of an executed coalition action (Smith, 2002:383).

Knowing that good indicators of effects must be both observable and relevant, the next challenge for the assessor is to generate a set of indicators that meets these criterion.

Since effects represent a change in capability or behavior, the indicators assessors seek must reveal the nature of the system capability or behavior. Assessors can begin by looking at performance measures.

Two types of performance measures exist: aggregate indicators and point indicators. Aggregate indicators provide a measure of the overall throughput of a system. Point indicators provide detection and measurement of an event that differs from the established norm. Both aggregate indicators and point indicators require a database on the system in question and continued monitoring of that system. Assessors can use these measures to reveal how the system functions. Likewise, physical and functional effects can indicate the success of a particular coalition action. Physical and functional effects are highly quantifiable, therefore indicators relating to system capability are generally easier to determine (Smith, 2002:366, 369; Mann, Endersby, and Searle, 2002:37).

Joint Warfare Center Pamphlet 7 describes how indicators should represent changes in the behavioral state of a system (JWFC Doctrine Pam 7, 2004:13). Changes in system behavior can indicate ongoing adaptive decision making processes of an adversary, which cross over into the psychological realm (Smith, 2002:370). Mann *et al* note that psychological changes can be difficult to observe and track accurately (Mann, Endersby, and Searle, 2002:39). However, performance assessment, including aggregate and point indicators, can be used to assess behavioral changes. Fundamentally, potentially observable behavior indicators fall into two categories: 1) evidence of transmitting guidance for a course of action; and 2) the physical acts that the course of action involves. These actions of will likely include those that the enemy wants the coalition to see and those which the enemy wants to conceal (Smith, 2002:370, 388, 390).

Indicators that relate directly to coalition actions and to planned effects are not always possible to observe or determine. However, other areas exist to determine appropriate indicators for a given effect. For example, any military reaction by an enemy will involve decisions in the political, diplomatic, and economic areas. Similarly, moves in the economic, political, and diplomatic areas are likely to parallel actions in the military area. If analysts look beyond the immediate set of military observables, they might be able to find indicators that are substantially easier to see and track (Smith, 2002:391). In as much, a search for evidence that an action failed to achieve an effect may be more productive than a search for positively reinforcing evidence (Mann, Endersby, and Searle, 2002:54). Another important point is that observations need not be precise to be useful. It may be sufficient to know that an activity has intensified or that communications between certain entities has occurred in order to determine a change in the system (Smith, 2002:390).

This thesis advocates the use of indicators as a means to determine the state of the system of interest. The state of the system will tell assessors how close coalition forces are to achieving the desired effects, and indicators will reveal to assessors the current state of the system. Highlighting the most observable indicators of success/failure of an effect is also a basis for an ISR collection plan (Smith, 2002:397).

2.7.5 *Assessing Unexpected Enemy Reactions.*

The methodology presented in Chapter 3 leaves room to perform subjective assessments when the enemy reacts in a manner inconsistent with the set of predefined indicators for evidence of a desired effect. Likewise, the methodology applies a progress function to different states of the systems of interest. The effect on the enemy is a function of the combination of states of separate systems. The combination that occurs in reality may not have already been assigned a value per the progress function. When the enemy reaction is unexpected or the combination of system states has not been assigned progress value *a priori*, the indicators and states witnessed by assessors needs to be assessed *ad hoc*. Smith provides assessors with a list of relevant questions to characterize unexpected enemy reactions, system states, and effects. The set of questions helps assessors to identify what the enemy reaction, system state, or effect is and the nature or extent of the reaction, state, or effect (Smith, 2002:384):

- Is the reaction symmetric/asymmetric?
- Does the reaction involve an escalation of force?
- Was there no observed reaction?
- If so, does this represent a decision not to act, a decision to postpone any reaction, an inability to react, or an inability for the coalition to observe/detect the reaction?
- Which military capabilities were used?
- What scale and geographic scope?
- Which warfare areas?
- Was it a lateral escalation?
- Did the enemy attempt to exploit coalition vulnerabilities? If so which ones?
- Did the reaction expose enemy vulnerabilities, if so which ones?
- How fast did the enemy react?
- How long was the reaction sustained?
- How long could it have been sustained?

- How well were the operations coordinated/synchronized?
- What was observable and what aspects of the operation may have been unable to be detected?

These questions are used to determine how the enemy perceived the military actions of the coalition forces and can then be used to make assessments (Smith, 2002:384).

2.8 Cause-and-Effect Diagrams

Developed by Dr. Kaoru Ishikawa in the field of Quality Control, cause-and-effect diagrams are a powerful tool that illustrate the relationship between results of a manufacturing process (characteristics) and the possible technical causes considered to exact an effect on the manufacturing process. Cause-and-effect diagrams are drawn to clearly illustrate various causes affecting product quality by sorting out and relating the causes. Cause-and-effect diagrams are sometimes called Ishikawa diagrams, or fishbone charts because of their topology (Ishikawa, 1991:229; 1989:25; Ryan, 2000:23).

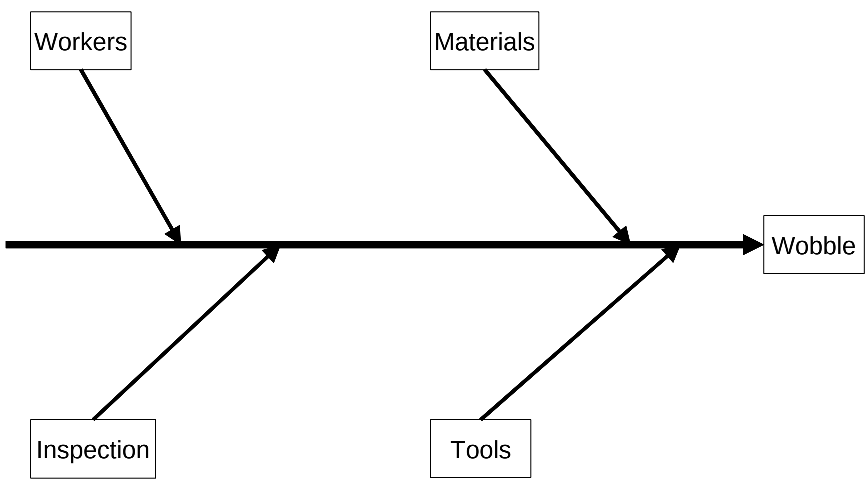


Figure 2.8 Cause-and-Effect Diagram (Ishikawa, 1989:20)

Analysts construct cause-and-effect diagrams by first determining the quality characteristic of interest (i.e. wobble during machine rotation). This characteristic is something that one wants to improve and control. Next, analysts write the main factors which may be causing the quality characteristic. It is recommended to group the major possible causal factors of the characteristic into such items as raw materials, equipment, method of work, measuring method, etc. Each individual group will form a branch of the diagram (Figure 2.8). Finally, onto each of these branches, analysts write the detailed factors which may be the cause. These factors are like twigs on the branch. On each of the twigs, analysts write even more detailed factors making smaller twigs. Defining and linking these causal factors should lead to the source of the quality characteristic (Ishikawa, 1989:19-20). See Figure 2.9 for a small example.

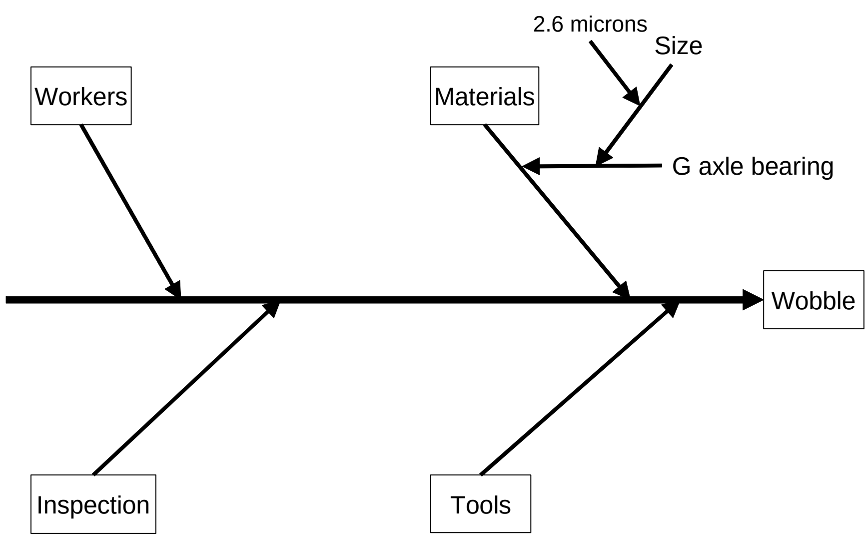


Figure 2.9 Branching of Cause-and-Effect Diagram (Ishikawa, 1989:20)

In order for cause-and-effect diagrams to be useful, they need to illustrate the appropriate level of detail. Cause-and-effect diagrams should look complicated as in Figure 2.10(a); if the diagram looks more like Figure 2.10(b), then the knowledge of the process is too shallow or the diagram is too generalized. Furthermore, if the cause-and-effect diagram only lists five or six causes (even though the form is correct) then the diagram is probably inadequate. This implies that a useful cause-and-effect diagram (one that provides insight into the process) requires at least seven to ten twigs and branches (Ishikawa, 1989:28-29).

Cause-and-effect diagrams have two key advantages: 1) they can be used for any problem where the aim is to get results by knowing the relationships between causes and effects; 2) they are easily understood by anyone (Ishikawa, 1989:28-29). This thesis utilizes cause-and-effect to develop a new diagram called an *effects-tree diagram*. Cause-and-effect diagrams were developed to actively seek out causes because merely listing causes is not really useful (Ishikawa, 1989:25; 1991:231). The primary interest of this thesis is effects. The author notes that merely listing effects is not really useful either. Therefore, this thesis will use effects-tree diagrams, which are based on cause-and-effect diagrams, as the basis for a tool that aids EBO planners and assessors to actively seek out effects of combat operations.

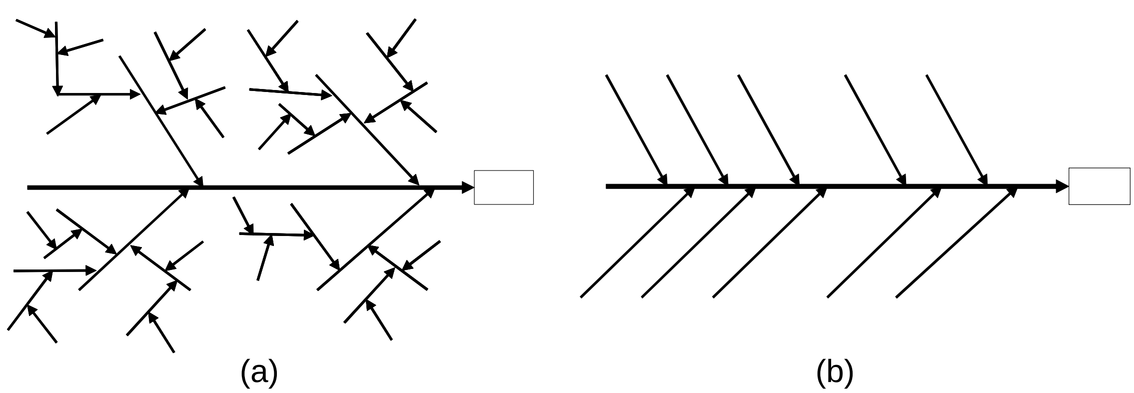


Figure 2.10 Fishbone Charts (Ishikawa, 1989:28)

2.9 BLUE FLAG 04

This thesis will also build upon a method for enumerating effects that was developed informally at a BLUE FLAG exercise in February of 2004 while the author served as the Deputy Chief of the Operational Assessments (OA) team, 12th Air Force. At the exercise, the CFACC pushed the OA team to develop indicators to measure progress towards the attainment of CFACC objectives. The OA team worked with the Strategy Division's planners to develop these indicators by enumerating second and third-order (indirect) effects until measurable indicators of enemy reactions were reached. This method for enumerating effects was based on single and multiple actions associated with key desired effects (Thoele, 2004). In Chapter 3, this thesis takes the principles developed by the OA team in 2004 and combines them with principles from the cause-and-effect diagrams to create *effects-tree diagrams*.

2.10 40-70 Principle

In his biography, *My American Journey,* Colin Powell describes his philosophy on decision making with incomplete information. He believes that the key to making good decisions is to not make decisions too quickly, but to make timely decisions. Powell states that in to order make an informed decision, a decision maker must have at least 40 percent of the information. Likewise, a decision maker should not wait until he has 100 percent of the information, because by then, "it is almost always too late" (Powell, 1995:393). Powell surmises that a decision maker needs between 40 to 70 percent of the information. When he has the amount of information in that range, he can "go with his gut" (Powell, 1995:393). This thesis uses the lower bound of Powell's range of required information as a thumb rule to determine the state of a system. Phase VI of the EBA methodology described in Chapter 3 will require evidence for at least 40 percent of the indicators for a given state before assessors can reasonably conclude that a system is in that state.

2.11 Assumption about Enemy Behavior

In order to determine the capability and behavior states of the enemy, it is necessary to anticipate how the enemy will react to friendly actions taken against the enemy PMESII systems. This is no trivial task. As Allen points out, the enemy is "normally uncooperative, he will do the unexpected, the undesired, and the unplanned" (Allen, 2005:8-9). Similarly, Smith states that the enemy will not respond as expected; therefore, the planners and assessors "must plan for an intelligent adversary who will be determined to defeat [commander's] efforts by whatever means possible" (Smith, 2002:254). Smith considers this particular view of the enemy to be "prudent planning" (Smith, 200:254). In this thesis, this view of the enemy is a fundamental assumption that is used to derive potential enemy behaviors resulting from friendly actions. To be clear, the assumption is that the enemy will continue to fight by whatever means available to him. As one avenue of war-making is blocked, the enemy will seek others, determined to defeat the commander's efforts.

2.12 Risk Assessment

In his Risk Filtering, Ranking and Management (RFRM) methodology, Haimes provides tools useful to the problem of performing EBA. RFRM is a methodology for identifying, prioritizing, assessing, and managing scenarios of risk to large-scale systems from multiple overlapping perspectives. In RFRM, Haimes integrates empirical and conceptual methods, descriptive and normative methods, as well as quantitative and qualitative methods to implement a comprehensive approach to the problems of identifying and managing system risks (Haimes, 2004:277,279).

Procedures for identifying risk require analysts to establish priorities among a large number of individual contributions to the overall system risk. To manage the total risk of a system, identifying what can go wrong and the associated consequences and likelihoods (risk assessment) helps generate mitigation options with their trade-offs and impacts on future decisions. RFRM ranks the critical elements of risk and thus contributes to the analysis of mitigation options, which facilitates a seemingly intractable decision problem by focusing on the most important contributors of risk (Haimes, 2004:276-277).

The eight phases of RFRM are summarized as follows (Haimes, 2004:280):

I. Scenario Identification—An "as-planned" or "success scenario" is developed using Hierarchical Holographic Modeling (HMM), which is a holistic methodology to decompose the attributes of a system while representing the system through multiple perspectives and hierarchies; risk scenarios are then developed based on what can go wrong in the success scenario (Haimes, 2004:89, 280).

II. Scenario Filtering—Risk scenarios are filtered based on the responsibilities and interests of the relevant system user.

III. Bicriteria Filtering and Ranking—The remaining risk scenarios are further filtered based on qualitative likelihoods and consequences.

IV. Multicriteria Evaluation—Eleven criteria are developed that relate the ability of the risk scenario to defeat the system.

V. Quantitative Ranking—Additional filtering/ranking of scenarios is accomplished based on quantitative and qualitative matrix scales of likelihood and consequence.

VI. Risk Management—Risk management options are developed to mitigate remaining risk scenarios including cost estimate, performance benefits, and risk reduction of each option.

VII. Safeguarding Against Mission Critical Items—Analysts evaluate the performance of the options selected in phase VI.

VIII. Operational Feedback—Analysts use the experience and information gained during implementation of mitigation measures to refine scenario filtering and the decision processes of earlier phases.

This thesis draws from two general aspects of RFRM to attack the EBA problem. First, as Haimes points out, the phases of RFRM "reflect a philosophical approach rather than a mechanical methodology" (Haimes, 2004:280). The RFRM phases imply an iterative process wherein analysts move in and out of phases, repeating each as necessary to improve the overall process. The EBA phases of this thesis are modeled after the RFRM phases to capture the same spirit of iteration. Second, by incorporating a variety of approaches—empirical and conceptual, descriptive and normative, as well as quantitative and qualitative—Haimes is able to capture the intent of the decision makers as well as provide mathematical rigor to risk assessment. The EBA methodology presented in Chapter 3 aims to provide this same balance between subjective assessment and objective assessment in order to provide insight to the completion of friendly actions and achievement of desired effects.

The RFRM contributes a more specific characteristic to this thesis as well. Phase III of RFRM combines two types of information: likelihood of what can go wrong with a system, and the associated consequences. To do this, Haimes presents an example using the ordinal version of the U.S. Air Force risk matrix as adapted from Military Standard (MIL-STD) 882, which is cited in Roland and Moriarty (Haimes, 204:282). Haimes' matrix is presented here in Figure 2.11.

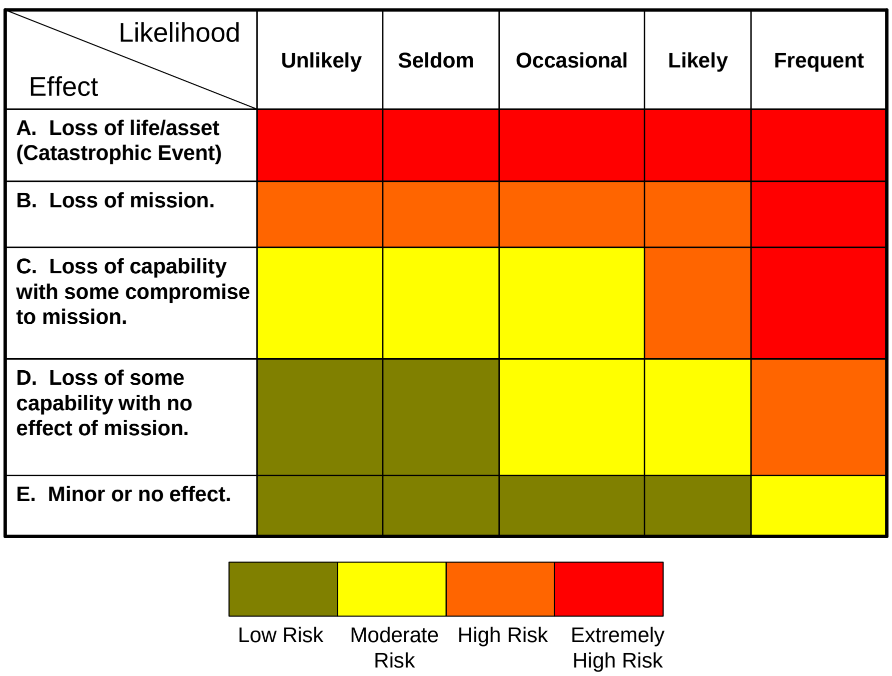


Figure 2.11 Example risk matrix for RFRM Phase III (Haimes, 2004:283)

In phase III, Haimes combines the likelihoods and consequences of risk scenarios into a joint concept called "severity." To do this, Haimes divides the likelihood of risk source into five discrete ranges. Similarly, Haimes divides the consequence scale into four or five ranges. The scales are then placed in matrix form and the cells are assigned relative levels of risk severity. The scenario categories identified in phase I are then distributed into cells of the matrix; those falling into the “low risk” category are filtered out and set aside for later consideration (Haimes, 2004:282).

This thesis utilizes the consequence scale that Haimes presents in phase III of RFRM as the inspiration for an ordinal scale for the state of enemy systems. After friendly actions have been taken against an enemy system, the system will transition from its current state to another state, and ultimately to a desired state. The EBA methodology aims to track the system as it transitions from state to state using the states of the ordinal scale and indicators that the system is in a certain state. The system states are then used to determine the progress of commanders’ objectives.

2.13 Value Functions and Progress Functions in EBO

As stated earlier in the chapter, previous assessment efforts have used linear additive value functions to determine attainment of commanders’ objectives. This thesis views the use of value functions as inappropriate for the purpose of assessing attainment of commanders’ objectives in an EBO context, as the necessary conditions of a linear additive value function are not met within the interdependence of an EBO model.

The necessary conditions of a linear additive value function include having attributes of an alternative that are mutually preferentially independent. That is, all other attributes being equal, a level X of an attribute is always preferred to level X' (French, 1986: 105-107, 120). In EBO however, this condition is not met. If the attributes are taken to be the enemy systems, and the attribute levels are taken to be the states of those systems, then for a given system, an arbitrary state X may not always be preferred to state

X'. When other systems of a network are considered, synergies among the enemy systems could yield situations wherein X' is preferred to X when the states of other systems are considered. For example, the desired end state of a conflict may include severing the command, control, and communications (C3) links to an enemy facility. However, if the lines are being exploited by coalition forces, or the enemy is expected to have an undesired reaction (say, fire theater ballistic missiles if communications are cut) then keeping the C3 intact may actually be a state of the system closer to the attainment of the objective than when the C3 is severed.

Similarly, in previous assessment efforts the value function is based upon a hierarchical strategy-to-task structure. In a hierarchy structure, the elements within each tier of the hierarchy are divided to be mutually exclusive and collectively exhaustive. The elements at each level of the hierarchy must completely describe the element of the next higher level in the hierarchy (collectively exhaustive). Likewise, the elements on the same level of the hierarchy must not overlap so as to keep from double counting the element's contribution to the level above it (mutually exclusive) (Kirkwood, 1997:16-17). Chapter 3 will discuss in detail the implications of these two properties of hierarchies in an EBO model. Essentially, a set of effects are defined to be collectively exhaustive with regards to the attainment of an objective. However, since an effect may contribute to multiple objectives, and effects can contribute to achieving other effects, the effects are inherently interrelated, thus not mutually exclusive. Violating the mutual-exclusivity property also makes the use of a linear additive value function inappropriate for use in an EBO model.

Instead of the linear additive value function, this thesis will introduce a *progress function* in Chapter 3 to determine attainment of objectives. In this function, the different states of enemy systems will be considered as a vector of states. Military planners and subject matter experts will use their experience and intuition to map these vectors to a value, which determines the progress towards objective attainment. In this function, the differences between the state vectors are best expressed qualitatively rather than quantitatively. The use of a progress function (rather than a value function) indicates a subtle difference in the underlying purpose for using the function. A value function represents the preference of a decision maker amongst a set of alternatives. The progress function defined in this thesis represents the level attainment of a military objective. While these two functions can be expressed by the same mathematical formulations, the functions express different concepts. This thesis aims to represent the state of an enemy network that best represents the commander's view of objective attainment, which implies more than the commander's preference amongst a set of alternatives.

2.14 Conclusion

Chapter 2 presented an overview of EBO that includes the definition of *effect*—a change in the state of system. EBO has four key, interrelated components: a System-of Systems Analysis (SoSA), Effects-Based Planning (EBP), Effects-Based Execution (EBE), and Effects-Based Assessment (EBA). To develop a methodology to perform EBA, this thesis draws from previous assessment efforts such as the large-scale effort of OIF. In order to improve upon past efforts, this thesis looks to medical diagnosis methods that use criteria or indicators to determine the state of a patient or system. To develop the methodology further, tools in the fields of quality control and risk assessment are used to derive system states and a set of indicators to signal the presence of those states. These elements are then combined with the mathematics from decision theory to develop progress functions that represent the level of attainment of commanders' objectives. Chapter 3 presents the EBA methodology of this thesis in detail.

3 Methodology

3.1 Introduction

The ultimate goal of Effects-Based Assessment (EBA) is to provide insight to the Combined Forces Air Component Commander (CFACC) and Combined Air Operations Center (CAOC) staff. The CFACC wants to know what progress has been made towards his objectives and desired effects. Similarly, the CAOC staff wants to know how the operational plan is doing with regards to achieving the desired effects, and just as important, the CAOC staff wants to know how coalition forces are doing with regards to executing the plan. The EBA methodology described in this chapter is designed to provide this insight.

Section 3.2 describes the mathematical construct of EBA. The progress function is defined including the use of effects, indicators, regions and state vectors. Section 3.3 describes a seven-phase methodology for implementing EBA in an operational context. The methodology begins with defining effects and concludes with a method to view the progress of coalition actions and their effects on the enemy over time.

3.2 Mathematical Construct of EBA

In general the EBA process aims to provide a quantitative measure of progress of the CFACC objectives and desired effects. Per the Effects-Based Planning (EBP) Course of Action (COA) development process, the progress towards effects achievement determines the progress towards objective attainment. That is, the progress of the objectives is a function of the progress of the effects. Similarly, the progress of the effects is a function of friendly actions and enemy reactions. The EBA methodology tracks friendly actions and observes the enemy reactions in order to assess the progress of the desired effects. The progress of the effects is then used to generate the progress of the CFACC objectives.

3.2.1 *Progress of an Objective.*

For each CFACC objective, the EBP process produces a finite set of desired effects. Let $E_k = \{e_1, e_2, ..., e_{n_k}\}$ be the set of n_k desired effects for objective k. For each system q, there exists a set of states $S_q = \{s^0, s^1, ..., s^e\}$, where $q = 1, 2, ..., n_k$. This notation assumes one system for each desired effect, but the notation could be adapted to accommodate vectors of multiple systems per effect.

In general, an effect is a change in system state Δs where

$$\Delta s \equiv s^w \rightarrow s^x \text{ for } s^w,\ s^x \in S_q$$

where $s^w \rightarrow s^x$ denotes the transition from state s^w to state s^x. In order to achieve desired effect $e \in E_k$, system q must transition from the initial state s^0 to the desired state s^e, denoted as

$$e_q \equiv \Delta s_q = s_q^0 \rightarrow s_q^e$$

That is, the desired effect on system q is the change from the initial state s_q^0 to the desired state s_q^e. Achievement of these effects will be used to determine the progress towards the attainment of objective k.

This thesis defines *progress* as the level of attainment of an objective, represented by a value $p \in [0,1]$, where 0 denotes no attainment and 1 denotes complete attainment.

Let O_k be the progress of objective *k*. Then, O_k can be described as a function of the current system states:

$$O_k = f(s_1, s_2 ..., s_{n_k})$$

where *f* is a *progress function* such that $f : \mathbb{R}^n \to [0,1]$ and s_q is the state of system *q*. Using this function, $O_k = f(s_1^e, s_2^e ..., s_{n_k}^e) = 1$ and $O_k = f(s_1^0, s_2^0 ..., s_{n_k}^0) = 0$.

In the previous assessment efforts mentioned in Chapter 2, (reference Sections 2.5 and 2.13), the progress of objectives was determined by an additive value function. Additive value functions require two fundamental assumptions to be met: 1) the components within each level of the hierarchy are mutually exclusive with regards to each other and 2) the components are collectively exhaustive with regards to the next level up the hierarchy. EBO considers *operational effects that are inherently dependent* and therefore not mutually exclusive. Achievement of one effect may contribute to or impede the achievement of other effects. Therefore, the first assumption is usually not met and the use of an additive value function is generally inappropriate. However, in EBO the effects are taken to be collectively exhaustive within a given objective. In the sense of the progress function, collectively exhaustive means that the set of effects provides the complete set of arguments for the progress function.

The vector $\mathbf{s}_k = (s_1^m, s_2^m, ..., s_{n_k}^m) \in \mathbb{R}^{n_k}$ is called the state vector of objective *k*, where s_q^m represents the current state of system *q*, and $m \in \{0,1,...,e\}$. Each state vector $\mathbf{s}_k$ represents a different point on the n_k-dimensional hypercube, which represents the progress towards attainment of objective *k*. For the system of interest $n_{[q]}$, as the state *s* of $n_{[q]}$ changes, the element s_q^m changes and $\mathbf{s}_k$ moves from point to point on the hypercube progressing towards the attainment of objective *k*.

Consider the case where $n_k = 2$ and each system has five states. All systems begin in state 0 (Figure 3.1a). After coalition actions have been taken, the objective moves to point (2,2) (Figure 3.1b). Put another way, the system of interest in the first effect $n_{[1]}$, which corresponds to the first element of the vector, transitions to state 2. Likewise, the system of interest in the second effect $n_{[2]}$, which corresponds to the second element of the vector, also transitions to state 2. In the next assessment, the systems transitions to state vector $\mathbf{s}_k = (3,1)$ as shown in Figure 3.1c. In Figure 3.1d, the systems have transitioned to state vectors (3,4) and then to its desired end state (5,5).

The progress function $f(\cdot)$ can be viewed as mapping the state vectors to bounded regions of the *n*-dimensional hypercube. Let $R_y^n \subseteq \mathbb{R}^n$, $y \in \mathbb{N}$ be a region of state vectors $\mathbf{s}_k$ such that all $\mathbf{s}_k \in R_y$ map to the same progress value p_y. Then, $O_k = p_y$. Figure 3.2 depicts an example of three regions (y = 1, 2, 3) and their associated progress values. In this example, the first state vector (0,0) is in Region 1. The second state vector (2,2) is in Region 2. The third state vector (3,1) returns to Region 1. The fourth and fifth state vectors (3,4) and (5,5) are in Region 3. Therefore, the values for O_k for each assessment corresponding to the state vectors in Figure 3.2 are as follows: 0.33, 0.67, 0.33, 1.00, and 1.00. Note that, by definition of Region 3, the desired end state vector $\mathbf{s}_k^e = \{(3,3); (4,3); (5,3); (3,4); (4,4); (5,4); (3,5); (4,5); (5,5)\}$.

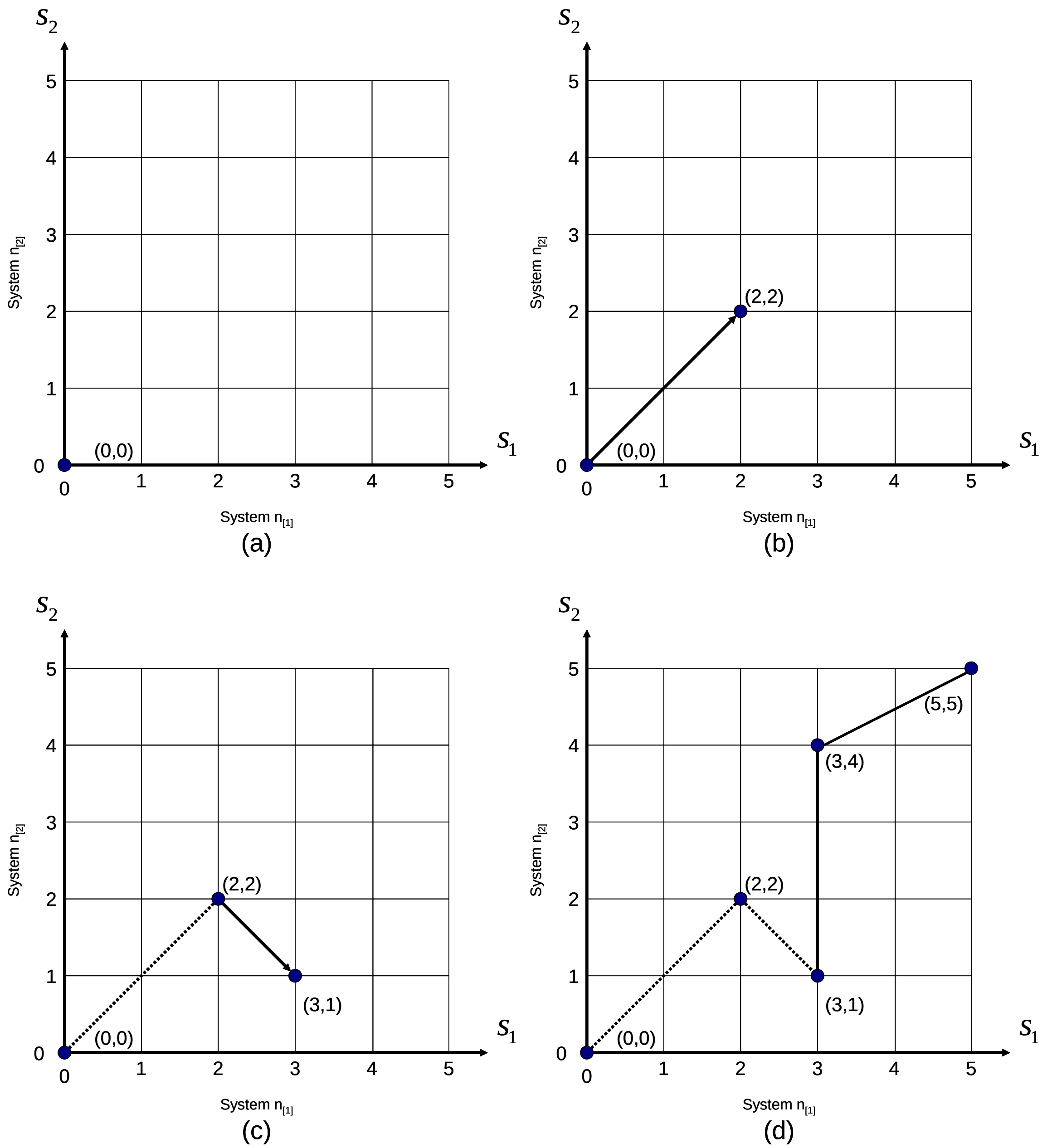
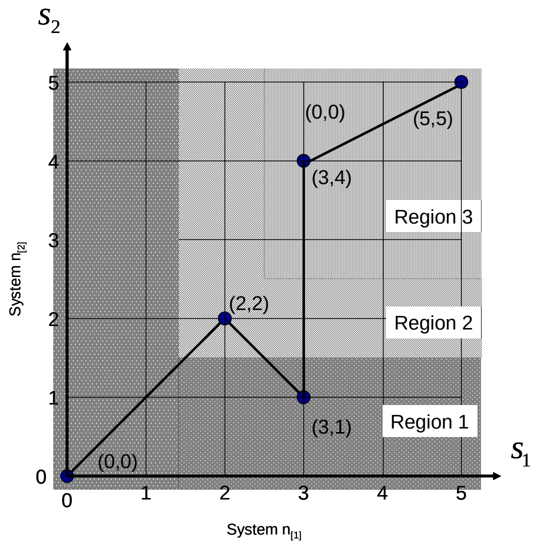


Figure 3.1 Progress of Objective *k*



p_y-values

R_y^n	p_y
Region 1	0.33
Region 2	0.67
Region 3	1.00

Figure 3.2 Progress regions and p_y-values.

3.2.2 *Relationship between System States and Assessment Indicators.*

For each state s_q^m of system $n_{[q]}$, s_q^m is defined by a function $g: I_q \rightarrow S_q$ such that

$$s_q^m = g(i_1, i_2, \ldots, i_r)$$

where $I = \{i_1, i_2 \ldots, i_r\}$ is a set of indicators i, $i \in \{0,1\}$. When a predefined number of indicators exists for a given state, $i = 1$ for some $i \in I$, $n_{[q]}$ is said to be in state s_q^m. In Figure 3.3, the states are defined such that the system will transition in a series from the initial state s^0 to the desired state s^e as a result of the friendly actions taken and enemy reactions.

Using indicators to assess the state of the system of interest, assessors then use the changes in system states (the effects) to build the state vectors. The state vectors are then used as inputs to the progress function. Thus, this EBA construct builds upon the indicators to make an assessment of the progress towards objective attainment. In order to perform these calculations, all the relevant parameters must be defined (i.e., the states of the n_k systems for objective k, or the state vector $(s_1^{m_1}, s_2^{m_2}, ..., s_{n_k}^{m_{n_k}})$. The remainder of the chapter describes how the planners and assessors develop the parameters beginning with the central piece of EBO, the effects.

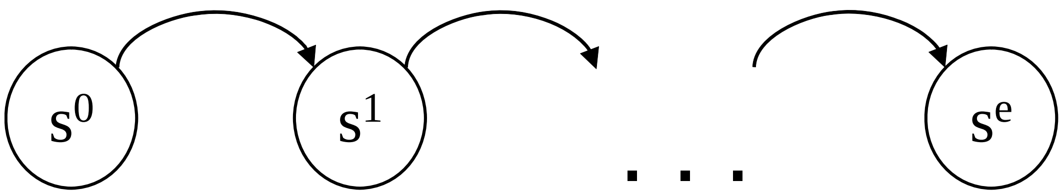


Figure 3.3 State transition diagram for system $n_{[q]}$

3.3 Seven-Phase EBA Methodology

In order to apply the above theoretical construct to an operational environment, this thesis decomposes the EBA process into seven phases. At any point in the process, planners and assessors can be simultaneously working in any of the phases. The phases have a general chronological order with each phase producing material required in the subsequent phases. However, unlike a rigid series of fixed steps, the phases can be revisited iteratively and in various orders to improve the EBA process and output.

EBA is a vital and complementary part of EBP. Planners and assessors work in concert to develop an assessable effects-based plan. The EBA and EBP processes support and enhance each other; as the plan changes, the assessment plan also changes. Just as in EBP, much of the work described in the EBA phases should be accomplished prior to the start of the Effects-Based Execution (EBE). During combat operations, the elements of EBP and EBA are then subsequently altered as the campaign evolves.

The phases of EBA are as follows:

Phase I: Desired Effect Definition. For each operational-level effect, assessors and planners develop a statement completely describing the desired effect; this statement identifies the enemy system of interest, the initial state of the system, the desired end state of the system, and the start and end times of the state change.

Phase II: Indicator Development. Planners and assessors develop a set of measurable indicators based on anticipated enemy system reactions to planned coalition actions and desired effects. This thesis defines a measurable indicator as one that is *observable* and *distinguishable*. Effects-tree diagrams are introduced to facilitate this phase.

Phase III: System State Definition. The set of measurable indicators is partitioned into ordinal states that describe the system of interest as it reacts to friendly actions.

Phase IV: Actions Assessment. Coalition actions are tracked using Measures of Performance (MOP), similar to those used in OIF, to track the CFACC actions. The MOPs are then plotted on a time axis to view trends.

Phase V: Effects Assessment. The indicators and MOPs are used as evidence for an assessment of the state of the systems of interest. The resulting state of the systems is monitored over time to view trends towards the desired end state.

Phase VI: Objectives Assessment. The progress function is defined by planners anticipating state vectors that will result from friendly actions. As state vectors are determined during EBE, the vectors are mapped to progress values according to this function.

Phase VII: Campaign Assessment. Actions assessment, effects assessment, and objective assessment are brought together with the time dimension to observe how the enemy systems react to the friendly actions. In this phase, assessors determine if the actions executed are achieving the desired effects and are accomplishing the CFACC objectives as planned.

3.3.1 *Phase I: Precisely Defining Effects to be Assessable.*

Effects are the heart of EBO, and desired effects of friendly actions on the enemy are what direct the entire EBO process. Effects direct the EBA portion of the process in two ways: 1) assessing the attainment of commander's objectives is accomplished by assessing the achievement of a set of desired effects; 2) effects are used to derive indicators that determine the achievement of those effects. Phase I lays out the specifications required of an effect definition so that the achievement of the effect can be accurately assessed.

The EBA process begins with a set of CFACC objectives and a set of desired effects that must be achieved in order to attain the objectives. For each objective, planners identify a set of effects that apply to that objective. With regards to the overarching objective, the set of effects must be collectively exhaustive. Put another way, for a given objective, there should exist an effect for each system that must undergo a state change. These effects taken together completely describe everything that must occur to attain the objective. The collectively exhaustive property enables the analytical leap from effects achievement to objective attainment; if all the effects have been achieved, then the objective has been attained.

In order to assess the achievement of the effects, assessors must derive from the effects measurable indicators that give insight to the state of the system. Indicators are evidence that a system state change has occurred. A well-defined effect description guides the search for indicators so that assessors can track data representing the resulting system states after friendly actions have been executed. In order to meet these assessment requirements, the effects must be clearly and precisely defined.

Gallagher *et al* state that an effect is clearly and precisely defined when a desired functional capability or desired behavior along with a range, extent, start time and end time are specified (Gallagher, True, and Whiteman, 2004:9). This thesis adds to these specifications the initial state of the system, the system state before any coalition actions are taken. Therefore, for each effect, planners and assessors need to define the following specifications:

- *System of interest*; this is what Gallagher *et al* describe as the range; a capability-range is the affected area, such as target, city, region or state, whereas behavior-range is the affected individual, group or nation (Gallagher, True, and Whiteman, 2004:9); this specification answers the question "What system is to be affected?"
- *Initial State of the System*; this specification is the baseline for comparison after coalition actions have been taken. This specification answers the question "What is the beginning state of the system?" To answer this question, enemy systems need to be tracked before conflict ensues. Assessors may need to integrate historical data to establish performance norms of physical systems or behavioral

norms of human systems (Smith, 2002:397). A quality SoSA model, should be able to provide input as to the initial states of the system as well.

- *Desired End State*; this is what Gallagher *et al* describe as the Extent; the extent specifies the resulting level of capability or behavior—whether it is decreased, maintained or increased (Gallagher, True, and Whiteman, 2004:9); this specification answers the question "What is the desired change in capability/behavior of the system?'
- *Start time*; start time answers the question "When is the change to take place?"
- *End time*; end time, when combined with start time, answers the question "How long does the effect last?"

In conclusion, effects are well-defined when they are described by the system of interest, the initial state of the system, the desired end state, and start time and duration of the effect. Effects defined this way will adequately support the assessment of the objective and the derivation of appropriate indicators.

3.3.2 *Phase II: Developing Measurable Indicators with Effects-Tree Diagrams.*

The hardest task of an assessment effort is determining what data is observable, obtainable by intelligence assets, and provides insight to the nature of the enemy's capabilities and behavior. How do analysts know if the effects are being achieved? What indicators should be chosen? What metrics should be used? What intelligence options are available for data collection on the indicators? How can more options be generated? One approach to determine the state of an enemy system (as discussed in Section 2.9) includes an analysis of the most likely enemy reactions to friendly actions taken against enemy system nodes. Phase III builds on this approach to generate a set of measurable indicators. This thesis defines a measurable indicator as one that is *observable* and *distinguishable*. Observable denotes the indicator is detectable by the intelligence assets available to the JFC, including but not limited to traditional ISR, open-source intelligence, SIGINT, HUMINT, ELINT, MASINT, etc. Distinguishable denotes that when the indicator changes, the change is evident to the assessors. For example, when assessing the combat strength of an enemy infantry division, the unit itself may be observable. However, the particular strength of the unit may not be distinguishable; similarly, the unit may not actually be distinguishable from other enemy units. Conversely, the life status of an enemy leader (whether he is living or dead) is certainly distinguishable, but it may not be observable because his whereabouts are unknown.

A difficult task for planners is determining the most likely effects to be generated by different courses of action. For instance, destruction of a single node can simultaneously have indirect effects at all levels of warfare and across all types PMESII systems. With multiple layers of indirect effects, it becomes increasingly difficult to precisely predict enemy system reactions. Historically, its been difficult to predict beyond third-order effects with any certainty (Smith, 2002:397; Mann, Endersby, and Searle, 2002:34, 39). To overcome these challenges, this thesis introduces a tool called an *effects-tree diagram*. This section will first describe the general form and construction of an effects-tree diagram and then follow with a detailed example.

3.3.2.1 *Constructing Effects-Tree Diagrams.*

Developing an effects-tree diagram is similar to creating a cause-and-effect diagram, the quality control tool described in Section 2.8. It is necessary to know both causes and effects in great detail and in concrete terms in order to illustrate their relationship and make them useful (Ishikawa, 1989:18). Effects-tree diagrams can be thought of as the reversal of cause-and-effect diagrams. Cause-and-effects diagrams begin with a resulting effect and work backward to determine root causes. Effects-tree diagrams begin with a military action against an enemy network node (a cause) and work forward to determine the resulting effects.

Step 1 (Figure 3.4): Determine the operational-level enemy system of interest to be diagramed. Write the initial state s^0 on the left side of the diagram and draw a box around it. Similarly, write the desired state s^e on the right side of the diagram and draw a box around it. Then draw an arrow from the initial state to the desired state. This arrow represents the transition of the system from the initial state to the desired state.

Figure 3.4 Effects-Tree Diagram Step 1

Step 2 (Figure 3.5): List any indicators of the initial and desired state that can be derived from the effect definition in Phase I. Add these to the diagram by drawing a branch from the system state. On this branch draw smaller branches containing the indicators. Indicator branches are denoted by the circles on the branch. It may be necessary to list indirect effects of the system state in order to reach measurable indicators of the system state.

Figure 3.5 Effects-Tree Diagram Step 2

Step 3 (Figure 3.6): Draw the planned friendly actions $A_1, A_2, \ldots, A_n$, to be taken against the system with arrows directed to the shaft of the central arrow. These actions are prescribed by the O-E-N-A-R chain resulting from EBP. In effects-tree diagrams, these arrows represent causal linkages.

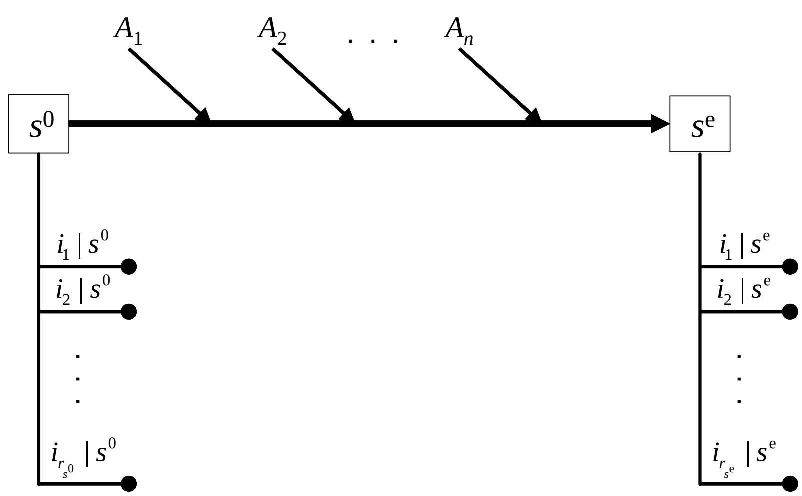


Figure 3.6 Effects-Tree Diagram Step 3

Step 4: For each action, draw a branch of arrows down from the central line. The vertical line of this branch represents the set of all indirect effects E_I resulting from the achievement of the desired end state s^e. The arrows represent *enemy reactions* (indirect effects E_I) to the friendly action that resulted in the desired end state of the system.

Assessors now consider the indirect effects that would be caused by each action taken in isolation. That is, assume that action A_n is 100-percent successful at achieving the desired effect on the enemy system. Assume no other friendly actions were taken, and the enemy system has transitioned to the desired end state s^e. This is done for each action, hence a branch is drawn for the set of enemy reactions resulting from the desired state caused by each action as shown in Figure 3.7. Assessors should consider the reaction of all nodes within the system as well as the reactions of other systems of the PMESII network connected to the system of interest. To consider all potential enemy reactions, assessors assume that the enemy will continue to fight by all means available to him (reference Section 2.11). With this assumption, an additional question for the assessors becomes "Given that action A_n alone causes the desired end state s^e, how does the enemy react in order to keep fighting?" The answers to this question are then added to the diagram as arrow branches.

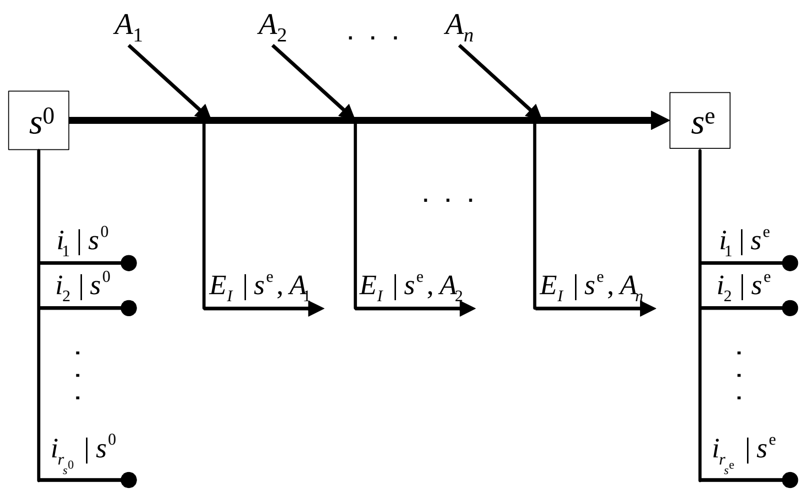


Figure 3.7 Effects-Tree Diagram Step 4

Step 5 (Figure 3.8): Adding branches to the diagram should lead to measurable indicators of the indirect effects $i_1, i_2, ..., i_r$; therefore assessors should continue adding branches until they reach measurable indicators. Assessors must try to understand the cause-and-effect relationship as fully as possible and increase the number of sub-branches by continually asking, "how does that action affect the system? How would the system react? How can the effect be observed?" Planners and assessors must ask what else might happen, because in a complex system, no action ever creates a single outcome. There is always some other indirect effect to consider (Mann, Endersby, and Searle, 2002:52). It is important to note that to arrive at measurable indicators, several intermediate arrow branches (indirect effects) may need to be drawn before drawing the indicator branch.

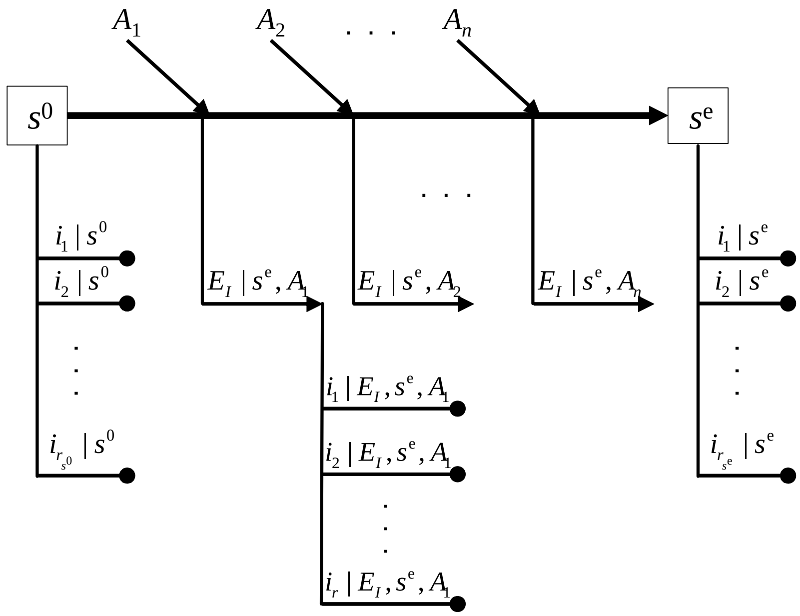


Figure 3.8 Effects-Tree Diagram Step 5

The effects-tree diagram helps organize and relate the impact of actions and their indirect effects to the rest of the enemy system. The key to observing indirect effects in effects-tree diagrams is the reiteration of the questions How does that action affect the system? How would the system react? How can the effect be observed? For each indirect effect generated, analysts need to expand the tree by answering these questions.

For planning purposes, assessors should include as many relevant people as possible when building effects-tree diagrams. Planners, assessors, and intelligence analysts should all be included in order to determine enemy reactions and indirect effects of an action.

Assessors need to make an effects-tree diagram for each effect within a given objective. Likewise, when the effects-tree diagram begins to reveal potential indicators, it is useful to classify the indicators by organizations that can provide the necessary data to perform the assessments process. To this end, do not cut effects and potential indicators because there is no known way to observe or quantify them. Include all effects considered important for the action and desired effect, regardless of whether or not they are presently being measured or are capable of being measured; these effects may still provide insight to planners after the measurable indicators have been chosen.

When the diagram is complete, planners and assessors should have developed approximately 10 potential indicators for each desired effect. A set of indicators of this size will enable partitioning the indicators into states in Phase III. Keep in mind, however, that in practice, the total number of indicators capable of being tracked for an entire objective is around 50 to 60. Note, a single indicator may provide evidence for multiple effects and should be used for as many effects as appropriate. These indicators then need to be coordinated with the ISR division in order to make the indicators part of the overall ISR collection plan.

3.3.2.2 *Effects-Tree Diagram Example.*

The following example of an effects-tree diagram is based on a scenario of the notional country of Exstan. As Exstani governance moves towards a stable democracy, the next round of elections are planned to take place in six months. As the elections get closer, terrorist attacks have increased in number and intensity. The coalition has determined the following desired effect against Kobra, a ruthless terrorist organization determined to rule Exstan:

- *System of interest*: Kobra terrorist organization.
- *Initial State of the System*: 3 Kobra Commander hideouts; 4 Kobra training camps; 10 other terror group bases sympathetic to Kobra; 15 air bases and

military storage facilities. Kobra is capable of conducting as many as ten simultaneous attacks throughout the country with varying degrees of destruction and casualties.

- *Desired End State*: Kobra incapable to perform a single attack that results in 5 or more casualties.
- *Start time*: Effect to begin on or before D+15.
- *End time*: Effect not to end before D+195.

The first step of the tree-diagram flows directly from the desired effect definition as seen in Figure 3.9.

Figure 3.9 Effects-Tree Diagram Example—Step 1

Figure 3.10 depicts the indicators that immediately come to mind to assess the state of Kobra. Assessors often stop at this point when trying to determine success indicators for military actions. However, tracking only one indicator to determine the effect of multiple military actions has two limitations: 1) the indicator may not be measurable in practice; and 2) the indicator may change based on other factors independent of friendly actions. The first limitation could result in assessors having a non-observable indicator on which to base the assessment of an effect. The second limitation could result in assessors making incorrect assessment based on what appears to be a direct causation. In this example, the number of Kobra attacks will likely be affected by friendly actions, but Kobra attacks also may be affected by other factors internal to the

Kobra organization. Assessors want to know the impact of the synergy of friendly actions on the system and view how the system changes as a result of those actions. Developing multiple indicators will aid this goal.

Figure 3.10 Effects-Tree Diagram Example—Step 2

Step 3 (Figure 3.11) begins to look at the impact of each friendly action. In this example, the planners have decided on a four actions against four separate subsystems of the Kobra terrorist organization: neutralize command and control (C2) leadership; destroy Kobra sanctuary; destroy Kobra military equipment; and influence Kobra fielded forces to capitulate.

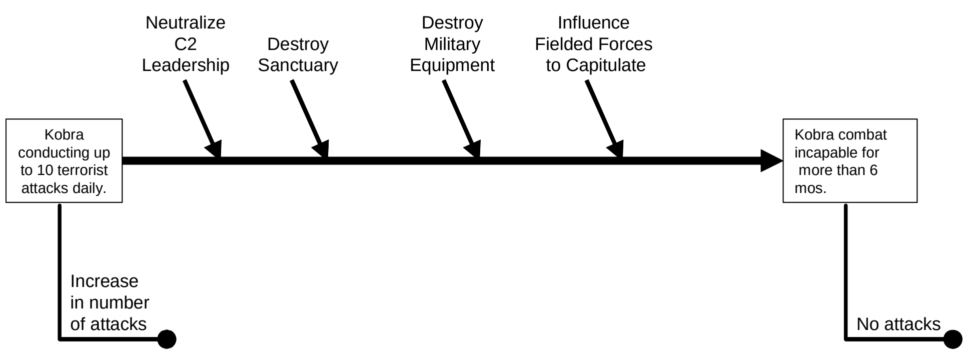


Figure 3.11 Effects-Tree Diagram Example—Step 3

Figure 3.12 shows the initial branching of the diagram with a branch for each planned action against the system. These branches represent the indirect effects resulting from the achievement of the desired effect given the action is successful in isolation from the other actions. Figure 3.13 depicts the completion of the effects branch with the "Neutralize C2 Leadership" branch, showing the anticipated indirect effects and their associated measurable indicators. The full effects-tree diagram for this example is given in Appendix A. The list of unique indicators developed from this diagram are given in Table 3.1.

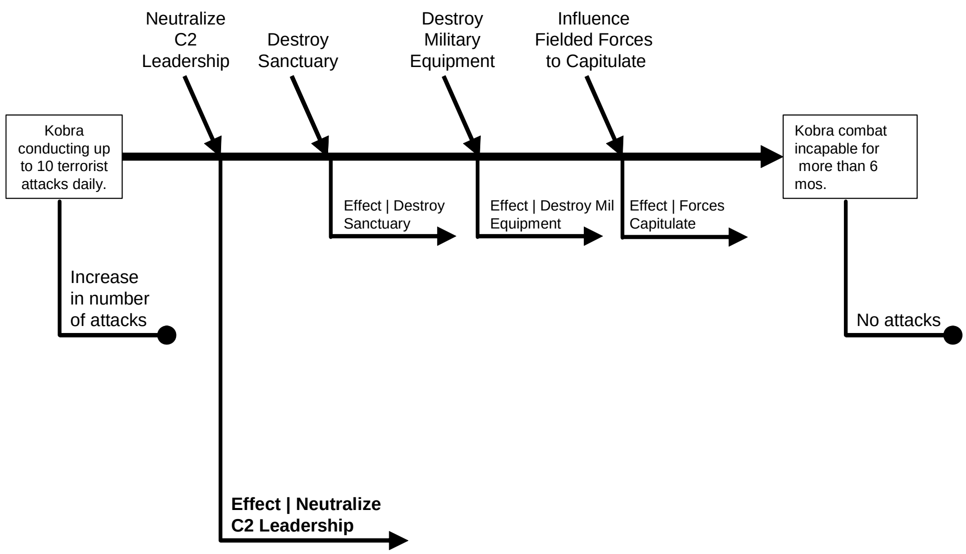


Figure 3.12 Effects-Tree Example—Step 4

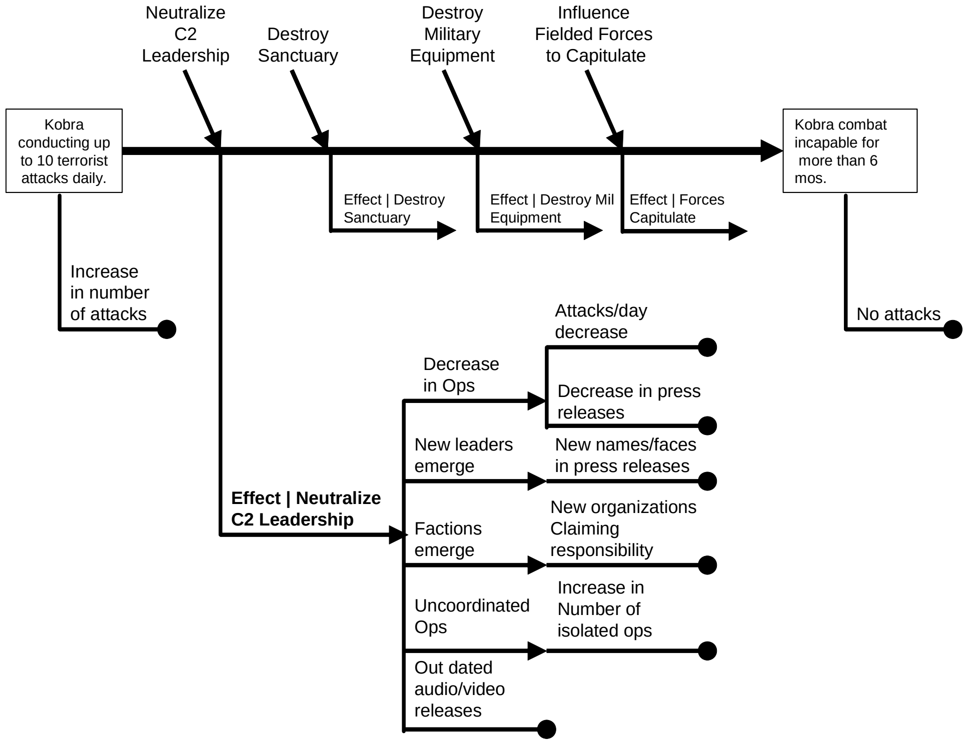


Figure 3.13 Effects-Tree Example—Step 5

Table 3.1 Indicators Generated from Effects-Tree Diagram Example

Neutralize C2 Leadership	Destroy Sanctuary	Destroy Military Equipment	Influence Fielded Forces to Capitulate
Attacks/day decrease	Attacks/day decrease	Increased use of improvised explosives	Attacks/day decrease
Decrease in press releases	Decrease in press releases	Decrease in attacks aimed at high casualties	Decrease in press release
New name/faces in press	Increased traffic at borders	Increase in attacks aimed at infrastructure	Increased attacks on high visibility targets
New organizations claiming responsibility	Increased rhetoric in bordering countries	Increased traffic at borders (smuggling)	Increased attacks on high casualty targets
Increase in number of isolated ops	Increased use of alternate comm	Increased attacks on coalition facilities	Increased demonstrations
Dated audio/video releases		Increased thefts from security forces	Increased traffic to training camps
			Small scale attacks
			Increase web postings of suicide bombers
			Increased threats and press releases

In Phase II, assessors make three crucial assumptions: 1) the action under consideration is 100-percent successful in creating the desired effect; 2) the action is the only action that has taken place to achieve the desired effect; 3) the enemy will continue to fight by any means necessary. The first two assumptions are made in order to generate potential indirect effects and for that purpose alone. They do not in any way represent the intentions of the planners that each action will be the sole means to achieve the desired effect. By making these assumptions with each effect-tree diagram, assessors are able to generate a list of many possible enemy reactions that might result from each one of the friendly actions. The assumptions alleviate the problem of determining the reactions from all possible actions simultaneously. Viewing the enemy through these assumptions allows planners to conceive possible indirect effects one at a time.

When the diagram is complete, the assessors will have a list of measurable indicators. These indicators taken together represent how the enemy might react to all of the friendly actions executed in EBE. Before execution, the assessors know with certainty neither how successful the friendly actions will be nor how the enemy will react to said actions. The list of indicators then represents what might happen given any combination of friendly actions and enemy reactions. Though developed under strict assumptions, each indicator combined with other indicators provides a range of possible enemy system reactions. In the next phase, this range will be described qualitatively by a series of ordinal system states. The set of indicators will then be partitioned according to these states.

3.3.3 *Phase III: Defining System States by Partitioning the Indicators.*

In order to track progress towards the achievement of a desired effect, the EBA process must track the state of the systems of interest as the systems' state changes. Knowing the state of the system will give insight into the effectiveness of the actions taken. The indicators developed in Phase II will be used for this purpose.

In Phase I, the initial and desired end states of the system are defined. However, other possible intermediate states are not always defined *a priori* as the initial and desired states are defined. When this is the case, the intermediate states can be defined by partitioning the indicators. The assessors can bin together indicators that represent similar levels of consequences under the same label to form an ordinal scale of system states. The intermediate states are essentially pseudo states. These pseudo states, while not precisely states of the system, are a collection of indicators by which assessors can measure progress towards the desired end state.

Phase III describes two ways to partition the set of indicators into states. Both methods place each indicator into a predefined state of ordinal consequences. The first ordinal scale is the familiar stoplight-chart assessment states: red, amber, and green. The second scale is more detailed, consisting of five states. This scale is similar to the consequence scale presented by Haimes in the Risk Filtering and Ranking Methodology for risk assessment (reference Section 2.13). In the stoplight chart method for partitioning the indicators, each color of the stoplight—red, amber, and green—represents a state of the system (Figure 3.14). Red is the least desired state as defined by the commander, amber is a moderate or acceptable level given the progress of operations, and green is the desired end state. Planners and assessors examine each indicator developed in Phase II and determine which system state the indicator best represents. The mechanism for partitioning the indicators is the question "if this indicator occurs, what is the most likely state of the enemy system?"

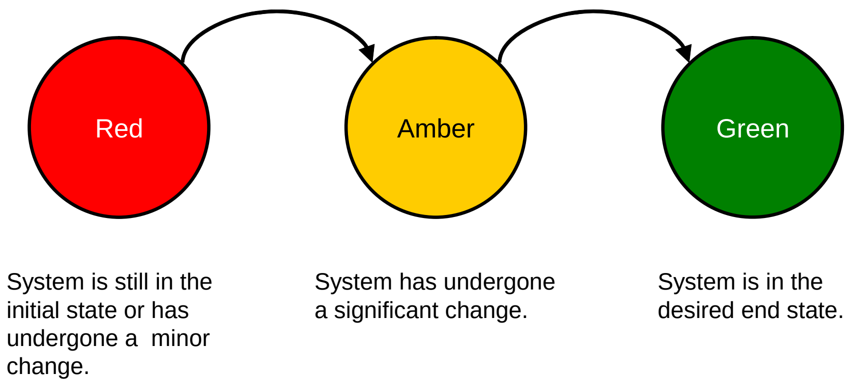
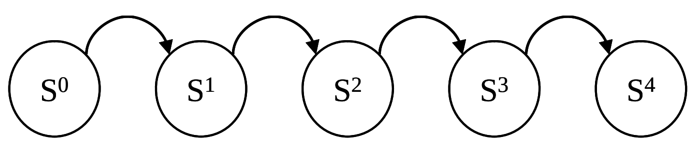


Figure 3.14 Stoplight Chart System States

The five-state consequence scale (5S), pictured in Figure 3.15, is similar to the stoplight scale but has more intermediate states. More states allows assessors to view progress over time more easily and gives a greater fidelity to the overall EBA process. In the first state of 5S after actions have been taken, the system has undergone little or no change and is effectively still in s^0. In the second state, the system has undergone some recognizable change but the function of the system is the same. In the third state, the system has undergone a change and the system function has been altered to a noticeable degree. In the fourth state, the system function has changed significantly, but the system is not yet in the desired state. Finally, the fifth state is the desired end state of the system. Figure 3.15 summarizes example state descriptions for changes in capability and changes in behavior.

When Phase III is complete, every indicator has been assigned to one of the defined states. For a given effect, all indicators developed in Phase II must be attached to a state of the system, and every state must have at least one indicator. If either condition is not met, Phase II may need to be revisited to generate more indicators, or the state descriptions need to be redefined to lessen the number of states. The number of states may vary; this thesis only presents three-state and five-state models as examples. Two-state or four-state models may better represent the enemy system state transitions that result from friendly actions. Assessors should readjust both the set of indicators and the ordinal scales of system states as necessary. Remember, the goal of Phase III is to specify a set of states that the system will likely transition into as result of friendly actions, and to conduct an appropriate partitioning of the set of indicators to describe the conditions of each state. As an example, consider the Exstan indicators. Table 3.2 shows a partition of the indicators listed previously in Table 3.1.



Capability

S^0: Minor or no change in capability

S^1: Some change in capability; no effect on mission

S^2: Loss of capability with some effect on mission

S^3: Loss of mission

S^4: Complete loss of system capability or desired capability attained

Behavior

S^0: Minor or no change in behavior

S^1: Some change in behavior

S^2: Noticeable changes in behavior; other behaviors evident

S^3: Original behavior is ceased

S^4: Desired behavior

Figure 3.15 Five-State Transition Model for Capabilities and Behaviors

Table 3.2 Example of Indicator Partitioning

S^m_{Kobra}	S^0	S^1	S^2	S^3	S^e
State Description	Little or no change in warfare methods	Some change in methods with little or no effect on overall combat capability	Significant change in methods with some effect on combat capability	Complete change in method	Complete loss of combat capability
Indicators	Increased use of IEDs	Decrease in press releases	Increased threats and press releases	Increased demonstrations	No attacks.
	New names and faces in leadership positions in press	Decrease in attacks aimed at high casualties	Decrease in number of attacks per day	Increased rhetoric in bordering countries	Dated audio/video releases
	Increased use of alternate comm	Increased attacks on high visibility targets	Increased attacks on infrastructure	Increased thefts from security forces	
	Increased attacks on coalition facilities	Increased number of uncoordinated/isolated ops	Small scale attacks		
	Increased attacks on high-casualty targets	New organizations claiming responsibility for attacks	Increased web postings of suicide bombers		
	Increased traffic to training camps	Increased smuggling/traffic at borders			
		Increased traffic at the borders			

3.3.4 *Phase IV: Assessing Friendly Actions Taken against Enemy Systems.*

Phase IV describes the basic elements of assessing the completion of coalition actions prescribed by the COAs defined in EBP. Tracking actions is nothing new. The process described in this thesis is very similar to the process used in OIF to track the completion of CFACC tasks. Essentially, assessors assign Measures of Performance (MOPs) to the actions and track the MOPs.

For each action of an effect, planners have a set of action-node pairings. The goal of the actions assessment is to determine if the action has been completed to the level required to produce the effect on the node. In order to make this determination, assessors examine the nodes. For each action-node pairing assessors develop MOPs.

Combat actions often take on similar forms, and their associated MOPs are also similar. Since MOPs have been used in the past, Phase IV can draw from the format of past MOPs. For example, actions of the type "destroy enemy nodes" can be measured with an MOP, "percent of enemy nodes destroyed." This MOP can then be assessed via a physical assessment. In order to determine that enough enemy nodes have been destroyed, certain parameters are required. Assessors must know the initial number of existing nodes and the number of nodes required to achieve the effect. The initial number of existing nodes is called the *baseline*. The number of nodes required to achieve the effect is called the *goal level* or *target level*. It is possible, and often is the case, that 100 percent of the enemy nodes need be destroyed in order to create the effect. Sometimes, however, not all of the nodes need be destroyed. Whatever the level of nodes needing to be destroyed, the assessors need to declare it.

Thoele *et al* offer a short list of predefined MOPs based on coalition tasks in OIF (reference section 2.5). Table 3.3 summarizes example actions and MOPs based on the OIF assessment model. Once the MOPs have been defined, just as with the indicators in Phase II, the MOPs should be coordinated with the ISR division to acquire data for the baselines and target values as well as to develop a collection plan for tracking MOPs when combat operations commence.

Table 3.3 Example MOPs for Friendly Actions (Thoele, DiSebastian, and Garcia, 2004)

Coalition Action	Example MOP
Degrade/Disrupt/Destroy/Neutralize the enemy nodes	Percentage of enemy nodes degraded, disrupted, destroyed, or neutralized
Detect and Identify specific enemy capabilities (GPS jamming, etc.)	Number of occurrences of enemy capability detected and identified
Maintain 24-hour coverage or specific coalition capability	Percentage of coverage or capability achieved over 24-hour period

In order to aid the planners, tracking the MOPs should include a time dimension in order to view trends. That is, the level of the MOP should be plotted against a time axis for each day of the campaign (Figure 3.16). The actions may also be assessed collectively. To determine the accomplishment of a set of actions for an effect, a linear additive value function may be used wherein each action MOP is given a weight $w \in [0,1]$ as it applies to the effect and $\sum_i w_i = 1$. Then the completion of all actions for an effect may be given by a value function

$$v = \sum_i w_i c_i$$

where w_i is the weight of the action and c_i is the level of completion of the action, $c \in [0,1]$. The value v can be plotted over time as well.

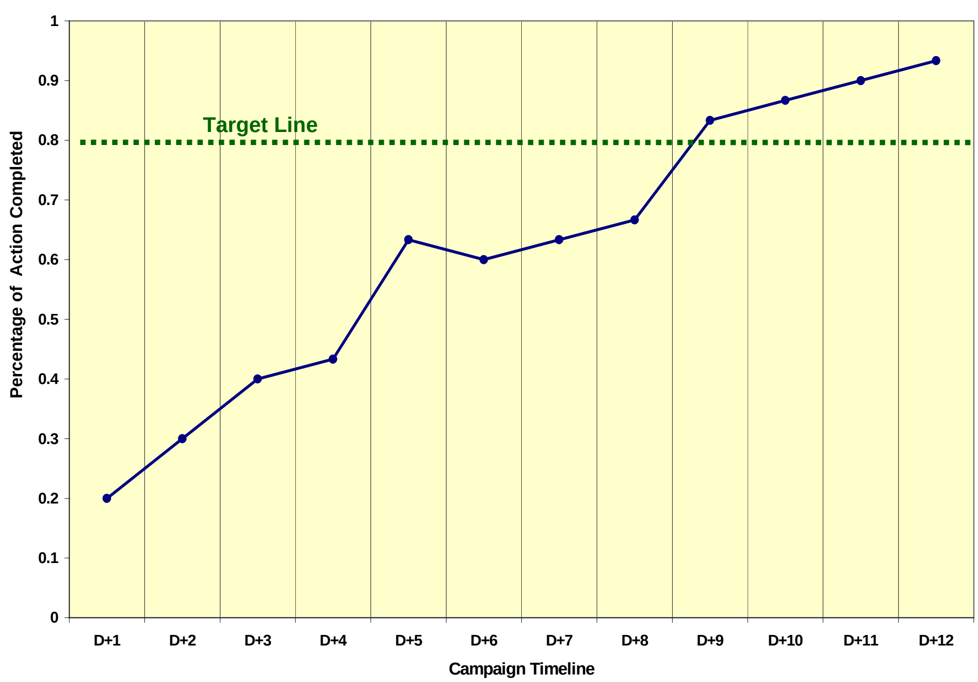


Figure 3.16 Actions Completion

Assessing coalition actions is a necessary piece of EBA, answering the question "How well is the plan being executed?" For each action, assessors can define MOPs based on previous assessment efforts or develop new MOPs appropriate for the COA. The MOPs can be tracked individually or aggregated as they support an effect. To aid planners, the level of completion of the actions should be plotted in a graph against time to view developing trends. The actions assessment will be used along with the effects assessment (Phase V) to build a campaign assessment chart in Phase VII.

3.3.5 *Phase V: Assessing Effects based on Indicators of Enemy Reactions.*

As aforementioned, an effect is a change in state Δs of an enemy system. Friendly actions are synchronized to produce the desired effect

$$\Delta s = s^0 \to s^e$$

If the system state transitions are defined as $s^0 \to s^1 \to s^2 \to s^3$ where s^0 is the initial state and s^3 is the desired state, the desired effect is $\Delta s = s^0 \to s^3$. However, any state change such as $s^0 \to s^1$ can also be viewed as an effect on the system. By monitoring these changes in system states, assessors aim to view progress towards achieving the desired effects. Therefore, assessors must determine the system states to determine which Δs has occurred.

In order to determine what effects friendly actions have had on the system of interest, assessors need to determine the state of the system. The state of the system can be described by the set of indicators defined in earlier phases of the EBA process. More specifically, this relationship is described by the function $g : I \to S$ such that

$$s^m = g_m(i_1, i_2, \ldots i_r)$$

where and, $I_m = \{i_1, i_2 \ldots, i_r\}$ is a set of indicators i, $i \in \{0,1\}$. When a predefined number of indicators exists for a state $s^m \in S$, then the system of interest $n_{[q]}$ is said to be in s^m. Essentially, $g(\cdot)$ is based on an assessment of whether or not enough evidence exists (via the indicators) to declare a system in a particular state. To aid assessors, this thesis advocates the use of the 40-percent rule inspired by Powell (reference section 2.10).

The forty-percent rule simply states that if assessors have evidence of at least 40 percent of the indicators of a given state, then it is reasonable to conclude that the system is in that state. In this method, the weight of each indicator is normalized with the other indicators within that state, so that each indicator provides equal weight of evidence for the state. Therefore, the weight of an indicator is a function of the number of indicators in that state. That is to say, if state A has more indicators assigned to it than state B, assessors will need to witness more of the indicators of state A to declare the system in state A than to declare it in state B. This condition agrees with the logic used to create the indicators. The assumption is that all indicators are equally likely to occur. Given the coalition actions taken, it is not known with certainty how the system will react. Thus the more indicators showing evidence of a system being in state s^m the greater the chance that the system is in that state.

Using the 40-percent rule, assessors can reasonably conclude that the system resides in the highest state for which greater than or equal to 40 percent of its indicators have been observed. (In this thesis, *higher* denotes a state that is closer to the desired state.) Problems, however, arise when evidence exists for indicators in multiple states and no state has evidence of 40 percent of its indicators, or when multiple states have evidence for greater than 40 percent of their indicators. How then do assessors decide which state the system is in? The question rephrased asks, “given the evidence of system indicators, what is the likelihood that the system is in a particular state?” The following guidelines provide some answers to this question:

1) The system has the highest likelihood of being in the state with the highest percentage of its indicators observed.
2) If there is a tie in the percentage of observed indicators for multiple states, then it is more likely that the system is in the higher state. This conclusion is based on the following assumptions: given that the system is actually in the lower state, the likelihood of seeing the higher-state indicators is quite low. Conversely, given the system as actually in the higher state, the likelihood of seeing the lower-state indicators is high. This assumption is based upon the fact that the coalition actions are designed to achieve the higher system states. Assessors expect the actions to achieve the higher states. However, caution is warranted in this situation. While the presence of an indicator in the higher state is evidence that the system may be in that state, without additional evidence it may be prudent to proceed as though the system is in the lower state until more evidence is available.
3) If multiple states have evidence of more than 40 percent of the indicators, then it is more likely that the system is in the higher state. (This is based on the same assumptions as number 2.)

As in all assessment efforts, however, the point of the guidelines are to provide insight. Subject-matter experts (SME)—i.e., system experts, intelligence operators, leadership with other sources of information—and operational knowledge gained from experience can trump the state assessment provided by the guidelines. Likewise, in practice, actual enemy reactions may not correspond directly to the predefined indicators. When this occurs, assessors can use Smith's questions (reference Section 2.7.5) as catalysts for assessing the state of an enemy system. Whether the assessment is made via the indicators, SME opinion, or *ad hoc* based on an unanticipated enemy reaction, the goal of Phase V is to determine the state of the systems of interest in terms of the desired effects. These state assessments will provide inputs to the objective progress function in Phase VI.

3.3.6 *Phase VI: Assessing the Progress of the Objective based on the State of the Enemy Systems.*

In order to assess the progress of objective *k*, assessors need to define the progress function O_k for the objective. Phase VI describes how to define this function. First, the no-attainment and full-attainment regions are defined by two sets of state vectors. These regions are the ones that map to $p = 0$ and $p = 1$ respectively. Next, the remaining state vectors are binned together into a middle region for which the *p*-values will be later assigned. Then, the projected progress curve is defined based on the time-series actions developed in EBP and the anticipated resulting state vectors. The anticipated state vectors are assigned *p*-values based on planners' input. Finally, as the campaign is executed and assessments are made regarding the states of the systems, those states are assigned approximate *p*-values via pair-wise comparisons with the existing state vectors, thus completing the progress function.

The no-attainment and full-attainment regions correspond to the red and green states of a stoplight chart. Using the stoplight-chart nomenclature works particularly well in an operational setting as commanders are used to seeing operational objectives described in terms of red, amber, and green (reference Section 2.5). To map state vectors to the green and red regions, assessors need only choose those vectors which describe full attainment of the objective and those that describe no attainment of the objective. There will always be at least one vector in each of these regions; the vector $(s_1^0, s_2^0, ..., s_n^0)$ in the red region, and the vector $(s_1^e, s_2^e, ..., s_n^e)$ in the green region. The red and green regions are then assigned the *p*-values 0 and 1 respectively. Any vectors not mapped to red and green regions fall into the amber region by default.

Assessors next build a progress curve based on the planned time-phase actions and anticipated enemy system states resulting from those actions as described in EBP. The end points of the progress curve can be derived directly from the definition of the desired effect from Phase I. At the start of the campaign (D+0), all systems are in their initial states. Likewise, the desired end state of a system is planned to be achieved by the start date from the desired effect definition. Figure 3.17 illustrates the following example: Let objective *k* have two systems of interest, each with five possible states (including the initial state). In this example, the desired end state for both systems is to start on D+5. The planners anticipate that after the first day of the campaign, both of the enemy systems will have transitioned into state two. Similarly, after three days of the campaign, both systems will have transitioned into state three. Therefore, the planners have anticipated that the vector states will transition as follows:

$$(0,0) \rightarrow (2,2) \rightarrow (3,3) \rightarrow (4,4)$$

The question the assessors must then ask the planners is "how much of the objective will be attained at each of the anticipated state vectors?" In this example, the planners think approximately 30 percent of the objective will be attained after the first day (state vector (2,2)). Likewise, approximately 70 percent of the objective will be attained after the third day (state vector (3,3)). The state vectors can then plotted on a timeline against the percentage of the objective attained. Connecting the points then results in an a progress curve for which assessors can compare the assessed progress as EBE commences during Phase VII. Figure 3.17 helps illustrate this process.

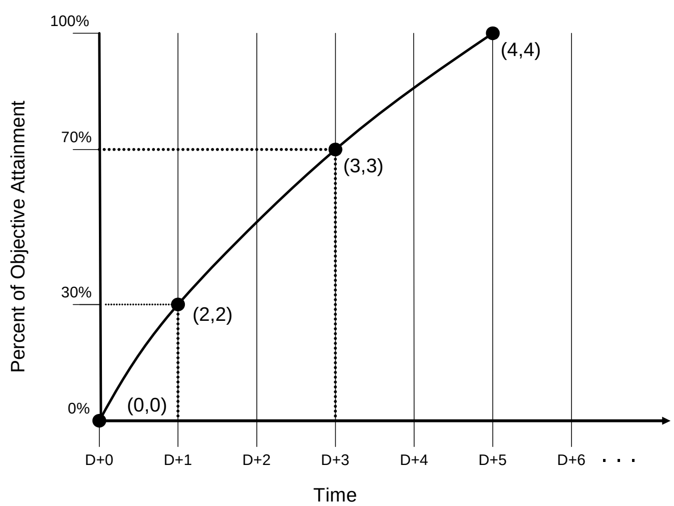


Figure 3.17 Projected Progress Function

The assigned levels of attainment for the anticipated state vectors begin the progress function. Figure 3.18 illustrates the progress function based on these initial mappings.

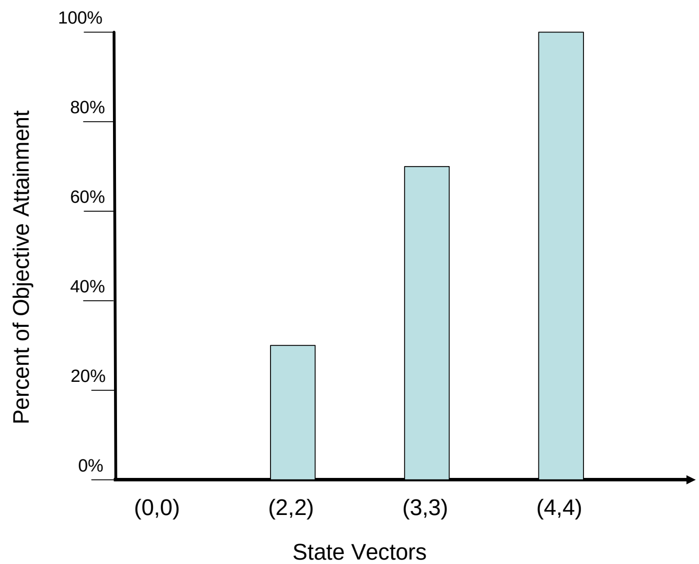


Figure 3.18 Progress Function After Initial Mappings of State Vectors

At this point, only a fraction of the possible state vectors have been mapped to progress values: the no-attainment vectors (p = 0), the full attainment vectors (p = 1), and the anticipated state vectors that the planners have mapped to approximate p-values. The final item in this phase is to map the remaining state vectors to p-values. Put another way, for each state vector $\mathbf{s}_k$, assessors assign $\mathbf{s}_k$ to a value $f(\mathbf{s}_k)$ on the "percent of objective attainment" line.

Mapping all possible state vectors, however, may be intractable. Even for a small number of systems and the associated system states, for each system q, the number of possible state vectors can be quite large. In fact, for any number n_k systems and number of states of the system m_q, the number of $\mathbf{s}_k$ vectors is equal to $\prod_{q=1}^{n_k} m_q$. From the earlier example in Section 3.2.1, with two systems having six states each (including the initial state), $n_k = 2$ and $m_q = 6$ for all q, which yields $6 \times 6 = 36$ different state vectors that need to be considered. As n_k and m_q increase, the number of state vectors could quickly explode.

This state vector explosion problem is not intractable. With an initial progress function defined, all that is required is to map the state vectors that occur as a result of friendly actions during EBE when they occur. That is, as assessors determine the states of the systems of interest, they need only determine in which interval of the progress function the vector belongs and approximate the value associated with it. Again, the purpose of the progress function is to show progress towards the attainment of the objective. Exact measurements are not as important as ordinal relationships; assessors need only to know approximate relationships between the state vectors to determine if the commander is getting closer to objective attainment or further away from it. Another example helps illustrate this point. Let the state vector (3,1) be the vector assessed after the first day of the campaign. Then assessors must map (3,1) to a *p*-value. Figure 3.19 shows that the planners have determined that (3,1) yields attainment of the objective somewhere between (2,2) and (3,3), closer to (3,3) than to (2,2). Furthermore the planners determine the level objective attainment to be about 55%, or a *p*-value of 0.55. The assessors can then add to the categorical progress function as shown in Figure 3.20.

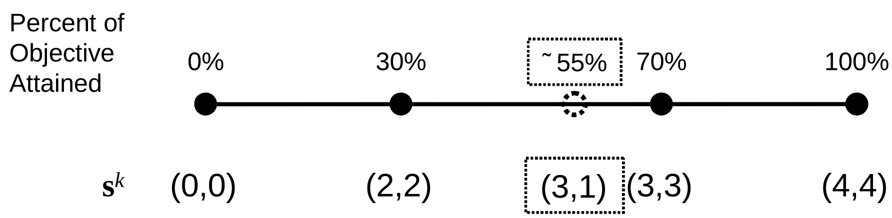


Figure 3.19 Mapping new state vectors individually

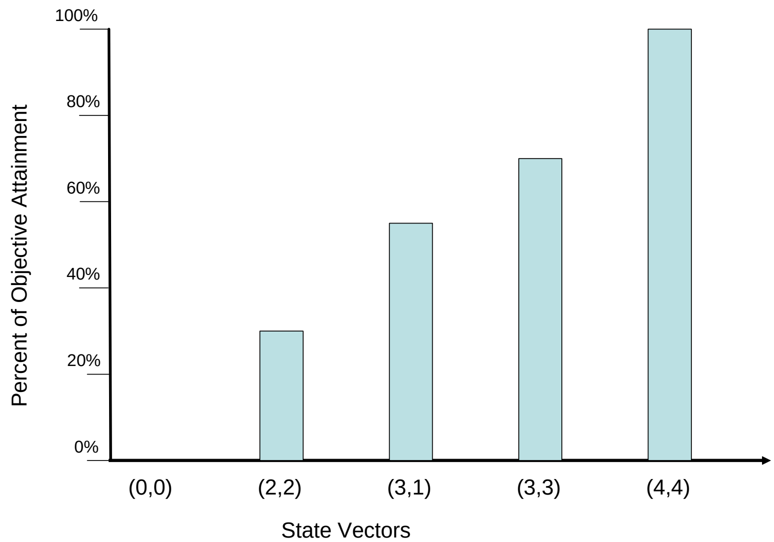


Figure 3.20 Discrete progress function after first day of campaign.

3.3.7 *Phase VII: Campaign Assessment.*

Phase VII combines the results of Phases IV, V, and VI with the time dimension. Phase VII allows planners and assessors to view the objective attainment and actions accomplishment over time to get an overall picture of the evolution of the entire campaign. The planners chose the actions in order to achieve the desired effects and attain the objectives. In this phase, assessors can view whether the enemy is responding as expected to the friendly actions as well as view whether or not the effects are being achieved in the planned timeframe.

If the effects have been achieved yet the actions have not been accomplished, or if the actions have been accomplished and the effects have not yet been achieved, then important questions need to be investigated. In either case, the relationship between the actions and effects is in question. The SoSA model may need to be reconsidered, as well as the knowledge of the enemy, the indicators, and actions chosen by the planners. Figure 3.21 illustrates an example view of objectives versus actions over time.

Plotting the levels of action completion versus the objective attainment can provide insight by describing the relationships between the actions and effects. As in Figure 3.22, a general form of a functional relationship may be able to be determined. If the plot looks like line A then the CFACC is experiencing diminishing returns on the actions taken. Line B represents a linear relationship between the CFACC's actions and the effects. Line C shows the CFACC experiencing increasing returns on his actions. Graphs such as these can help planners adjust weights of effort to support lagging effects and objectives. Regression analysis could also be used to look at the contribution of the individual actions with regards to the effects.

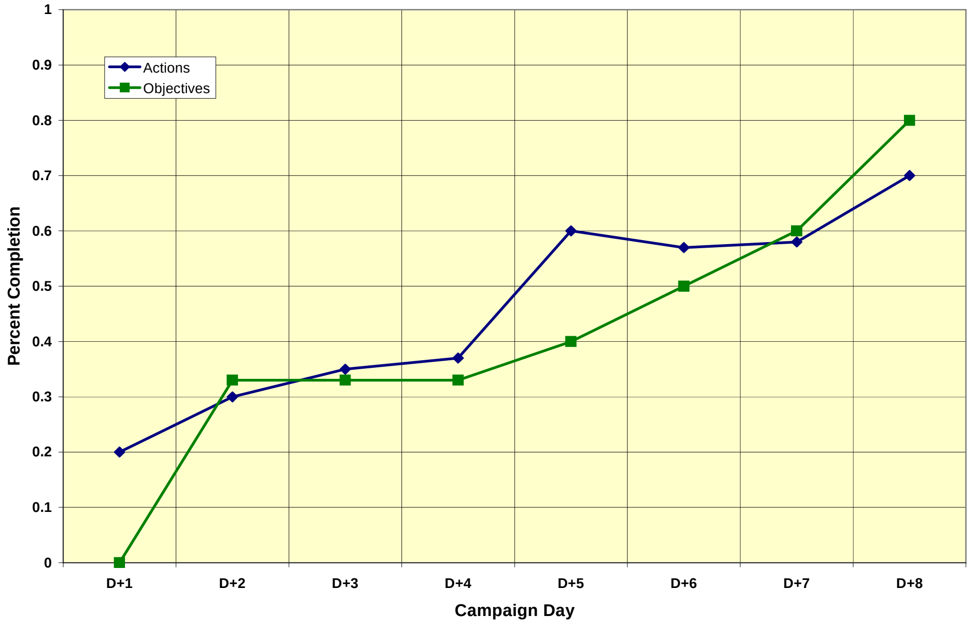


Figure 3.21 Effects and Actions over Time

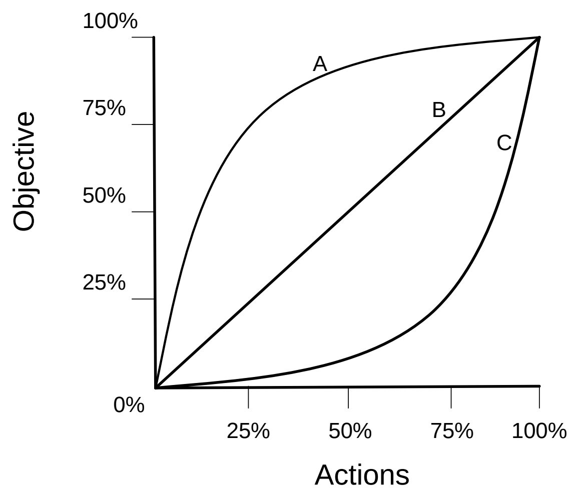


Figure 3.22 Objectives vs Actions Graph

Defining a planned progress curve in Phase VI allows assessors to compare the actual progress over time as EBE commences. On a graph such as Figure 3.23, planners and commanders can see when progress shortfalls have taken place and adjust future plans accordingly. Figure 3.23 builds on the example from Section 3.3.6. In this example the friendly actions taken have produced state vector (3,1) on campaign day D+1, and state vector (3,2) on D+3 and D+5. As these state vectors occur, planners rate them according to their approximate attainment of the objective—(3,1) rates 55 percent attainment and (3,2) rates 60 percent attainment. When compared to the planned progress curve, planners and assessors can see that the progress was ahead of schedule on D+1 but then fell behind schedule for the remaining assessment days. Assessors can then investigate the actions accomplished on those days along with the effects achieved to determine the cause of the progress shortfall. Planners can then adjust the plan to return to schedule, adjust the schedule, or determine another course of action as needed.

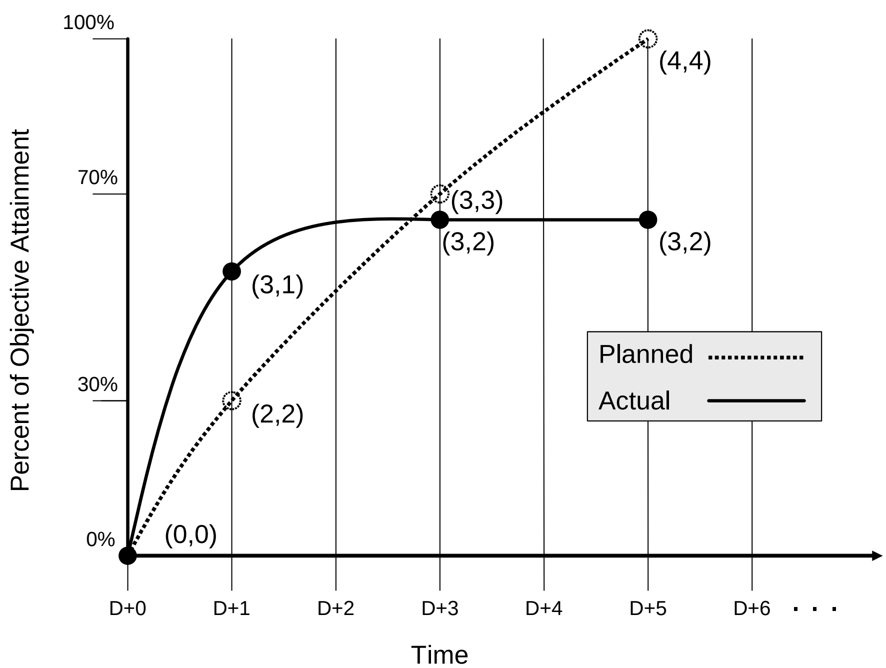


Figure 3.23 Planned Progress vs. Actual Progress

In summary, campaign assessment combines actions assessment, effects assessment, and objective assessment in the temporal domain to determine how the effects respond to the actions taken. Plotting the objectives and actions together can reveal this relationship. Likewise, plotting the planned progress curves versus the actual progress curves can reveal important insight to planners and commanders.

3.4 Conclusion

The goal of EBA is to provide insight to commanders and planners about coalition actions, enemy reactions, achievement of effects, and attainment of objectives. The mathematical construct described in the first part of the chapter defines the progress function, states, state vectors, and regions in order to provide the foundation for implementation of the EBA methodology. In order to be useful in an operational environment, assessors must work with planners from the beginning of EBP to create an assessable plan. Using the tools and methods described in the second part of the chapter, assessors and planners can develop a set of indicators to determine the states of systems, which represent achievement of effects. These effects can then be mapped to quantities via a progress function defined with input from the planners. Effects and actions can be tracked over time to view trends. Taken together, the actions, effects, objectives, and time provide commanders and planners with an insightful model of the battlespace.

4 Results and Analysis

4.1 Introduction

Chapter 4 applies the methodology presented in Chapter 3 to two scenarios. The first scenario is based on Operation DENY FORCE, which describes a notional combat operations air campaign set in 2010. The original scenario was developed for the purpose of the Dynamic Air & Space Effects-Based Assessment (DASEA) critical experiment (McCrabb, 2005:1). The second scenario describes a notional stability operations campaign developed by the author for the purpose of this thesis. Though the focus of Chapter 3 was on assessing the effects of combat operations, the phases of the Effects-Based Assessment (EBA) methodology are intended to be general enough to be applied to objectives and desired effects for stability operations as well.

Both scenarios are presented in the same general format. First, the general background of the scenario and the operational objectives are presented. Next, the first three phases of the EBA methodology are presented along with actions-assessment preparation and objective and campaign-assessment preparation for each objective. Then, the Effects-Based Execution (EBE) of the campaign is briefly described, followed by the last four phases of the EBA methodology.

4.2 Operation DENY FORCE

US intelligence agencies have been monitoring reports that Orangeland (OL), which the US considers a "rogue state" in the region, has taken steps to obtain weapons of mass destruction (WMD). OL has long viewed the US and its allies as adversaries, while the US allies in the region look to the US for security. Increasing evidence exists indicating that OL is developing WMD, especially research and development into chemical, biological and nuclear weapons and the deployment of those weapons on theater ballistic missiles (TBM). Ongoing US diplomatic efforts have openly and vigorously protested OL activities. However, these efforts have been largely unsuccessful as OL denies all accusations involving WMD. Meanwhile, terrorists in the US have executed multiple chemical attacks in various US cities. SECDEF has ordered the Combined Forces Commander (CFC) to begin contingency planning against OL with the goal of "compel[ling] Orangeland to stop WMD or TBM/CM development or employment activities" (McCrabb, 2005:2). This operation is called OPERATION DENY FORCE (ODF). The CFC has given the Combined Forces Air Component Commander (CFACC) the following operational objectives:

Objective 1: Gain and maintain air superiority.

Objective 2: Stop WMD activities of OL leadership.

4.2.1 *ODF Objective 1.*

The first three phases of the EBA methodology, along with actions-assessment preparation and objective and campaign-assessment preparation are presented for *Objective 1*: Gain and maintain air superiority.

4.2.1.1 *Phase I: Desired Effect Definition.*

For *Objective 1* (Gain and maintain air superiority) the planners define two desired effects.

Desired Effect 1.1:

- *System of interest*: Airspace within Orangeland Theater of Operation (OLTO).
- *Initial State of the System*: OL possesses seven OL military air bases, conducting less than 25 training and combat sorties per month. The overall operational capability of OL aviation is assessed as low, posing little threat to coalition forces. Two major civilian airports have combined air traffic that accounts for 10 to 12 flights per day.
- *Desired End State*: OL experiences complete loss of air sovereignty. No OL aviation traffic without the explicit permission of coalition forces; "if it flies it dies." In addition, Coalition forces have freedom of access for follow-on persistence forces.
- *Start time*: Effect to begin on or before D+2.
- *End time*: Indefinite; effect to be maintained as required by CFC.

Desired Effect 1.2:

- *System of interest*: OL Integrated Air Defense Systems (IADS).
- *Initial State of the System*: OL possesses approximately 200 Surface to Air Missiles (SAM) and 150 Early Warning (EW) and Ground Control Intercept (GCI) radars. The overall capability of the surface-to-air threat is assessed as medium. Primary concerns are concentrated strategic SAMs around OL's capital and large numbers of unlocated tactical SAMs throughout OLTO.
- *Desired End State*: IADS threat to coalition forces neutralized.
- *Start time*: Effect to begin D+1.
- *End time*: Indefinite; effect to be maintained as long as required by CFC.

4.2.1.2 *Phase II: Indicator Development.*

The initial analysis for Desired Effect 1.2 is presented before Desired Effect 1.1 because Desired Effect 1.2 is expected to contribute to Desired Effect 1.1.

Planners determine four actions to be taken in order to achieve Desired Effect 1.2:

- Destroy IADS Command and Control (C2) facilities.
- Destroy EW/GCI radars.
- Destroy IADS communications facilities.
- Destroy SAM sites.

Figure 4.1 depicts the effects-tree diagram used to develop a set of measurable indicators of the desired effect. Multiple actions will result in the system reaction of a decrease in the number of Surface-to-Air Fires (SAFIRES). The effects-tree analysis results in six unique indicators that will be used to determine the state of the OL IADS (shown in Table 4.1).

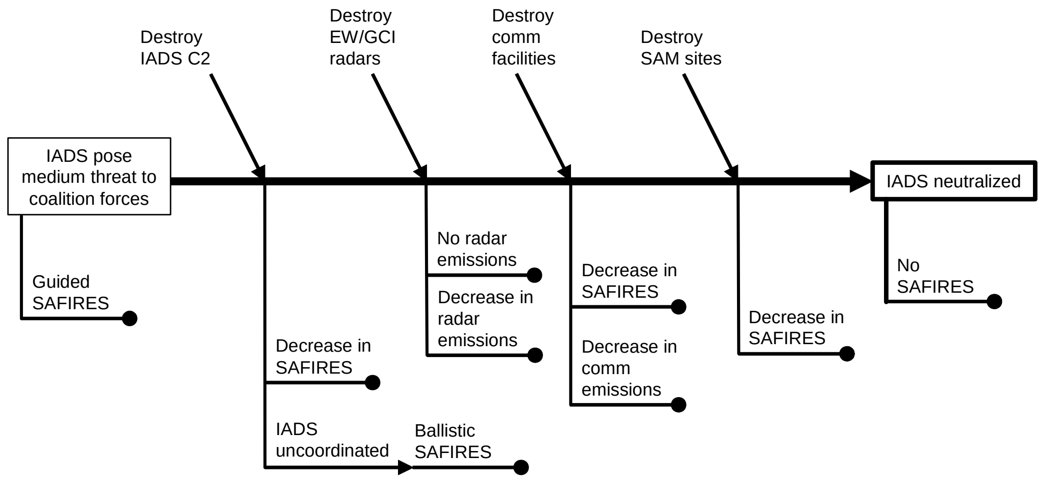


Figure 4.1 Effects-Tree Diagram for ODF Desired Effect 1.2

Desired Effect 1.2 (IADS neutralized) is the primary mechanism by which planners aim to achieve Desired Effect 1.1 (Air Superiority). Desired Effect 1.1 can be viewed as an indirect or secondary effect of achieving Desired Effect 1.2. Figure 4.2 depicts the effects-tree diagram resulting in the indicators given that IADS have been neutralized. The effects-tree diagram reveals the undesired collateral effect that OL reacts to the coalition air strikes by using civilian air craft as WMD. Since this issue is made known before EBE has commenced, the planners can revisit the planned Course of Action (COA) and determine if additional or different actions are required to mitigate the likelihood of OL using civilian aircraft as an offensive weapon. For example, an action such as "destroy OL airfield takeoff capability" might negate this collateral effect. Figure 4.2 yields eight unique indicators to determine the state of the air space in the OLTO. Notice that the indicator "No SAFIRES" is an indicator for both Desired Effect 1.1 and Desired Effect 1.2.

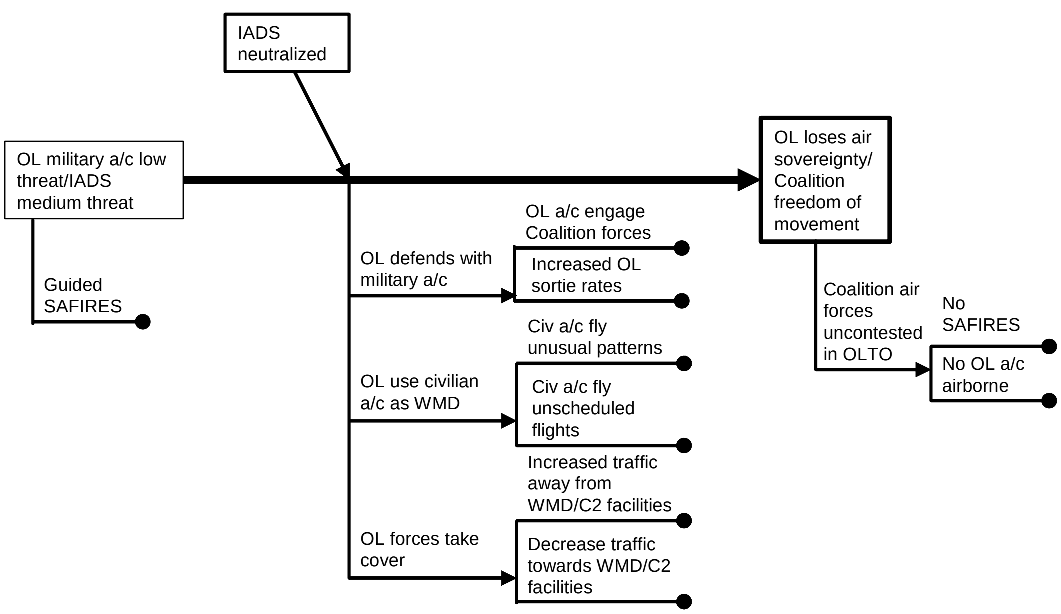


Figure 4.2 Effects-Tree Diagram for ODF Desired Effect 1.1

In general, indicators may overlap the desired effects. That is, the same indicator may be seen in more than one desired effect as is the case with "No SAFIRES" for Desired Effects 1.1 and 1.2. In practice, a single indicator may represent evidence for system states of multiple systems. This phenomena is due to the holistic understanding inherent in EBO. Indirect effects may cascade throughout the enemy systems, resulting in similar effects on a single system. This phenomena can aid assessors by producing an efficient set of indicators, however it can also hinder assessors by adding a factor of uncertainty to the assessment effort.

When the desired effects have a cumulative relationship as is the case above, the assessors can learn the states of multiple systems with fewer indicators, saving time and focusing valuable intelligence resources. However, if the desired effects are not components of the same causal linkage or the same chain of effects, the same indicator used as evidence for states of multiple systems causes the indicator to be worth less as evidence of an individual system state. This is due to the multiple factors contributing to the indicator from multiple lines of effects. As with the Jones Criteria (reference Section 2.6), the weights of the indicators depend on their relative occurrence as a result of each of the indirect effects. For example, an indicator that is anticipated to appear as result of an effect on system A, and only system A, is given more weight as evidence of that effect than an indicator that could appear as a result of an effect on system A or as a result of an effect on system B. Therefore, while having the same indicators represent evidence for states of multiple systems may appear to be more efficient, the information gained may actually be more uncertain, because assessors do not know the true cause of the indicator.

Assessors should therefore strive to determine other unique indicators for each effect on separate causal linkages. Ideally, assessors will be able to determine the states of the operational-level systems with approximately 50-60 indicators (reference Section 2.5). If the number of indicators greatly exceeds the 50-60 range, a filtering process may need to be employed to keep the assessment process manageable.

Table 4.1 summarizes the resulting indicators for Desired Effects 1.1 and 1.2.

Table 4.1 List of indicators for ODF Desired Effects 1.1 and 1.2

IADS Neutralized	OL loses air sovereignty/Coalition forces have freedom of movement
Decrease in SAFIRES	Increased OL sortie rates
No SAFIRES	Civ a/c fly unusual patterns
Decrease in radar emissions	Civ a/c fly unscheduled flight plans
Ballistic SAFIRES	Increased traffic away from WMD/C2 facilities
Decrease in comm. emissions	Decreased traffic towards WMD/C2 facilities
No radar emissions	No SAFIRES
	No OL a/c airborne
	OL a/c engage Coalition forces

4.2.1.3 *Phase III: System State Definition.*

The initial states of the OLTO and IADS systems $\mathbf{s}^0 = (s^0_{\text{OLTO}}, s^0_{\text{IADS}})$ and the desired states of the systems $\mathbf{s}^e = (s^e_{\text{OLTO}}, s^e_{\text{IADS}})$ flow directly from the effects definition of Phase I and the effects-tree diagrams of Phase II. For each effect of *Objective 1*, the state transitions are represented with a three-state model. The indicators are partitioned accordingly. As stated in Chapter 3, this phase may require a trial-and-error approach to determine the appropriate number of states and indicators for those states. Table 4.2 and Table 4.3 show the states and indicators decided upon by the assessors and planners in this scenario.

Table 4.2 Three-state model and indicators for ODF Desired Effect 1.2

S^m_{IADS}	S^0	S^1	S^e
State Description	Little or no change in IADS capability or behavior.	IADS undergone a significant change.	IADS threat to coalition forces neutralized.
Indicators	Guided SAFIRES	Decrease in SAFIRES	No SAFIRES
		Decreased radar emissions	Ballistic SAFIRES
		Decreased comm. emissions	No radar emissions

Table 4.3 Three-state model and indicators for ODF Desired Effect 1.1

S^m_{OLTO}	S^0	S^1	S^e
State Description (Given IADS neutralized)	OL a/c able and willing to contest coalition forces.	OL a/c contest Coalition forces indirectly.	OL experiences complete loss of air sovereignty and coalition forces have freedom of access for follow-on persistence forces.
Indicators	Increased sortie rates	Civilian a/c engage in unscheduled or unexpected flights	No SAFIRES
	OL a/c engage Coalition forces	Civilian a/c fly unusual flight patterns	No airborne OL a/c
		Mobile SAMs positioned near high-priority assets	Coalition forces uncontested in OL airspace

4.2.1.4 *Actions Assessment Preparation.*

The planners have identified four actions (see Section 4.2.1.2) to be taken in order to achieve both desired effects; the desired effect on the OL IADS is intended to have a cumulative effect resulting in the desired effect on the OLTO airspace. The actions chosen are all kinetic strikes on the IADS. Therefore, assessors choose the Measures of Performance (MOP) to be the percentage of targets destroyed. The planners set the target number for the planned actions—the required percentage of targets to be destroyed—at 80 percent. That is, planners believe that at least 80 percent of the actions must be completed in order to achieve the desired effect on the OL IADS and the OLTO airspace. These actions will be tracked as EBE commences to determine their level of accomplishment.

4.2.1.5 *Objective and Campaign Assessment Preparation.*

Assessors and planners develop an initial progress function based on the planned COA and anticipated level of objective attainment. The plan-line for the COA and anticipated objective achievement is shown in Figure 4.3. The initial progress function is depicted in Figure 4.4. For both examples presented in Chapter 4, it is implied that the current system states, effects achievement, objective attainment, and task accomplishment will each be assessed following the campaign day on which the actions took place. To aid discussion, this thesis will refer to the assessments made after the actions on day D+*x* as assessments *at D+x.*

For example, in Figure 4.3, the state vector (1,1), which corresponds to $(s^1_{\text{OLTO}}, s^1_{\text{IADS}})$, is anticipated to be reached at D+0 (after the actions of D+0). Planners determine that state vector (1,1) will yield approximately 80 percent of the overall objective attainment. State vector (2,2), which corresponds to $(s^e_{\text{OLTO}}, s^e_{\text{IADS}})$, is anticipated to be reached at D+1 (after actions on D+1) and yield 100-percent attainment of the objective.

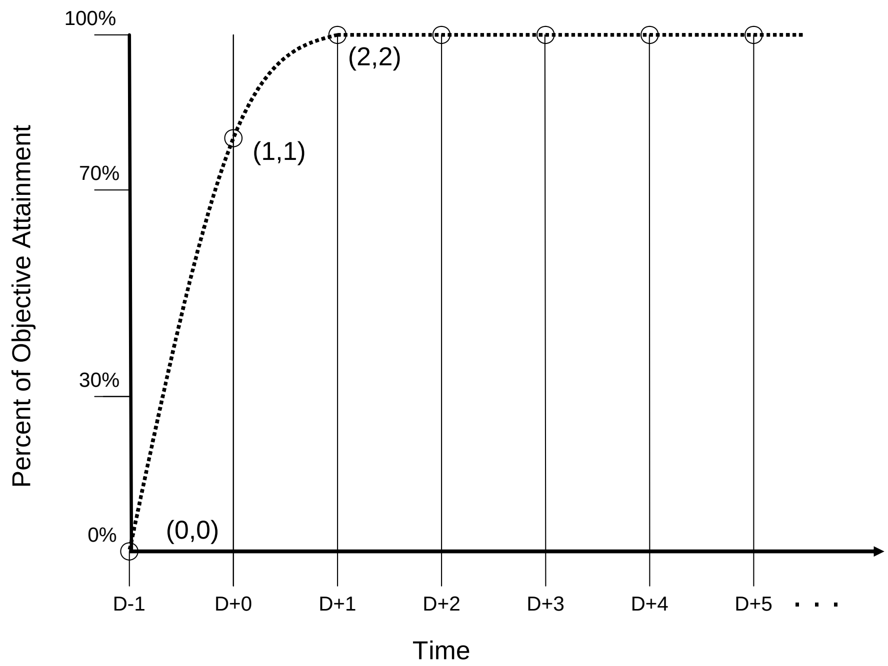


Figure 4.3 Planned Progress Line of ODF Objective 1

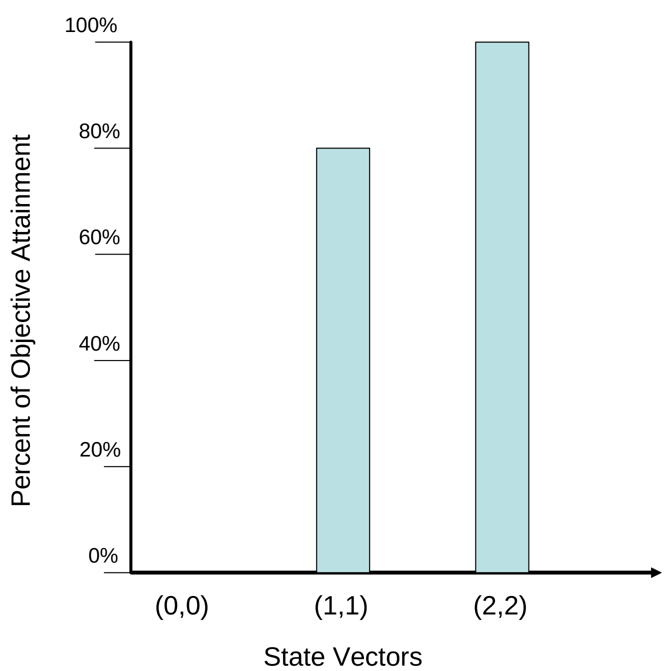


Figure 4.4 Initial Progress Function for ODF Objective 1

4.2.2 *ODF Objective 2.*

The first three phases along with actions-assessment preparation and objective and campaign-assessment preparation are presented for *Objective 2*: Stop WMD activities of OL leadership.

4.2.2.1 *Phase I: Effects Definition.*

For *Objective 2* (Stop WMD activities of OL leadership), the planners define three desired effects.

Desired Effect 2.1:

- *System of interest*: Orangeland leadership.
- *Initial State of the System*: OL denies all WMD accusations and unwilling to consider diplomatic negotiations. OL willing to use TBM/WMD rather than lose all of their current WMD capability as a result of coalition attacks; "use or lose" mindset.
- *Desired End State*: OL leadership views WMD assets as "at risk" with a moderate likelihood of losing all WMD capability. OL would rather negotiate terms for disarming WMD capability and ceasing WMD ambitions than lose any more capability; "negotiate or lose" mindset.
- *Start time*: Effect to begin on or before D+5.
- *End time*: Indefinite; effect to be maintained as long as required by CFC.

Desired Effect 2.2:

- *System of interest*: OL WMD Research and Development (R&D) facilities.

- *Initial State of the System*: Seven active chemical and biological R&D facilities and one nuclear R&D facility located throughout the country are currently operating at full capacity.
- *Desired End State*: No chemical/biological weapon R&D facilities operating at full-capacity. Facilities not to sustain irreparable damage; the operating level of all the facilities is to be degraded to less-than-full capacity.
- *Start time*: Effect to begin on or before D+1.
- *End time*: Effect not to end before D+10.

Desired Effect 2.3:

- *System of interest*: OL WMD deployment systems.
- *Initial State of the System*: Three deployment facilities have the capability to place WMD warheads on TBMs.
- *Desired End State*: These facilities physically and functionally destroyed.
- *Start time*: Effect to begin on or before D+4.
- *End time*: Effect not to end before D+10.

4.2.2.2 *Phase II: Indicator Development.*

Planners determine three actions to be taken in order to achieve a tactical effect (Electrical power disrupted at WMD R&D facilities) that will achieve Desired Effect 2.2 (Production disrupted at WMD R&D facilities):

- Disrupt Petroleum, Oil and Lubrication (POL) lines for backup EP outlets.
- Disrupt backup EP generators.
- Disrupt Electrical Power (EP) substations.

Figure 4.5 depicts the effects-tree diagram used to develop a set of measurable indicators for Desired Effect 2.2. This phase results in seven measurable indicators (as shown in Table 4.4) that will be used to determine the state of the WMD R&D facilities.

For Desired Effect 2.3, the planners determine four actions and two tactical effects required to achieve "WMD deployment capability disrupted."

- Destroy relay stations.
- Disrupt OL telecommunications (tactical effect).
- Destroy fiber optic cable lines for EP plants.
- Disrupt OL Command, Control, Communications, and Computer (C4) systems for EP (tactical effect).
- Destroy WMD storage facilities.
- Destroy POL for WMD units.

This effects-tree diagram pictured in Figure 4.6 results in seven measurable indicators that will be used to determine the state of the WMD deployment facilities. The effects-tree diagram also reveals four potential indicators that assessors deem unmeasurable, indicated by the dashed lines. Recall from Chapter 3 that an indicator must be observable and distinguishable in order to be measurable. Note that the indicators developed for Desired Effects 2.2 and 2.3 connote that ISR assets should be focused on the lines of communication (LOC) associated with the WMD R&D and deployment facilities.

Desired Effect 2.1 is a cumulative effect resulting from the achievement of Desired Effects 2.2 and 2.3. The effects-tree diagram pictured in Figure 4.7 yields 12 measurable indicators for Desired Effect 2.1. These indicators involve a variety of systems, including LOCs, military defense systems, diplomatic channels, TBM launch systems, and international terrorist activities.

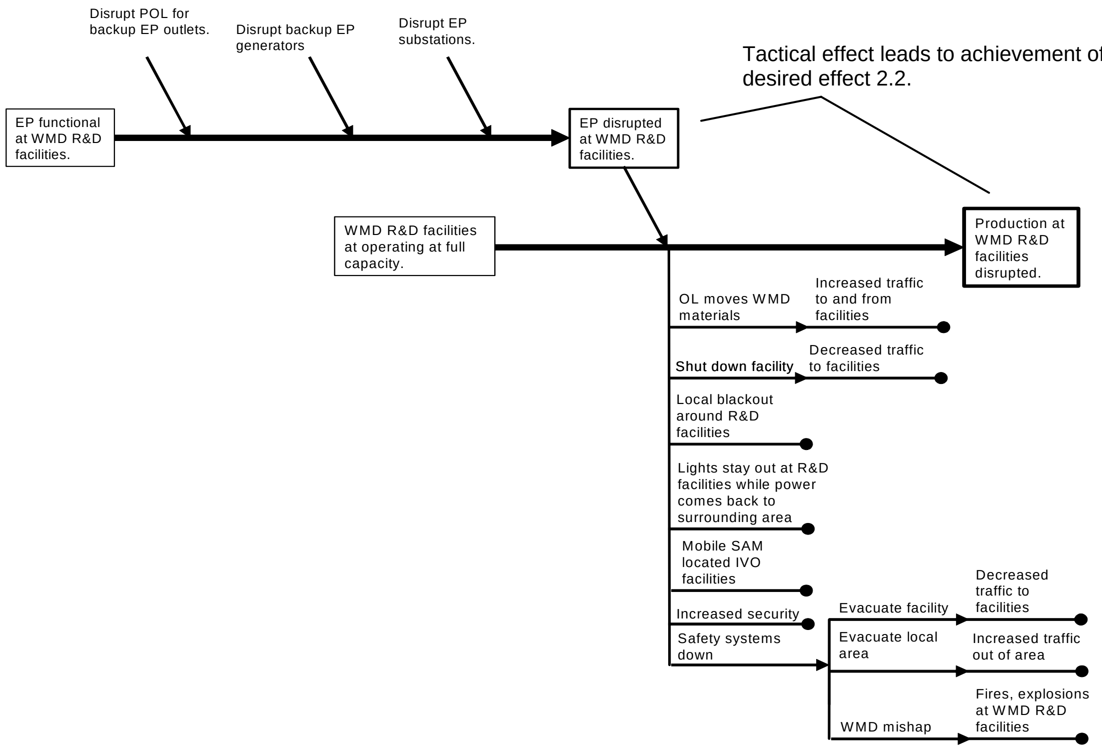


Figure 4.5 Effects-tree diagram for ODF Desired Effect 2.2

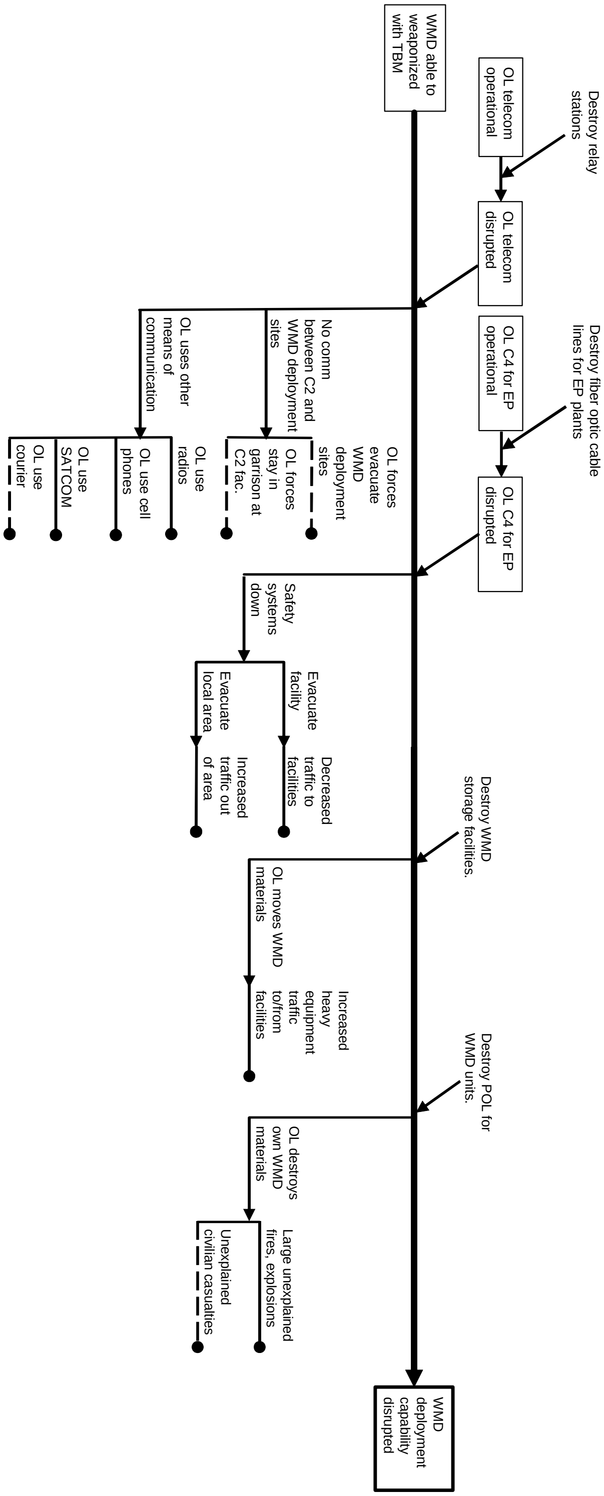


Figure 4.6 Effects-tree diagram for ODF Desired Effect 2.3

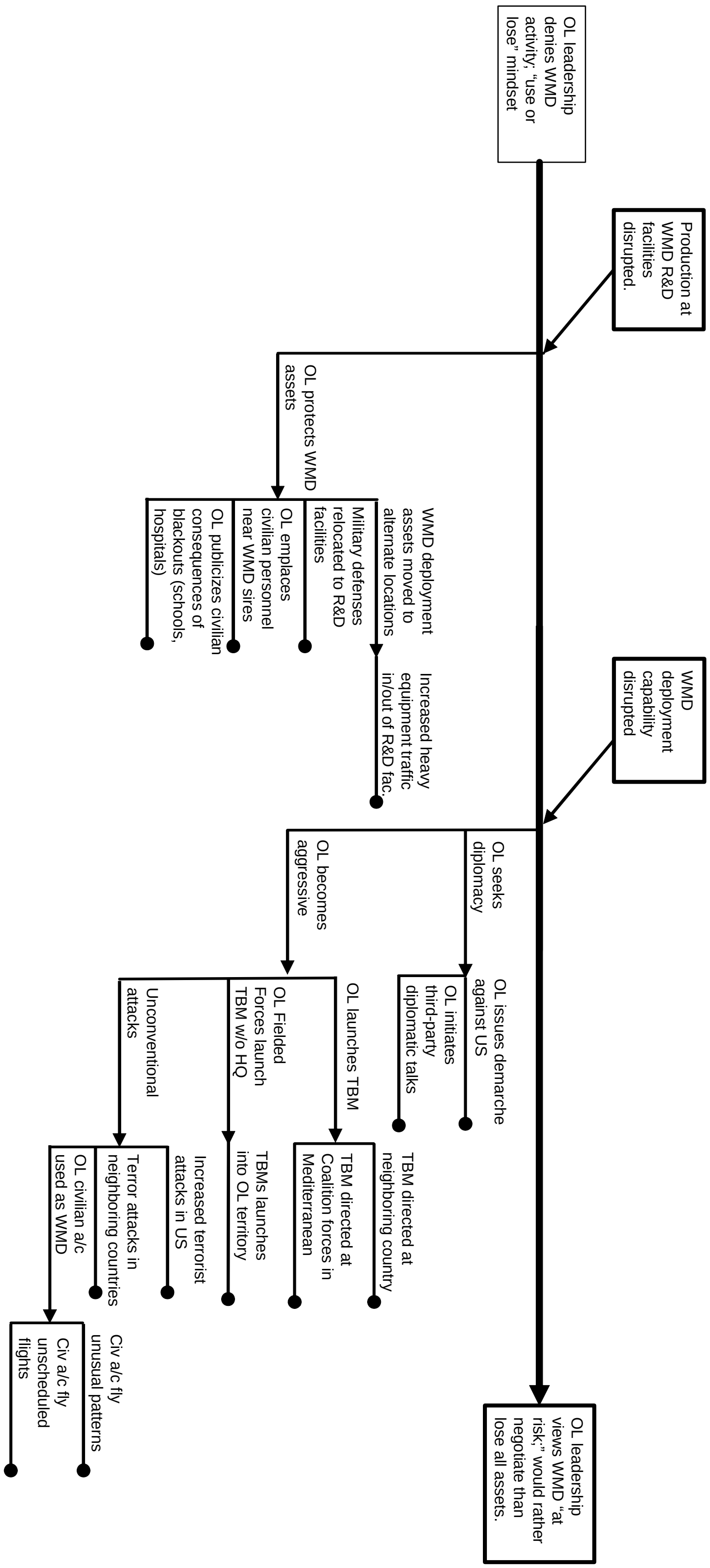


Figure 4.7 Effects-tree diagram for ODF Desired Effect 2.1

Table 4.4 summarizes the indicators developed in Phase II for Desired Effects 2.1, 2.2, and 2.3.

Table 4.4 List of indicators for ODF Desired Effects 2.1, 2.2, and 2.3

DE 2.1 OL leadership views WMD "at risk;" would rather negotiate than lose all WMD assets	DE 2.2 Production at WMD R&D facilities disrupted	DE 2.3 WMD deployment capability disrupted
Increased heavy equipment traffic in/out of WMD facilities	Decreased traffic to facilities	Increased heavy equipment traffic at WMD deployment sites
Military defenses relocated to WMD R&D facilities	Increased heavy-equipment traffic to and from facilities	Fires and explosions at WMD deployment sites
OL emplaces civilians IVO WMD sites	Local blackout around R&D facilities	Increased traffic out of/ decreased traffic to WMD deployment sites
OL publicizes civilian consequences (blackouts to hospitals/schools, casualties etc.)	Lights stay out at R&D facilities while power returns to surrounding area	OL forces evacuate WMD deployment sites*
OL issues a demarche against US	Explosions, fires at R&D facilities	OL forces garrison at WMD deployment sites*
OL initiates diplomacy via third party	Increased security at WMD R&D facilities	Increased cell phone use
OL launches TBM into own territory	Mobile SAM IVO WMD R&D facilities	Increased radio use
OL launches TBM at Coalition forces		Increased SATCOM use
OL launches TBM at neighboring countries		OL use courier to communicate*
Increased terrorist attacks in US/Coalition allies		Unexplained civilian casualties*
Terrorist attacks in neighboring countries		
OL civilian a/c used as WMD (flying irregular patterns/times)		

* unmeasurable indicator

4.2.2.3 *Phase III: System State Definition.*

The initial states of the systems and the desired states of the systems flow directly from the effects definition and the effects-tree diagrams. The state transitions for Desired Effect 2.1, 2.2, and 2.3 are represented by a four-state model, a two-state model, and a three-state model respectively. Tables 4.5, 4.6, and 4.7 show the states and indicators decided upon by the assessors and planners.

Table 4.5 State Transitions and Indicators for ODF Desired Effect 2.1

s^{m}_{OL}	s^{0}	s^{1}	s^{2}	s^{e}
State Description	Little or no change to system function.	System functionality affected.	Little bit better..	System unable to perform mission.
Indicators	OL launches TBM at Coalition forces	OL civilian a/c used as WMD (flying irregular patterns/times)	OL emplaces civilians IVO WMD sites	OL issues a demarche against US
	OL launches TBM at neighboring countries	OL publicizes civilian consequences (blackouts to hospitals/schools, casualties etc.)	Military defenses relocated to WMD R&D facilities	OL initiates diplomacy via third party
	Increased terrorist attacks in US/Coalition allies	OL launches TBM into own territory	Increased heavy equipment traffic in/out of WMD facilities	
	Terrorist attacks in neighboring countries			

Table 4.6 State Transitions and Indicators for ODF Desired Effect 2.2

$s^{m}_{\text{WMD R\&D}}$	s^{0}	s^{e}
State Description	Little or no change to system function.	System unable to perform mission.
Indicators	Increased heavy-equipment traffic to and from facilities	Local blackout around R&D facilities
	Increased security at WMD R&D facilities	Lights stay out at R&D facilities while power returns to surrounding area
	Mobile SAM IVO WMD R&D facilities	Decreased traffic to facilities
		Explosions, fires at R&D facilities

4.2.2.4 *Actions Assessment Preparation.*

The planners have identified a total of seven actions (see Section 4.2.2.2) to be taken in order to achieve the three desired effects associated with *Objective 2*. Again, the actions are all kinetic strikes. Therefore, assessors choose the percentage of the targets destroyed as the MOPs for the actions. Due to the precision nature of the planned friendly actions, the planners set the target number for the planned actions at 100 percent.

Every specified target needs to be successfully acted upon to achieve the desired effect. Note that the WMD R&D facilities are not targeted directly; only the support systems feeding the R&D facilities, illustrating the precision nature of the strikes. These actions will be tracked as EBE commences to determine their level of accomplishment.

Table 4.7 State Transitions and Indicators for ODF Desired Effect 2.3

$s^{m}_{\text{WMD Dep}}$	s^{0}	s^{1}	s^{e}
State Description	Little or no change to system function.	System functionality affected.	System unable to perform mission.
Indicators	Increased heavy equipment traffic at WMD deployment sites	Increased cell phone use	Fires and explosions at WMD deployment sites
	Increased traffic out of/ decreased traffic to WMD deployment sites	Increased radio use	OL forces evacuate WMD deployment sites*
	OL forces garrison at WMD deployment sites*	Increased SATCOM use	
		OL use courier to communicate*	

* unmeasurable indicator

4.2.2.5 *Objective Assessment Preparation.*

Assessors and planners next develop an initial progress function based on the planned COA and anticipated level of objective attainment. The plan-line for the COA and anticipated objective achievement for *Objective 2* is shown in Figure 4.8. The initial progress function, derived from the planned progress line, is depicted in Figure 4.9.

The state vector $(s^{m}_{\text{OL}}, s^{m}_{\text{WMD R\&D}}, s^{m}_{\text{WMD Dep}})$ represents the states of the systems of interest and is translated by the following vectors in the planned progress line and progress function: the state vector (0,1,1) is anticipated to be reached at D+0 and yield approximately 20 percent of the overall objective attainment. State vector (1,1,1) is anticipated to be reached at D+2 yielding 30 percent of objective attainment. State vector

(0,1,2) is anticipated to be reached at D+3. This state vector represents full achievement of Desired Effect 2.2, partial achievement of Desired Effect 2.3, and no achievement of Desired Effect 2.1, which is a return to the initial state of the OL leadership. This plan results from the planners' forecast that OL will have an undesired reaction to coalition air strikes and will likely fire a TBM at its neighbors. Per the effect definitions, state vector (3,1,2), representing the achievement of all the desired effects associated with this objective, is anticipated to be reached at D+4 and yield 100-percent attainment of the objective.

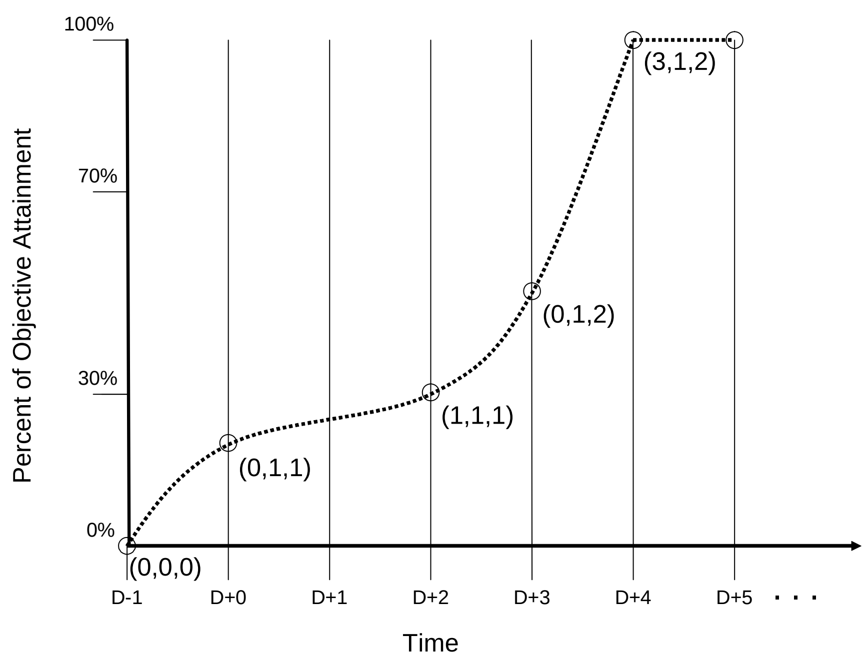


Figure 4.8 Planned Progress of ODF Objective 2

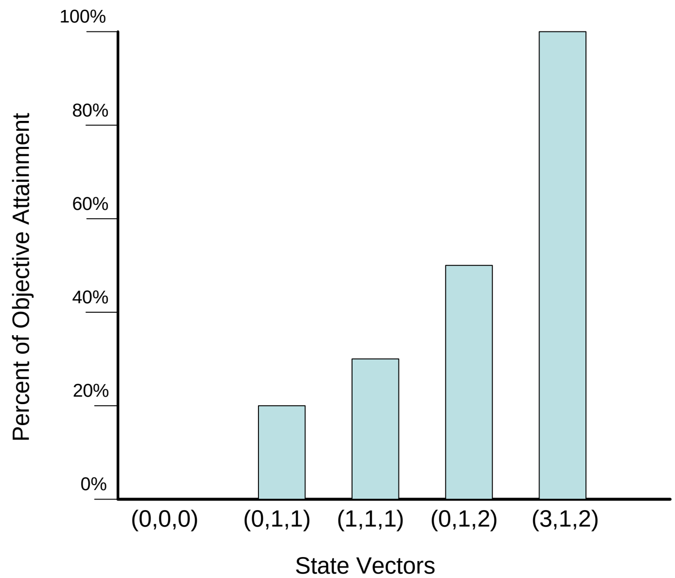


Figure 4.9 Initial Progress Function for ODF Objective 2

4.2.3 *Post Effects-Based Execution of ODF.*

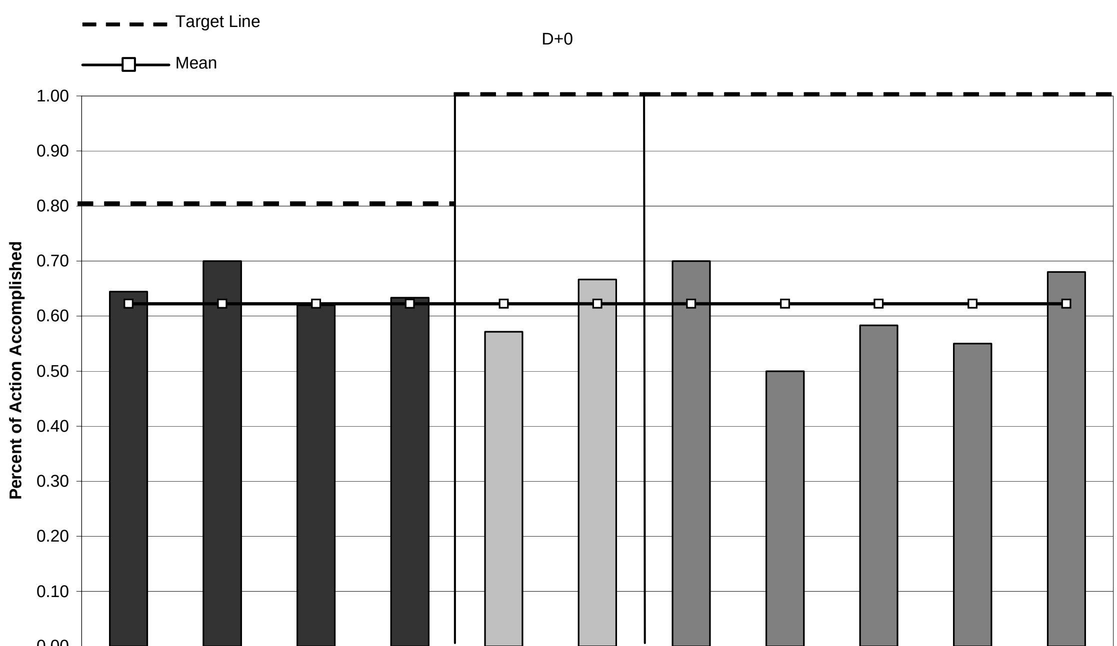
To describe the assessment methodology more fully, this section details the EBA process as EBE commences. Chapter 4 examines the ODF scenario at D+0 (D-Day) and at D+4 with the aim of showing enough assessment detail to demonstrate the methodology. For the interested reader, the observed indicators and daily cumulative actions accomplishment for the remaining campaign days are given in Appendix B.

4.2.3.1 *Phase IV: Actions Assessment.*

At D+0, strike results are mixed. Physical, functional, and system assessments reveal that the overall actions accomplishment is about 60 percent. Figure 4.10 lists the accomplishment of each action individually. As stated above, the planners determined that approximately 80 percent of the IADS targets needed to be successfully serviced to achieve Desired Effects 1.1 and 1.2. Similarly, to achieve Desired Effects 2.1, 2.2, and 2.3, all targets associated with the WMD R&D electrical power and WMD deployment facilities need to be successfully serviced. Therefore, at D+0, coalition forces are closer to accomplishing the actions associated with the IADS systems than they are to accomplishing the actions associated with the WMD and OL systems.

4.2.3.2 *Phase V: Effects Assessment.*

At D+0, some planned indicators are not being seen at all and some other planned indicators are returning ambiguous information. Tables 4.8 through 4.12 highlight in gray the indicators triggered by the available intelligence data. Table 4.8 (Desired Effect 1.2) illustrates that no SAFIRES were reported during the first day of air strikes, indicating that the IADS system might already be in the desired state.



	IADS Com	SAM sites	IADS C2	EW/CGI radar	EP stations	EP generators	EP POL	WMD storage	POL for WMD dep	Fiber optic lines for WMD dep	Telecom relay stations
D+0	0.64	0.70	0.62	0.63	0.57	0.67	0.70	0.50	0.58	0.55	0.68
Mean	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62

Figure 4.10 ODF Actions Accomplishment at D+0

Table 4.8 Desired Effect 1.2, IADS Indicators at D+0

S^{m}_{IADS}	S^{0}_{IADS}	S^{1}_{IADS}	S^{e}_{IADS}
State Description	Little or no change in IADS capability or behavior.	IADS undergone a significant change.	IADS threat to coalition forces neutralized.
Indicators	Guided SAFIRES	Decrease in SAFIRES	No SAFIRES
		Decreased radar emissions	Ballistic SAFIRES
		Decreased comm. emissions	No radar emissions

Table 4.9 (Desired Effect 1.1) illustrates similar indications (no SAFIRES, coalition forces uncontested in OL airspace, and no OL aircraft attempt to get airborne), placing OLTO airspace in the desired state as well.

Table 4.9 Desired Effect 1.1, OLTO Airspace Indicators at D+0

S^{m}_{OLTO}	S^{0}_{OLTO}	S^{1}_{OLTO}	S^{e}_{OLTO}
State Description (Given IADS neutralized)	OL a/c able and willing to contest coalition forces.	OL a/c contest Coalition forces indirectly.	OL experiences complete loss of air sovereignty and coalition forces have freedom of access for follow-on persistence forces.
Indicators	Increased sortie rates	Civilian a/c engage in unscheduled or unexpected flights	No SAFIRES
	OL a/c engage Coalition forces	Civilian a/c fly unusual flight patterns	No OL a/c fly w/o explicit approval from Coalition forces
		Increased traffic away from WMD/C2 facilities	Coalition forces uncontested in OL airspace
		Decreased traffic towards WMD/C2 facilities	No airborne OL a/c

In Table 4.10 (Desired Effect 2.2), assessors see the desired state s^e for the WMD R&D facilities with two indicators of that state, a local blackout around the facilities and power returning to surrounding areas but not the R&D facilities.

Table 4.10 Desired Effect 2.2, WMD R&D Facility Indicators at D+0

$s^{m}_{\text{WMD R\&D}}$	s^0	s^e
State Description	Little or no change to system function.	System unable to perform mission.
Indicators	Increased heavy-equipment traffic to and from facilities	Local blackout around R&D facilities
	Increased security at WMD R&D facilities	Lights stay out at R&D facilities while power returns to surrounding area
	Mobile SAM IVO WMD R&D facilities	Decreased traffic to facilities
		Explosions, fires at R&D facilities

In Table 4.11 (Desired Effect 2.3), assessors have witnessed indicators of two states, s^1 and s^e. Neither state has the prerequisite 40 percent of indicators observed, therefore the assessors must carefully consider the implications of the indicators. Using the guidelines for determining the system states, the assessors conclude that the system is most likely in the desired state, however since less than 60 percent of the actions against this system have been accomplished, the planners decide to declare the system in s^1.

Table 4.12 (Desired Effect 2.1) illustrates that OL launched TBMs at both Coalition forces and OL neighboring countries, placing the OL leadership in the initial state s^0.

Table 4.11 Desired Effect 2.3, WMD Deployment Capability Indicators at D+0

$s^{i}_{\text{WMD dep}}$	s^{0}	s^{1}	s^{e}
State Description	Little or no change to system function.	System functionality affected.	System unable to perform mission.
Indicators	Increased heavy equipment traffic at WMD deployment sites	Increased cell phone use	Fires and explosions at WMD deployment sites
	Increased traffic out of/ decreased traffic to WMD deployment sites	Increased radio use	OL forces evacuate WMD deployment sites*
	OL forces garrison at WMD deployment sites*	Increased SATCOM use	No activity at WMD deployment sites.
		OL use courier to communicate*	

Table 4.12 Desired Effect 2.1, OL Leadership Indicators at D+0

s^{m}_{OL}	s^{0}	s^{1}	s^{2}	s^{e}
State Description	Little or no change to system function.	System functionality affected.	Little bit worse.	System unable to perform mission.
Indicators	Increased heavy equipment traffic in/out of WMD facilities	Military defenses relocated to WMD R&D facilities	OL emplaces civilians IVO WMD sites	OL issues a demarche against US
	OL publicizes civilian consequences (blackouts to hospitals/schools, casualties etc.)	OL civilian a/c used as WMD (flying irregular patterns/times)	OL launches TBM into own territory	OL initiates diplomacy via third party
	OL launches TBM at Coalition forces			
	OL launches TBM at neighboring countries			
	Increased terrorist attacks in US/Coalition allies			
	Terrorist attacks in neighboring countries			

4.2.3.3 *Phases VI and VII: Objective and Campaign Assessment.*

After considering all the system states, the assessors determine the state vectors at D+0 to be (2,2) for *Objective 1* and (0,1,1) for *Objective 2*. Both state vectors have already been mapped to progress values via the progress function (reference Sections 4.2.1.5 and 4.2.2.5). Figure 4.11 and Figure 4.12 illustrate the actual progress line versus the planned progress line at D+0 for *Objectives 1* and *2*.

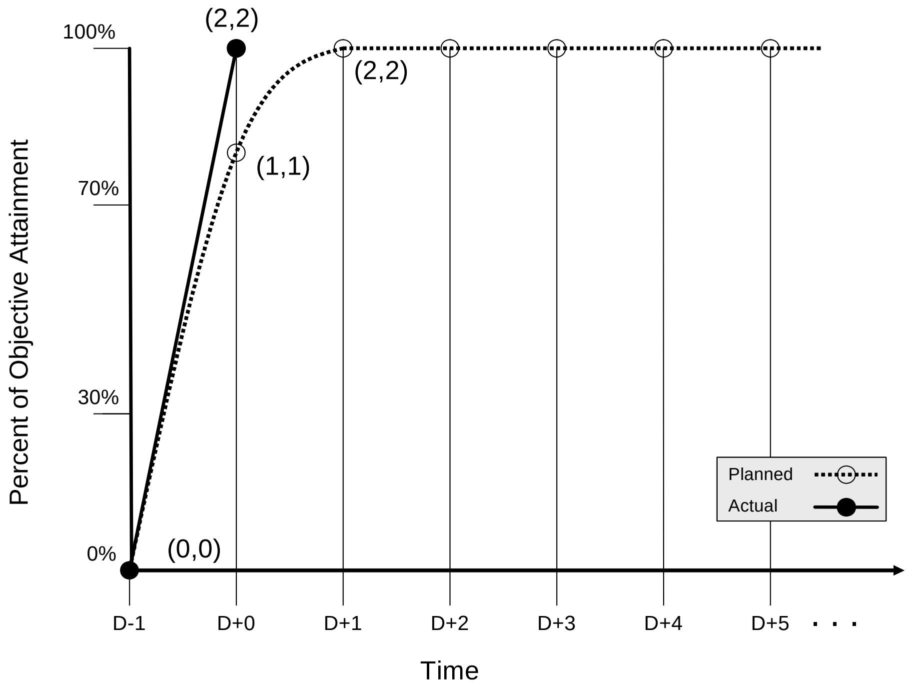


Figure 4.11 Actual Progress Line for Objective 1 at ODF D+0

This scenario now jumps ahead to the assessments at D+4. The cumulative actions accomplishment, current progress functions, and progress curves are shown as they exist at D+4 in order to illustrate how the assessment of ODF has changed over the first few days of the air campaign.

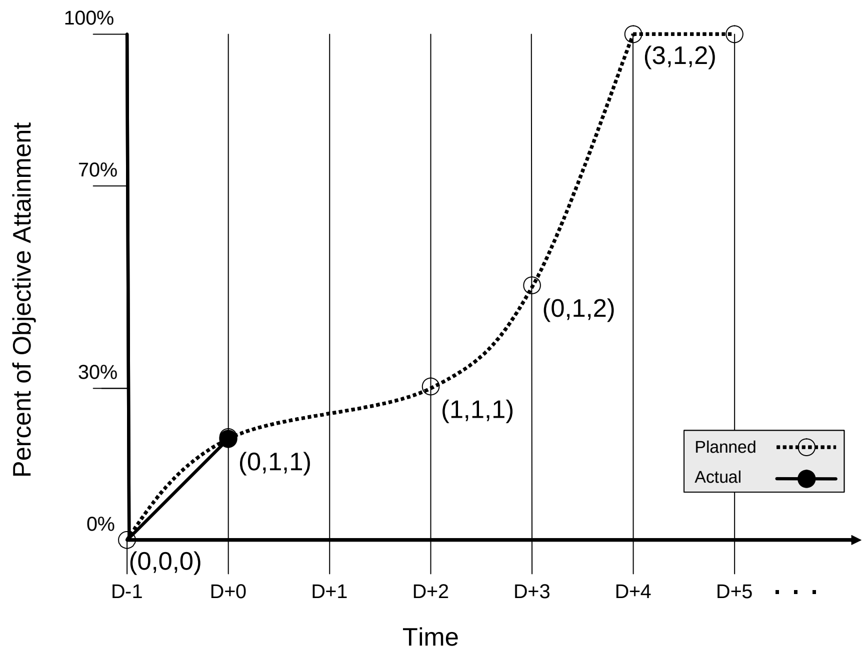
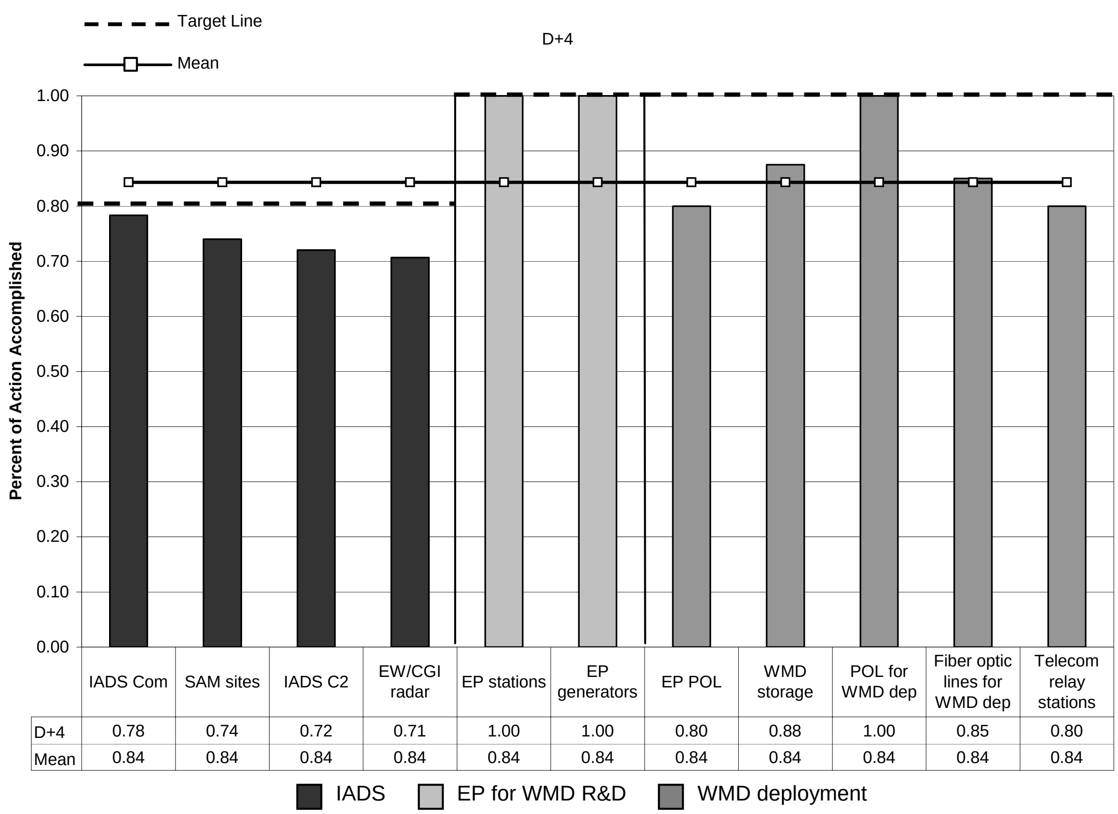


Figure 4.12 Actual Progress Line for Objective 2 at ODF D+0

Figure 4.13 depicts the levels of action accomplishment at D+4. Of the eleven actions, only three have reached their assigned target levels. The effects of these actions are shown in Figure 4.14 and Figure 4.15. The progress function for *Objective 1* (Figure 4.14) has been updated as the state vectors (0,1) and (1,2) have been observed via the indicators. *Objective 1* returns to full attainment at D+4 having previously dipped to only 30 percent attainment at D+2. The updated progress function for *Objective 2* (Figure 4.15) contains the state vectors that have been observed. All of the state vectors mapped to progress values by the planners are listed in increasing order of progress as follows: (0,0,0), (0,1,1), (1,0,2), (1,1,0), (1.1.1), (0,1,2), (2,1,1), and (3,1,2). *Objective 2* has not progressed as positively as *Objective 1* with an approximate progress of just over 20 percent objective attainment. Though the actions have not been fully accomplished for this objective, they are close and it appears that they are not having the desired effects.

The planners must take this into consideration when deciding on the next actions to execute.

At D+4 it appears that *Objective 1* is on plan while *Objective 2* is lagging. The CFACC and planners will take this into consideration for future COAs. As the air campaign progresses, the progress function and progress line will continue to be updated according to the assessment of the effects.



	IADS Com	SAM sites	IADS C2	EW/CGI radar	EP stations	EP generators	EP POL	WMD storage	POL for WMD dep	Fiber optic lines for WMD dep	Telecom relay stations
D+4	0.78	0.74	0.72	0.71	1.00	1.00	0.80	0.88	1.00	0.85	0.80
Mean	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84

Figure 4.13 Task Accomplishment at D+4

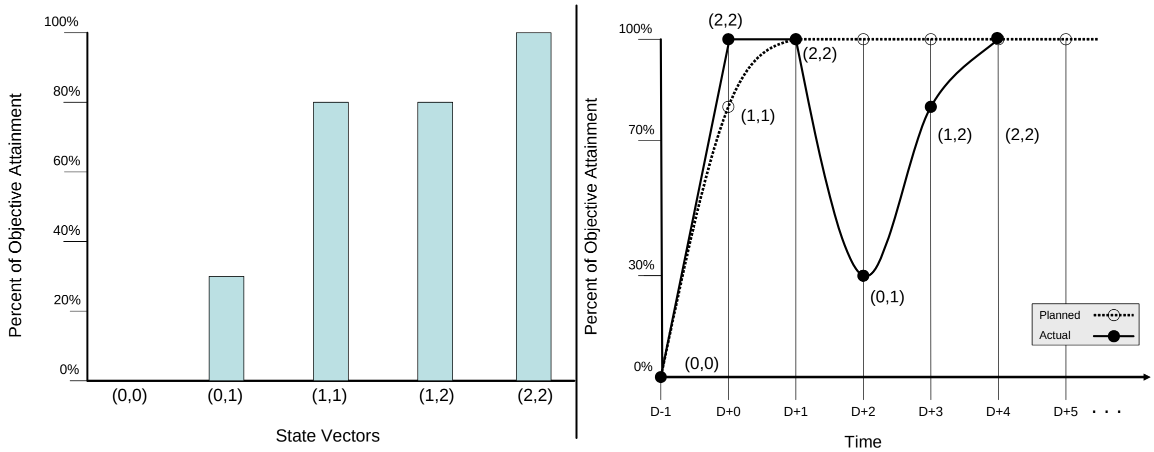


Figure 4.14 ODF Objective 1 Progress Function and Progress at D+5

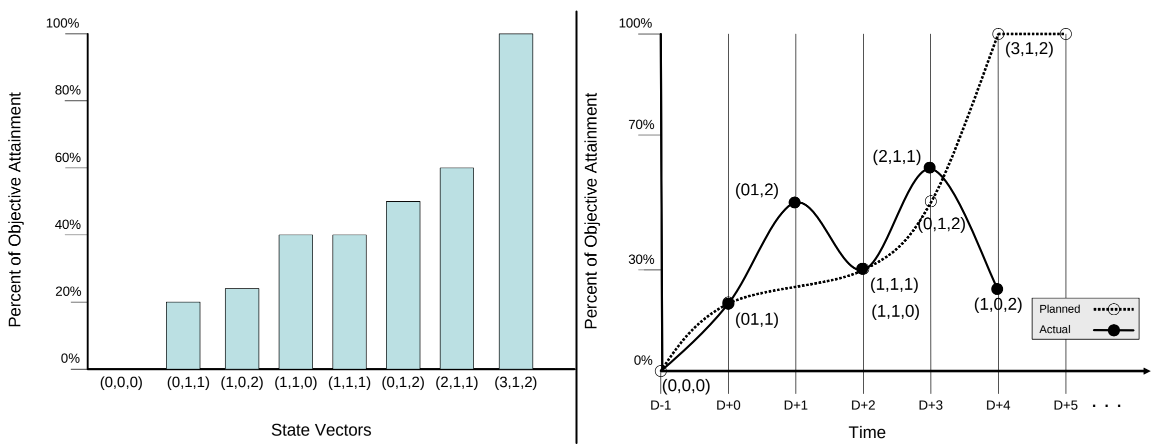


Figure 4.15 ODF Objective 2 Progress Function and Progress at D+5

4.3 Operation CLOSE GAP

Before the dictatorial rule of Syrpentor in Exstan, the Exstani education system was a highly regarded learning institution. Under the Syrpentor regime, public funds were siphoned off for military expenditures and other regime priorities. This shortage of funds, combined with the politicization of the education system, which enforced strict control over the curriculum, teachers, and administration, propelled the education system into a steady decline. The recent conflict that liberated the Exstani people compounded twenty years of neglect, leaving the education system virtually defunct. Nearly, all primary and secondary educational facilities require significant reconstruction. As Exstani governance moves towards a stable democracy, the demands on the US-lead coalition remain great. As a part of an overall campaign of stability operations, the Coalition has the following operational objective for the education system:

Objective 1: Improve quality and access to education.

4.3.1 *Phase I: Desired Effect Definition.*

For *Objective 1*, the planners define two desired effects.

Desired Effect 1:

- *System of interest*: Exstani school-age children.
- *Initial State of the System*: Few students attend school regularly due to limited availability of schools/teachers and limited access to school supplies.
- *Desired End State*: National education enrollment and attendance returned to pre-regime levels.
- *Start time*: 24 months from start of program.
- *End time*: Indefinite.

Desired Effect 2:

- *System of interest*: Exstan Education Infrastructure.
- *Initial State of the System*: Educational facilities at all levels are in shambles and are in dire need of repair. Few schools are open full-time due to lack of qualified

teachers and administrators. The schools that are open have no common text books or other learning materials.

- *Desired End State*: Infrastructure meets basic standards and provides basic educational supplies and tools for all schools nationwide.
- *Start time*: 24 months from start of program.
- *End time*: Indefinite.

4.3.2 *Phase II: Indicator Development.*

In Phase II, assessors analyze Desired Effect 2 before Desired Effect 1 because Desired Effect 2 is expected to have a cumulative effect contributing to Desired Effect 1. Planners determine seven actions to be taken in order to achieve Desired Effect 2:

- Rehabilitate substandard schools.
- Build new schools.
- Provide all schools with potable water and sanitation facilities.
- Train new teachers and administrators.
- Distribute desks and chalkboards to all schools.
- Distribute new math and science text books to all schools.
- Distribute sports equipment to all schools.

Figure 4.16 depicts the effects-tree diagram used to develop a set of measurable indicators for Desired Effect 2. Multiple actions are anticipated to result in similar system reactions. The effects-tree analysis results in 19 unique indicators that will be used to determine the state of the education infrastructure (shown in Table 4.13).

Using a similar process, Figure 4.17 illustrates the effects-tree diagram used to determine measurable indicators for Desired Effect 1. To build this effects-tree diagram, planners examine the COA, which includes four actions to be taken and one operational effect to be achieved in order to achieve Desired Effect 1:

- Establish model schools as "Centers of Excellence."
- Enroll out-of-school children in accelerated programs.
- Develop and broadcast early childhood television series promoting education.
- Education Infrastructure meets basic standards and provides basic educational supplies and tools for all schools nationwide (Desired Effect 2).

Again, multiple actions are anticipated to result in similar system reactions. This effects-tree analysis results in 13 unique indicators that will be used to determine the state of the Exstani school-age children (shown in Table 4.13).

This example illustrates two advantages over assessing combat operations. First, there is no enemy *per se* trying to deceive or conceal capabilities from coalition forces. Therefore, the systems needing to be monitored in order to measure the indicators are assumed to be easier to track. Second (and somewhat related), the desired effects in this example lend themselves to being measured directly. That is, the best indicators of the desired effects are the systems of interest themselves. For example, in Desired Effect 1 (enrollment and attendance return to pre-regime levels), assessors can track the number of students enrolled directly in order to determine the state of the system. Likewise, for Desired Effect 2 (infrastructure meets basic standards), assessors can track the educational facilities directly to determine the state of the education infrastructure.

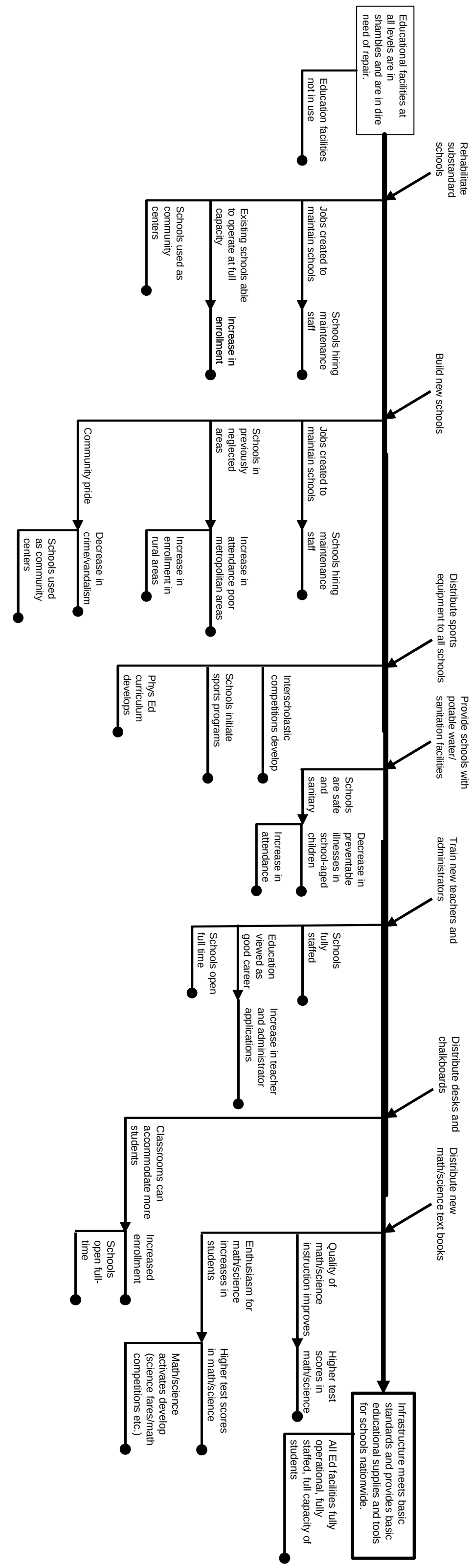


Figure 4.16 Effects-Tree Diagram for OCG Desired Effect 2

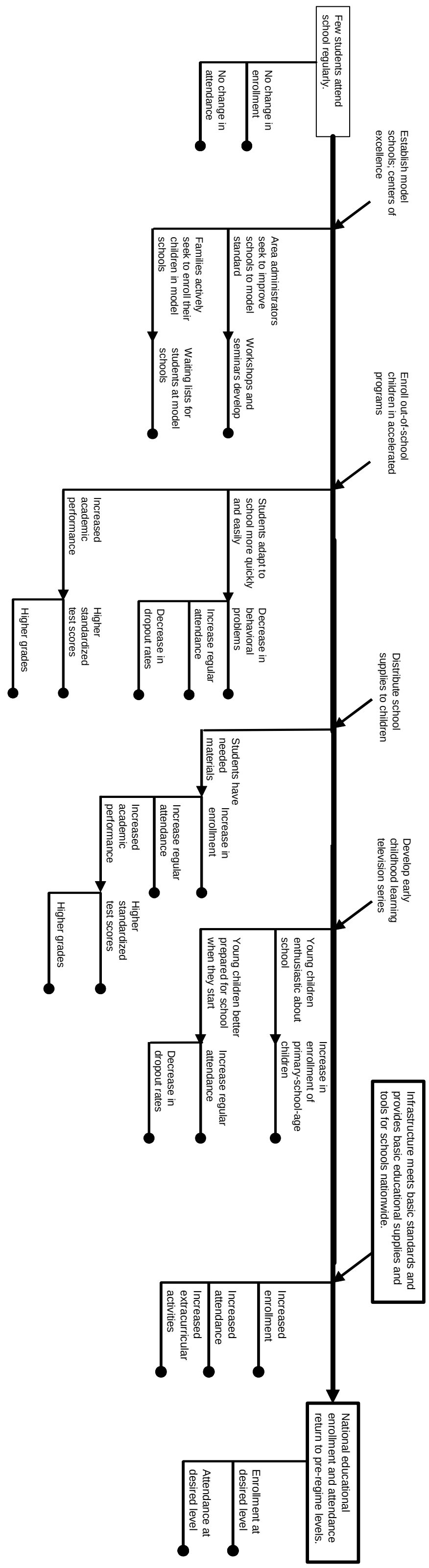


Figure 4.17 Effects-Tree Diagram for OCG Desired Effect 1

4.3.3 *Phase III: System State Definition.*

The initial states of the systems and the desired states of the systems flow directly from the effects definition and the effects-tree diagrams. Assessors aim to develop a state-transition model where each state has three to four indicators. This will provide the property of the model that at least two indicators need to be witnessed to meet the 40-percent rule. In this example, assessors represent the state transitions for Desired Effect 1 and 2 with a three-state model and a four-state model respectively. In this example, the number of indicators developed would allow the assessors to model the systems with more states if necessary. Tables 4.14 and 4.15 show the states and indicators decided upon by the assessors and planners. Again, assessors see that some indicators are evidence for multiple systems. Since the effects in OCG are along the same line of effects (one desired effect is to result as a cumulative effect of another) this provides the assessors with some efficiency in the set of indicators.

4.3.4 *Actions Assessment Preparation.*

The planners have identified 11 actions to be taken and one operational desired effect (see Section 4.3.2) to be achieved in order to achieve both desired effects. The desired effect on the Educational Infrastructure is intended to have a cumulative effect resulting in the desired effect on the Exstani school-aged children. After examining the actions, the assessors determine the MOPs to be the following:

- Percentage of required substandard schools rehabilitated.
- Percentage of required new schools built.
- Percentage of schools with potable water and sanitation facilities.

- Percentage of required new teachers and administrators trained.
- Percentage of required desks and chalkboards distributed.
- Percentage of required new math and science text books distributed.
- Percentage of required sports equipment distributed.
- Percentage of required "Centers of Excellence" completed.
- Percentage of required out-of-school children enrolled in accelerated programs.
- Early childhood television series broadcasting on Exstani television stations.
- Education Infrastructure (Desired Effect 2) measured via the effects assessment.

The planners set the target number for the planned actions at 100 percent. That is, planners believe that all planned actions must be accomplished completely, meeting all required numbers in order to achieve the desired effects. These actions will be tracked as EBE commences to determine their level of accomplishment.

4.3.5 *Objective and Campaign Assessment Preparation.*

Assessors and planners next develop a progress function based on the planned actions and anticipated levels of objective attainment. The planned progress line for the planned COA is shown in Figure 4.18. The initial progress function is depicted in Figure 4.19.

The state vector (1,1), which corresponds to $(s^1_{\text{Students}}, s^1_{\text{Infrastructure}})$, is anticipated to be reached six months after the program begins and yield approximately 20 percent of the overall objective attainment. State vector (2,2), which corresponds to $(s^2_{\text{Students}}, s^2_{\text{Infrastructure}})$, is anticipated to be reached 18 months after the program begins and yield approximately

60 percent attainment of the objective. The full attainment of the objective, state vector (2,3), is expected to be reached 24 months after the program begins.

Table 4.13 Indicators for OCG Desired Effects1 and 2

DE 1 Enrollment and attendance to pre-war levels.	**DE 2 Infrastructure is sound.**	
Administrators/teachers hold workshops and seminars to share best practices	Schools hiring maintenance staff	Increase in number of teacher and administrator applications
Waiting lists develop for model schools	Increase in enrollment	Schools open full time
Decrease in behavioral problems	Schools used as community centers	Higher math and science test scores
Increase in regular attendance	Increase in attendance in poor metropolitan areas	Math/science activities develop (fairs, competitions, etc.)
Decrease in dropout rates	Increase in enrollment in rural areas	Education facilities not in use
Higher standardized test scores	Decrease in crime/vandalism in and around schools	All Ed facilities fully operational
Higher grades	Interscholastic athletic competitions develop	Schools at full capacity for students
Increased enrollment	Schools initiate sports programs	
Development of sports, clubs, and after-school activities.	Schools develop PE curriculum	
Attendance at desired level	Decrease in preventable illnesses in children	
Enrollment at desired level	Increase attendance across the board	
No change or drop in enrollment	Schools fully staffed	
No change or drop in regular attendance		

4.3.6 *Post Effects-Based Execution.*

The OCG scenario is examined in this chapter after 18 months of stability operations have been executed. The actions and effects assessments after six months and 12 months are available in Appendix C.

Table 4.14 State Transitions and Indicators for OCG Desired Effect 1

s^{m}_{Students}	s^0	s^1	s^e
State Description	Little or no change to enrollment and attendance.	Noticeable increase in enrollment and attendance.	System at desired levels.
Indicators	Decrease in behavioral problems	Development of sports, clubs, and after-school activities.	Enrollment at desired level.
	Higher standardized test scores	Waiting lists develop for model schools	Attendance at desired level.
	Higher grades	Administrators/teachers hold workshops and seminars to share best practices	Decrease in dropout rates
	No change or drop in enrollment	Increase in regular attendance	
	No change or drop in regular attendance	Increased enrollment	

Table 4.15 State Transitions and Indicators for OCG Desired Effect 2

$s^{m}_{\text{Infrastructure}}$	s^0	s^1	s^2	s^e
State Description	Little or no change to system capability.	System capability noticeably increased.	System capability significantly increased.	System able to perform mission.
Indicators	Schools hiring maintenance staff	Interscholastic athletic competitions develop	Increase in attendance in poor metropolitan areas	Schools used as community centers
	Increase in number of teacher and administrator applications	Schools initiate sports programs	Increase in enrollment in rural areas	All Ed facilities fully operational
	Decrease in crime/vandalism in and around schools	Schools develop PE curriculum	Higher math and science test scores	Schools open full time
	Education facilities not in use	Math/science activities develop (fairs, competitions, etc.)	Decrease in preventable illnesses in children	Schools fully staffed
			Increase attendance across the board	Schools at full capacity for students
			Increase in enrollment	

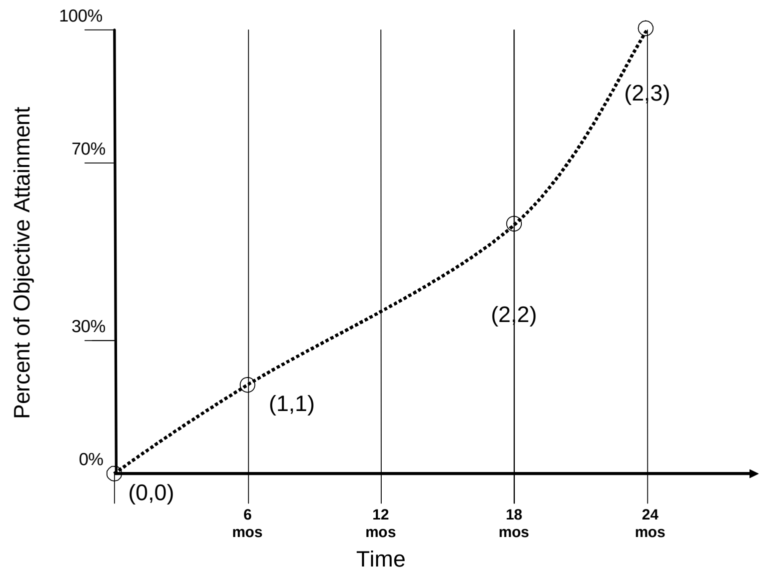


Figure 4.18 Planned Progress of OCG Objective 1

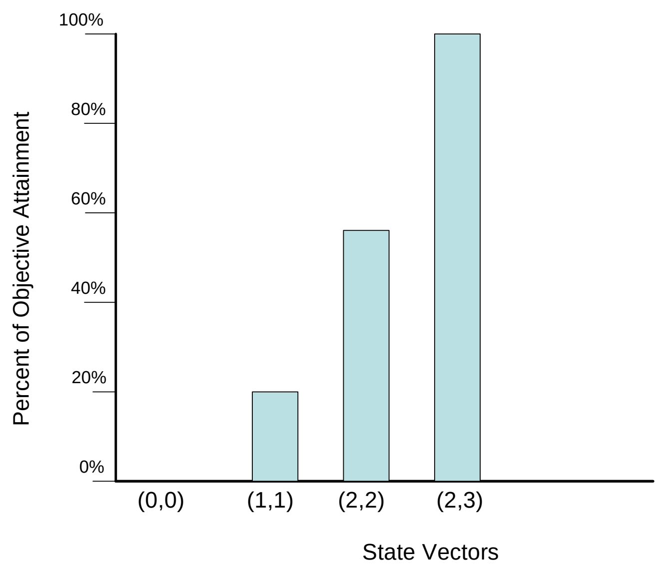
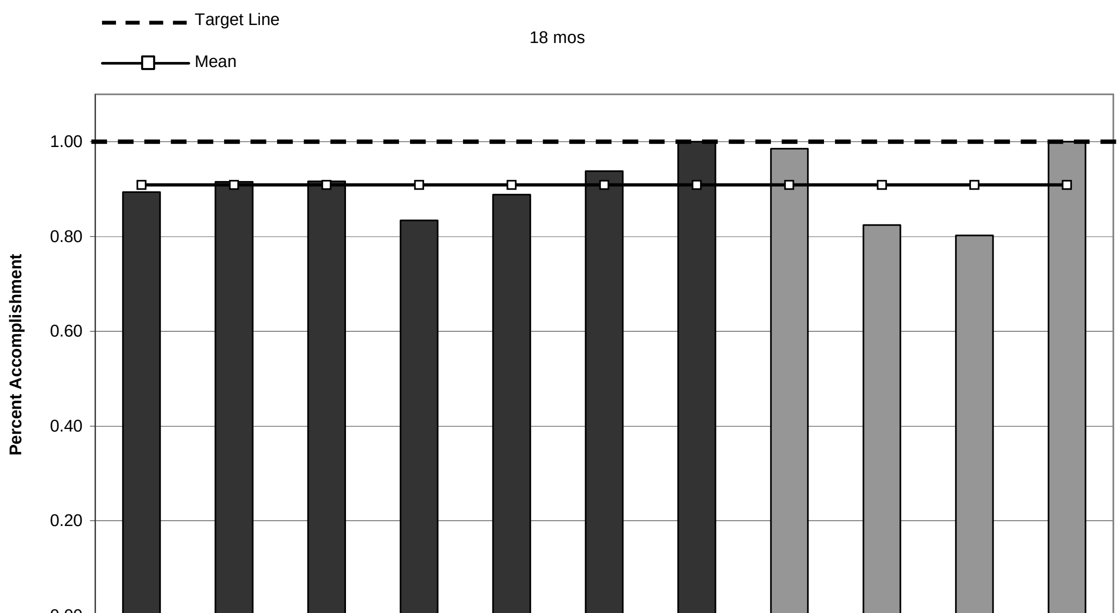


Figure 4.19 Initial Progress Function for OCG Objective 1

4.3.7 *Phase IV: Actions Assessment.*

Figure 4.20 depicts the cumulative levels of action accomplishment after 18 months. The actions are being accomplished as planned. Of the eleven actions, four have effectively reached 100-percent accomplishment, while the others have all been accomplished above 80 percent with a mean accomplishment of approximately 91 percent.



	Rehab substandard schools	Build new schools	Distribute sports equipment	Provide schools with	Train new teachers and	Distribute desks and chalkboard	Distribute new math and	Establish model schools/ce	Enroll out-of-school children	Distribute school supplies	Develop TV series
18 mos	0.89	0.92	0.92	0.83	0.89	0.94	1.00	0.99	0.82	0.80	1.00
Mean	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91

Actions

Infrastructure Students

Figure 4.20 OCG Actions Accomplishment at 18 Months

4.3.8 *Phase V: Effects Assessment.*

After 18 months of stability operations, assessors have indicators of increased performance of students in the classroom, the development of extracurricular activities, and an increase of regular attendance of students, but not increased enrollment. The infrastructure appears to be strengthening as the schools are fully staffed, with an increase in qualified applicants for teaching and administration positions, and the need to hire additional maintenance staff. The indicators observed by the assessors are given in Tables 4.16 and 4.17.

Table 4.16 Student Enrollment Indicators at 18 Months

s^m_{Students}	s^0	s^1	s^e
State Description	Little or no change to enrollment and attendance.	Noticeable increase in enrollment and attendance.	System at desired levels..
Indicators	Decrease in behavioral problems	Development of sports, clubs, and after-school activities.	Enrollment at desired level.
	Higher standardized test scores	Waiting lists develop for model schools	Attendance at desired level.
	Higher grades	Administrators/teachers hold workshops and seminars to share best practices	Decrease in dropout rates
		Increase in regular attendance	
		Increased enrollment	

The assessors see that for Desired Effect 1, there are two indicators of system state s^1 and one indicator for system state s^0. s^1 has two out of five indicators observed; using the 40-percent-rule, the assessors deem the student enrollment to be in s^1.

Table 4.17 Education Infrastructure at 18 Months

$s^{m}_{\text{Infrastructure}}$	s^0	s^1	s^2	s^e
State Description	Little or no change to system capability.	System capability noticeably increased.	System capability significantly increased.	System able to perform mission.
Indicators	Schools hiring maintenance staff	Interscholastic athletic competitions develop	Increase in attendance in poor metropolitan areas	Schools used as community centers
	Increase in number of teacher and administrator applications	Schools initiate sports programs	Increase in enrollment in rural areas	All Ed facilities fully operational
	Decrease in crime/vandalism in and around schools	Schools develop PE curriculum	Higher math and science test scores	Schools open full time
	Education facilities not in use	Math/science activities develop (fairs, competitions, etc.)	Decrease in preventable illnesses in children	Schools fully staffed
			Increase attendance across the board	Schools at full capacity for students
			Increase in enrollment	

Looking at the Education Infrastructure system, assessors see that the schools are fully staffed, however, assessors note that there are two indicators present for system state s^2. Likewise the schools are not yet to full capacity for students, and some facilities are either not yet fully operational or not yet open full-time. Therefore, the assessors declare that the education infrastructure is in system state s^2.

4.3.9 *Phases VI and VII: Objective and Campaign Assessment.*

The resulting state vector from the indicator analysis is $(s^1_{\text{Students}}, s^2_{\text{Infrastructure}})$, which is denoted (1,2). The planners have mapped state vector (1,2) to approximately 60 percent on the progress function. Figure 4.21 lists the progress function at the 18-month assessment. From the assessment at 12 months, this state vector represents a decrease in progress (Figure 4.22).

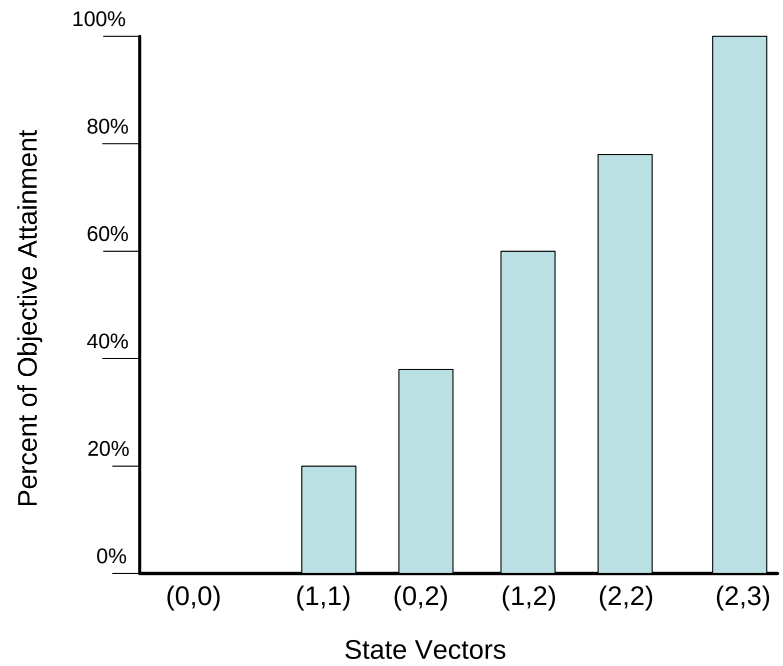


Figure 4.21 OCG Progress Function at 18 Months

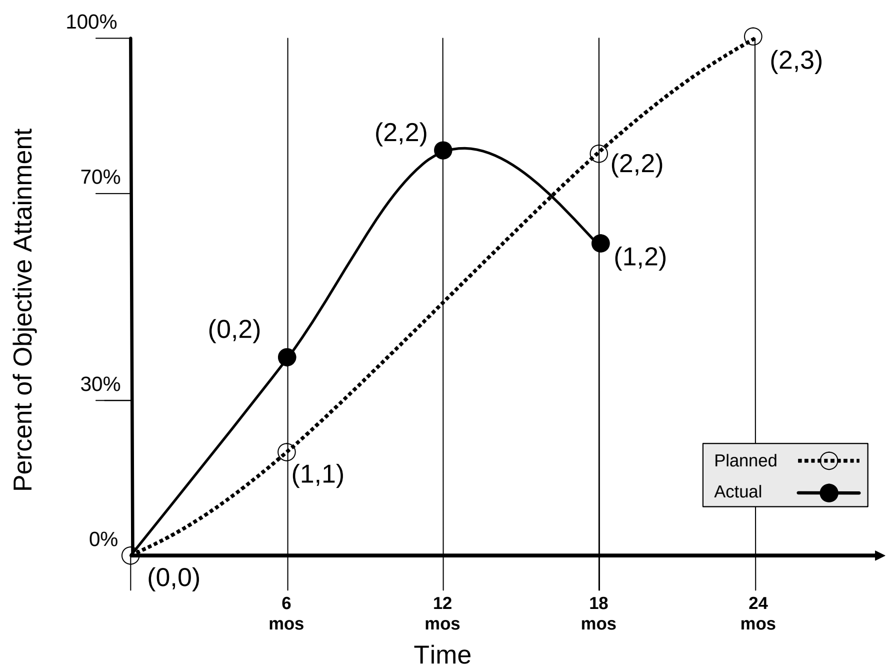


Figure 4.22 OCG Actual Progress Line for Objective 1 at 18 Months

The assessors attribute this decrease in progress to the fact that the student enrollment had reached pre-regime levels at the 12-month assessment (reference Appendix C), but the number of students enrolled has actually decreased since then. The reason for the unexpected decrease is unknown and warrants further investigation by the assessors.

4.4 Conclusion

In Chapter 4, EBA methodology was applied to two scenarios. The first scenario described how EBA can be implemented to assess an air campaign involving combat operations. The second scenario described how EBA can be applied to a nation-building campaign involving stability operations. Though the combat operations and stability operations have very different aims, the EBA methodology presented in this thesis can provide insight for each case into the accomplishment of planned actions, the achievement of desired effects, the attainment of objectives, and the progress of the overall campaign. Chapter 5, will discuss the advantages of this EBA methodology as applied to these two scenarios as well as some limitations of the methodology when it is put into practice.

5 Discussion

5.1 Introduction

Chapter 5 summarizes the results, contributions, and recommendations for future research of the Effects-Based Assessment (EBA) methodology presented in this thesis. The results discussed include the applicability and limitations of the EBA methodology to combat and stability operations. The primary recommendation of this thesis for future research are applications of stochastic analysis methods to the problem of EBA.

5.2 Results of the Research

This thesis set out to formulate an EBA construct that is timely, accurate, actionable, efficient, simple, quantifiable, adaptable, and most importantly, provides relevant insight to the CFACC and military planners. Chapter 4 demonstrated how the EBA methodology can be applied to both combat operations and stability operations. However, the application of the EBA methodology does not produce equivalent results for both types of operations.

When comparing the process of applying the EBA methodology to OPERATION DENY FORCE (ODF) and the process of applying the methodology to OPERATION CLOSE GAP (OCG), tracking the effects for ODF was more direct than tracking the effects for OCG. In OCG, the desired effects of the stability operations lent themselves to being tracked more easily by monitoring the systems of interest directly. In ODF, the systems involved included softer, human systems, which are inherently harder to monitor.

The desired effects in ODF therefore had to be largely monitored indirectly. It is in this example that the methodology proved its worth.

The main contributor to the method's applicability is the development of indicators in Phase II. When the system state can be measured directly, a formal methodology for determining system state indicators is not necessarily required. One need not watch for "red faced" people to determine the outside temperature if a thermometer were available. The same holds true for EBA. If a system can be measured directly, there is no need to go through the effects-tree analysis described in Phase II. The use of direct metrics would be more efficient and more appropriate than proxy indicators when the system can be measured directly Additionally, an added level of uncertainty accompanies the process when measuring systems indirectly. For example, "red faced" people may be an indicator of temperature, but it could also be an indicator of a state of embarrassment.

In Phase II, additional indicators of indirect effects are developed under a strict assumption about the enemy: the enemy will continue to fight by all means available to him (reference Section 2.11). Under this assumption, assessors can consider how individual friendly actions affect the enemy; these individual considerations then lead to a range of potential system reactions that describe all possible states of the system. This range or enemy reactions is vital to the fidelity of effects assessment and system state definition in Phase III.

In stability operations, however, there is not always an enemy *per se*. In the OCG scenario (reference Section 4.3) there is no enemy that continues to fight by all means available. Therefore, for the purposes of the effects-tree diagram, the assumption about the enemy is violated. This violation can result in a very narrow range of indirect effects produced by friendly actions, which in turn can result in a very narrow range of indicators. A narrow range of indicators leads to a less robust range of ordinal system states produced in Phase III, which results in a set of system states that do not completely represent the system as it transitions as a result of friendly actions. Ultimately, the differences in state vectors become more difficult to distinguish, which then makes the assessed progress of the objectives less insightful.

In summary, the EBA methodology presented in this thesis can be used to assess combat operations and stability operations, however, the methodology is most useful when assessing combat operations involving systems that cannot be assessed directly.

5.3 Contributions of the Research

This thesis advances the application of EBA by defining anticipated states of enemy systems, developing indicators to determine the state of enemy systems, and applying progress functions to the anticipated and desired states of the enemy systems in order to describe progress of the campaign towards attainment of the commander's objectives.

Defining effects as a change in a system state formulates the EBA problem in terms that allow for the application of more robust modeling techniques. Defining system states allows planners and assessors to model effects (*model* in the general sense) by considering a system's transitions from an initial state to a desired state. System states offer assessors a more tangible method for assessing effects. When effects are described in terms of system states, the planners consider actions to induce a system to transition into a desired state. Assessors then consider evidence of the system state. This is more robust than physical and functional assessments, because it explicitly takes into account the indirect effects influenced by the system states. These indirect effects are at the heart of the operational value of EBO.

Similarly, the deliberate and methodical development of indicators contributes to both planning and assessing effects-based operations. EBO is about effects; as such the EBO process should include a method wherein planners and assessors consider the direct and indirect effects of planned and executed military actions. The effects-tree diagram provides a means to accomplish this consideration. The effects-tree diagram combines the system states and planned friendly actions to generate a list of indirect effects. These indirect effects aid the planners by helping them determine potential collateral effects of the actions, potential unforeseen enemy reactions which can be mitigated by additional or different actions, and can highlight deficiencies in branch plans and sequels. Effects-tree diagrams aid assessors by leading to measurable indicators of indirect effects, which in turn can be used to describe enemy system states that represent the achievement of desired effects.

5.4 Recommendations for Future Research

This thesis offers two main suggestions for future research: methods to define system states directly, prior to developing indicators; and the use of stochastic modeling methods to determine current and future states of enemy systems. Phase III develops states by partitioning as set of indicators that describes a range of potential enemy system reactions. Another approach is to determine the intermediate states along with the initial state and desired state of the system before developing indicators. This could be done through analysis of the SoSA model or by a method similar to Gallagher's specifications for a precisely defined effect. Additional specifications could include items that describe intermediate states witnessed through combat modeling and systems-of-systems analysis.

Smith describes the second avenue for future research, which involves the development of collections and indications algorithms similar to indications and warning intelligence used during the Cold War era. These algorithms were developed to yield an overall probability of an enemy attack. A general process would nominate indicators, apply weights to those indicators and assemble the various inputs into a "coherent probabilistic understanding" of the nature of an enemy's behavior (Smith, 2002:382, 398). Stochastic methods exist to produce this coherent probabilistic understanding. One such method is the use of Hidden Markov Models (HMM). HMMs are widely used in speech recognition and the comparing of protein sequences. HMMs have also been applied to problems of conflict detection, failure analysis, medical diagnosis, knowledge assessment, and pattern recognition.

An HMM is variation of a Markov chain model. HMMs consist of a set of discrete states and a matrix $\mathbf{P} = \{p_{ij}\}$ of transition probabilities for a system moving from state i to state j. In addition, every state has a vector of observed symbol (or indicator) probabilities, $\mathbf{I} = \{i_j(k)\}$ that corresponds to the probability that the system will produce a symbol of type k when the system is in state j. Furthermore, the states cannot be directly observed and can only be determined from the indicators, ergo the term "hidden" (Schrodt, 1997:12).

This description of HMMs aligns well with the Phase V method of using indicators to determine system states presented in this thesis. To apply HMM to EBA, assessors would need to assign the state transition probabilities and the indicator probabilities, which is no small task. The benefit would be that HMMs would help answer questions such as "given a set of observed indicators, what is the most likely state of the system?" and "what state is the system most likely to transition to?" Further research into the applicability of HMMs to EBO could lead to more insightful assessments, which may include a methodology for predicting future states of enemy systems, a capability highly sought after by planners looking days and weeks ahead of current operations. Rabiner (1989) and Schrodt (1997) offer a baseline for HMMs; Falmagne and Doignon (1988) describe a similar procedure using finite Markov chains for assessing system states.

5.5 Conclusion

The EBA methodology presented in this thesis takes a big step towards complete operational implementation of EBO. As demonstrated in Chapter 4, the seven-phase EBA methodology can be applied to combat operations as well as stability operations, though it is suited best for combat operations where the systems of interest cannot be assessed directly. The contributions of the EBA construct presented here include the definition of enemy system states to be tracked as the systems change in order to determine achievement of desired effects; the development of indicators of system states using effects-tree diagrams; and the mapping of the system state vectors to approximate values of objective attainment via progress functions. Formulating desired effects in terms of system state transitions and using indicators to determine those states opens two areas for future research: defining the system states directly along with the initial state and desired end state of the system, and the use of Hidden Markov Models to determine the most likely system state and most likely future state given a set of observed indicators. In time, the EBA paradigm presented here, combined with further research, doctrinal development, and operational experience, will increase the crucial insight to commanders into the complex effects created by friendly actions on the battlespace and the enemy.

Appendix A Effects-Tree Diagram Example

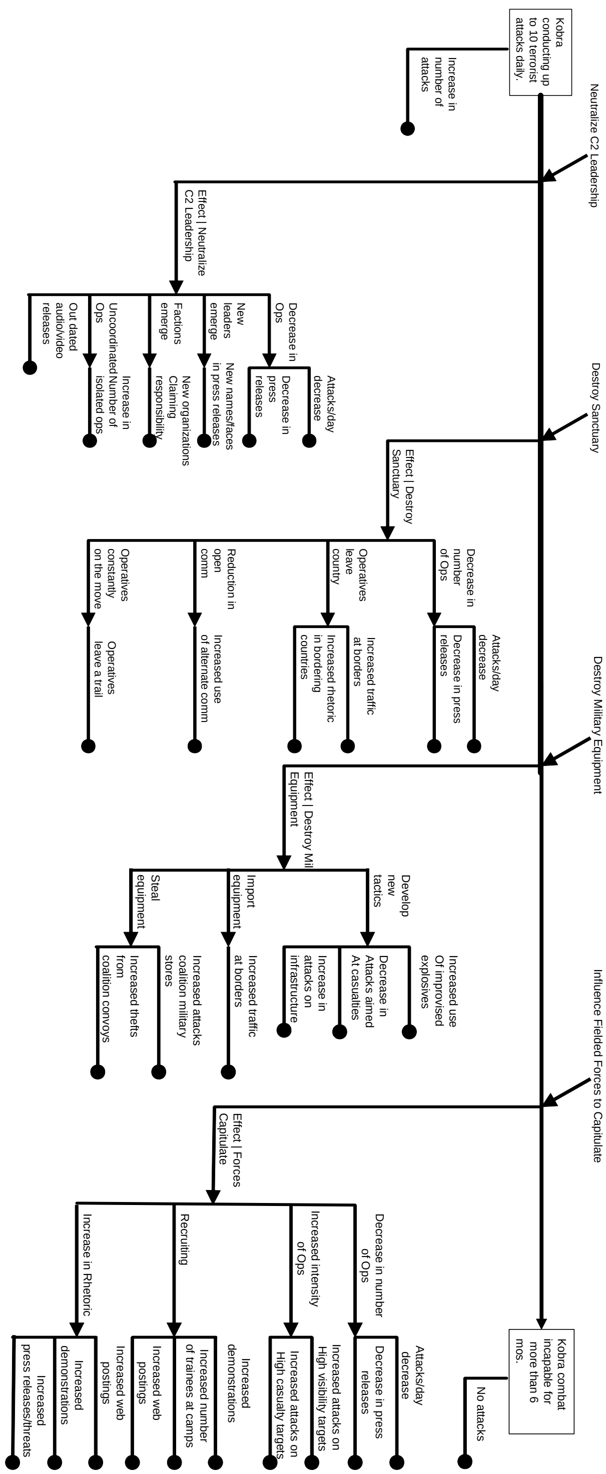


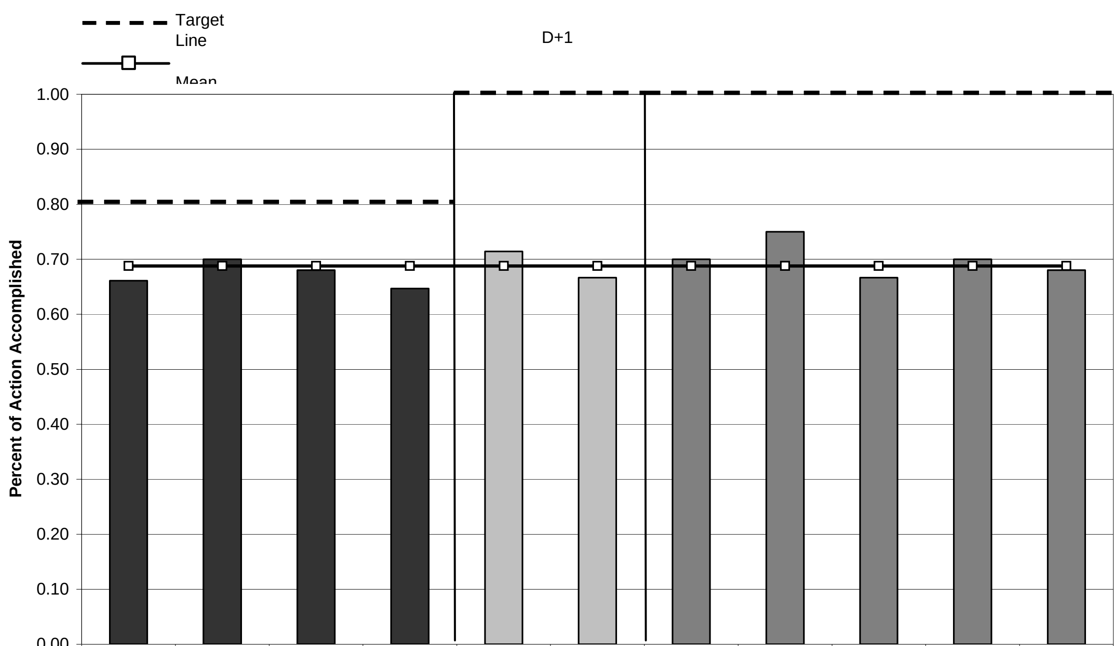
Figure A.1 Effects-Tree Diagram Example (reference Section 3.3.2.2)

Appendix B OPERATION DENY FORCE Data

Appendix B presents the data used to make the assessments in the OPERATION DENY FORCE (ODF) scenario in Chapter 4. The daily cumulative actions accomplishment are presented here for campaign days D+1 through D+3, and the observed indicators are presented for campaign days D+1 through D+4.

B.1 ODF at D+1

Figure B.1 illustrates the cumulative actions accomplishment at D+1. The mean accomplishment for all actions is 69 percent.



	IADS Com	SAM sites	IADS C2	EW/CGI radar	EP stations	EP generators	EP POL	WMD storage	POL for WMD dep	Fiber optic lines for WMD dep	Telecom relay stations
D+1	0.66	0.70	0.68	0.65	0.71	0.67	0.70	0.75	0.67	0.70	0.68
Mean	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69

IADS   EP for WMD R&D   WMD deployment

Figure B.1 ODF Actions Accomplishment at D+1

It is anticipated that Desired Effect 1.2 (IADS neutralized) will be achieved when 80 percent of the actions taken against the IADS are accomplished. The other actions must be 100 percent accomplished.

Tables B.1 and B.2 illustrate the indicators observed by ISR assets at D+1 for the desired effects of *Objective 1*. For Desired Effects 1.1 and 1.2, assessors determine that the occurrence of "No SAFIRES" puts the both the OLTO airspace and the IADS in desired state s^e. Therefore, the assessed state vector for *Objective 1* is (2,2).

Table B.1 ODF Desired Effect 1.1, OLTO Indicators at D+1

s^m_{OLTO}	s^0	s^1	s^e
State Description (Given IADS neutralized)	OL a/c able and willing to contest coalition forces.	OL a/c contest Coalition forces indirectly.	OL experiences complete loss of air sovereignty and coalition forces have freedom of access for follow-on persistence forces.
Indicators	Increased sortie rates	Civilian a/c engage in unscheduled or unexpected flights	No SAFIRES
	OL a/c engage Coalition forces	Civilian a/c fly unusual flight patterns	No airborne OL a/c
		Mobile SAMs positioned near high-priority assets	Coalition forces uncontested in OL airspace

Table B.2 ODF Desired Effect 1.2, IADS Indicators at D+1

s^m_{IADS}	s^0	s^1	s^e
State Description	Little or no change in IADS capability or behavior.	IADS undergone a significant change.	IADS threat to coalition forces neutralized.
Indicators	Guided SAFIRES	Decrease in SAFIRES	No SAFIRES
		Decreased radar emissions	Ballistic SAFIRES
		Decreased comm. emissions	No radar emissions

Tables B.3 through B.5 illustrate the indicators observed for the desired effects of *Objective 2*. For Desired Effect 2.1 (Table B.3), the only indicator observed of the OL leadership reaction is a protest against Coalition actions issued through a third-party embassy. OL still denies any WMD activity. Therefore, assessors determine the OL leadership to be in the initial state s^0 because the disposition of the OL leadership has not changed. For Desired Effect 2.2 (Table B.4), assessors determine the WMD R&D facilities to be in the desired state s^e due to the explosions at the R&D facilities, and because the power is still out at the facilities while it has returned to the surrounding area. Likewise, assessors determine the WMD deployment facilities to be in the desired state s^e due to seeing one-third of the indicators for the desired state, which is a greater proportion than the indicators for system state s^1. Therefore, the state vector for *Objective 2* is (0,1,2).

Table B.3 ODF Desired Effect 2.1, OL Leadership Indicators at D+1

s^m_{OL}	s^0	s^1	s^2	s^e
State Description	Little or no change to system function.	System functionality affected.	Little bit better..	System unable to perform mission.
Indicators	OL launches TBM at Coalition forces	OL civilian a/c used as WMD (flying irregular patterns/times)	OL emplaces civilians IVO WMD sites	OL issues a demarche against US
	OL launches TBM at neighboring countries	OL publicizes civilian consequences (blackouts to hospitals/schools, casualties etc.)	Military defenses relocated to WMD R&D facilities	OL initiates diplomacy via third party
	Increased terrorist attacks in US/Coalition allies	OL launches TBM into own territory	Increased heavy equipment traffic in/out of WMD facilities	
	Terrorist attacks in neighboring countries			

Table B.4 ODF Desired Effect 2.2, WMD R&D Indicators at D+1

$s^{m}_{\text{WMD R\&D}}$	s^{0}	s^{e}
State Description	Little or no change to system function.	System unable to perform mission.
Indicators	Increased heavy-equipment traffic to and from facilities	Local blackout around R&D facilities
	Increased security at WMD R&D facilities	Lights stay out at R&D facilities while power returns to surrounding area
	Mobile SAM IVO WMD R&D facilities	Decreased traffic to facilities
		Explosions, fires at R&D facilities

Table B.5 ODF Desired Effect 2.3, WMD Deployment Indicators at D+1

$s^{m}_{\text{WMD Dep}}$	s^{0}	s^{1}	s^{e}
State Description	Little or no change to system function.	System functionality affected.	System unable to perform mission.
Indicators	Increased heavy equipment traffic at WMD deployment sites	Increased cell phone use	Fires and explosions at WMD deployment sites
	Increased traffic out of/ decreased traffic to WMD deployment sites	Increased radio use	OL forces evacuate WMD deployment sites*
	OL forces garrison at WMD deployment sites*	Increased SATCOM use	
		OL use courier to communicate*	

* unmeasurable indicator

B.2 ODF at D+2

Figure B.2 illustrates the cumulative actions accomplishment at D+2. The mean accomplishment for all actions is 78 percent. All actions associated with the IADS have achieved above 70 percent, as have all other actions. The actions against the EP generators feeding the WMD R&D facilities have been 100 percent accomplished.

Tables B.6 and B.7 illustrate the indicators observed by ISR assets at D+2 for the desired effects of *Objective 1*. For Desired Effects 1.1, assessors observe two indicators of state s^0. For Desired Effect 1.2, assessors observe all the indicators of state s^1. Therefore, the assessed state vector for *Objective 1* is (0,1).

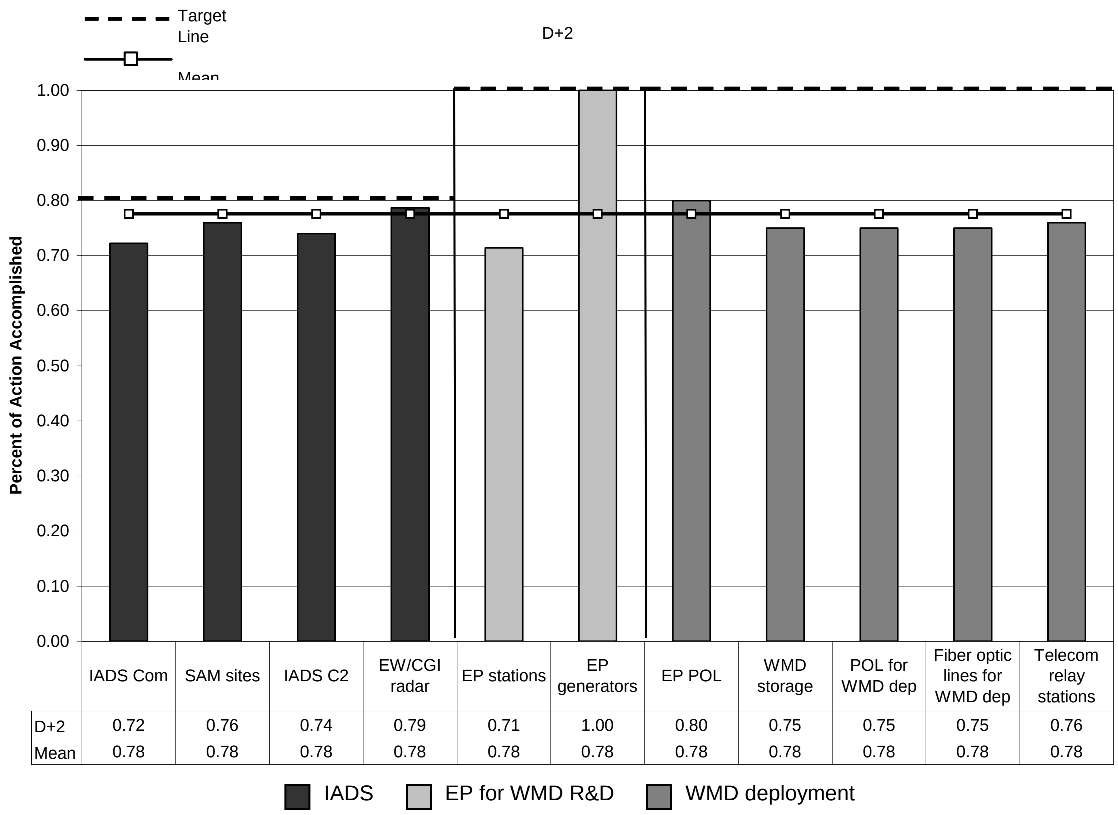


Figure B.2 ODF Actions Accomplishment at D+2

Table B.6 ODF Desired Effect 1.1, OLTO Indicators at D+2

s^m_{OLTO}	s^0	s^1	s^e
State Description (Given IADS neutralized)	OL a/c able and willing to contest coalition forces.	OL a/c contest Coalition forces indirectly.	OL experiences complete loss of air sovereignty and coalition forces have freedom of access for follow-on persistence forces.
Indicators	Increased sortie rates	Civilian a/c engage in unscheduled or unexpected flights	No SAFIRES
	OL a/c engage Coalition forces	Civilian a/c fly unusual flight patterns	No airborne OL a/c
		Mobile SAMs positioned near high-priority assets	Coalition forces uncontested in OL airspace

Table B.7 ODF Desired Effect 1.2, IADS Indicators at D+2

s^{m}_{IADS}	s^{0}	s^{1}	s^{e}
State Description	Little or no change in IADS capability or behavior.	IADS undergone a significant change.	IADS threat to coalition forces neutralized.
Indicators	Guided SAFIRES	Decrease in SAFIRES	No SAFIRES
		Decreased radar emissions	Ballistic SAFIRES
		Decreased comm. emissions	No radar emissions

Tables B.8 through B.10 illustrate the indicators observed for the desired effects of *Objective 2*. For Desired Effect 2.1 (Table B.8), assessors observe two indicators of state s^1 in addition to the OL leadership reaction of a protest against Coalition actions issued through a third-party embassy. Though OL continues to deny any WMD activity, the use of civilians as a deterrent to Coalition actions places OL in system state s^1.

Table B.8 ODF Desired Effect 2.1, OL Leadership Indicators at D+2

s^{m}_{OL}	s^{0}	s^{1}	s^{2}	s^{e}
State Description	Little or no change to system function.	System functionality affected.	Little bit better..	System unable to perform mission.
Indicators	OL launches TBM at Coalition forces	OL civilian a/c used as WMD (flying irregular patterns/times)	OL emplaces civilians IVO WMD sites	OL issues a demarche against US
	OL launches TBM at neighboring countries	OL publicizes civilian consequences (blackouts to hospitals/schools, casualties etc.)	Military defenses relocated to WMD R&D facilities	OL initiates diplomacy via third party
	Increased terrorist attacks in US/Coalition allies	OL launches TBM into own territory	Increased heavy equipment traffic in/out of WMD facilities	
	Terrorist attacks in neighboring countries			

For Desired Effect 2.2 (Table B.9), the electrical power indicators remain, so the WMD R&D facilities remain in the desired state s^e. For Desired Effect 2.3 (Table B.10), assessors observe increased traffic, both regular and heavy equipment, to and from the WMD deployment sites. Therefore, the state vector for *Objective 2* is (1,1,0).

Table B.9 ODF Desired Effect 2.2, WMD R&D Indicators at D+2

$S^{m}_{\text{WMD R\&D}}$	S^{0}	S^{e}
State Description	Little or no change to system function.	System unable to perform mission.
Indicators	Increased heavy-equipment traffic to and from facilities	Local blackout around R&D facilities
	Increased security at WMD R&D facilities	Lights stay out at R&D facilities while power returns to surrounding area
	Mobile SAM IVO WMD R&D facilities	Decreased traffic to facilities
		Explosions, fires at R&D facilities

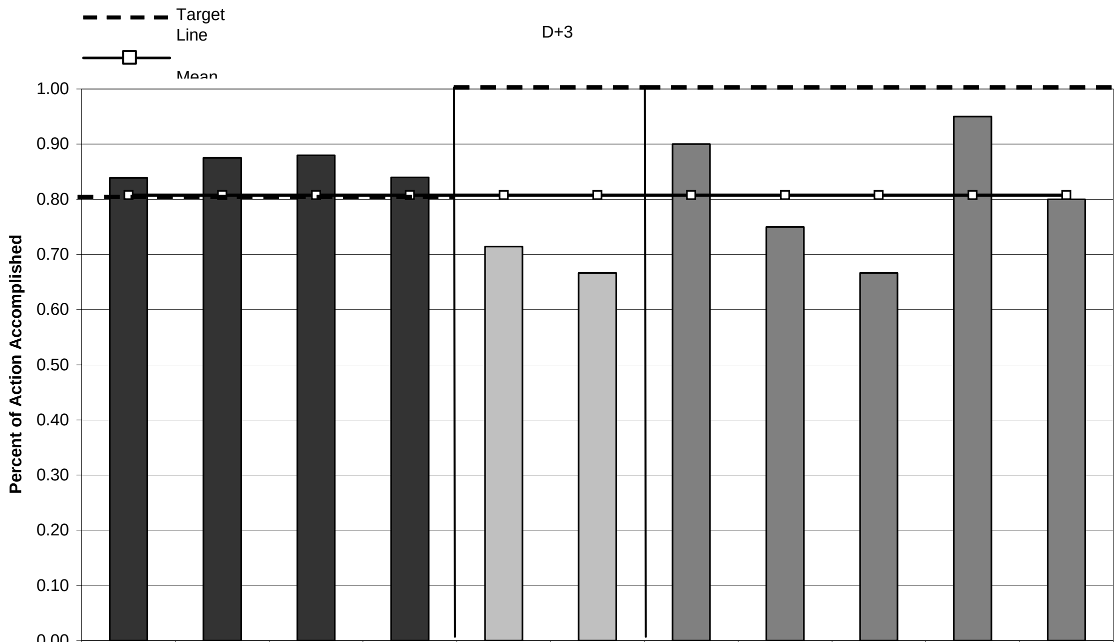
Table B.10 ODF Desired Effect 2.3, WMD Deployment Indicators at D+2

$S^{m}_{\text{WMD Dep}}$	S^{0}	S^{1}	S^{e}
State Description	Little or no change to system function.	System functionality affected.	System unable to perform mission.
Indicators	Increased heavy equipment traffic at WMD deployment sites	Increased cell phone use	Fires and explosions at WMD deployment sites
	Increased traffic out of/ decreased traffic to WMD deployment sites	Increased radio use	OL forces evacuate WMD deployment sites*
	OL forces garrison at WMD deployment sites*	Increased SATCOM use	
		OL use courier to communicate*	

* unmeasurable indicator

B.3 ODF at D+3

Figure B.3 illustrates the cumulative actions accomplishment at D+3. The mean accomplishment for all actions has increased to 81 percent. All actions associated with the IADS have been accomplished above the required 80-percent level. However, OL has reconstituted some of the EP systems and the POL for WMD deployment, which negates some of the actions accomplishment for *Objective 2*.



	IADS Com	SAM sites	IADS C2	EW/CGI radar	EP stations	EP generators	EP POL	WMD storage	POL for WMD dep	Fiber optic lines for WMD dep	Telecom relay stations
D+3	0.84	0.88	0.88	0.84	0.71	0.67	0.90	0.75	0.67	0.95	0.80
Mean	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81

Figure B.3 ODF Actions Accomplishment at D+3

For *Objective 1*, Tables B.11 and B.12 illustrate that assessors continue observe no SAFIRES, however OL is continuing to use civilian aircraft to challenge Coalition forces with the added indicator that OL military aircraft are now engaging Coalition forces. This places the OLTO airspace in state s^1 and the IADS in state s^e. Therefore the state vector for *Objective 1* is (1,2).

Table B.11 ODF Desired Effect 1.1, OLTO Indicators at D+3

s^{m}_{OLTO}	s^0	s^1	s^e
State Description (Given IADS neutralized)	OL a/c able and willing to contest coalition forces.	OL a/c contest Coalition forces indirectly.	OL experiences complete loss of air sovereignty and coalition forces have freedom of access for follow-on persistence forces.
Indicators	Increased sortie rates	Civilian a/c engage in unscheduled or unexpected flights	No SAFIRES
	OL a/c engage Coalition forces	Civilian a/c fly unusual flight patterns	No airborne OL a/c
		Mobile SAMs positioned near high-priority assets	Coalition forces uncontested in OL airspace

Table B.12 ODF Desired Effect 1.2, IADS Indicators at D+3

s^{m}_{IADS}	s^0	s^1	s^e
State Description	Little or no change in IADS capability or behavior.	IADS undergone a significant change.	IADS threat to coalition forces neutralized.
Indicators	Guided SAFIRES	Decrease in SAFIRES	No SAFIRES
		Decreased radar emissions	Ballistic SAFIRES
		Decreased comm. emissions	No radar emissions

In *Objective 2*, assessors observe the indicator that OL has emplaced large numbers of civilian “protestors” in the vicinity of suspected WMD sites. This lone indicator places the OL leadership in state s^2, as seen in Table B.13. For Desired Effect 2.2 (Table B.14), assessors again observe the same indicators involving the electrical power supply, and deem the WMD R&D facilities in the desired state s^e. For Desired Effect 2.3 (Table B.15), assessors observe the continuation of traffic in and out of the WMD deployment sites with the additional indicators of increased use of alternate communications. The assessors determine the WMD R&D facilities to be in state s^1. Therefore, the state vector for *Objective 2* is (2,1,1).

Table B.13 ODF Desired Effect 2.1, OL Leadership Indicators at D+3

s^m_{OL}	s^0	s^1	s^2	s^e
State Description	Little or no change to system function.	System functionality affected.	Little bit better..	System unable to perform mission.
Indicators	OL launches TBM at Coalition forces	OL civilian a/c used as WMD (flying irregular patterns/times)	OL emplaces civilians IVO WMD sites	OL issues a demarche against US
	OL launches TBM at neighboring countries	OL publicizes civilian consequences (blackouts to hospitals/schools, casualties etc.)	Military defenses relocated to WMD R&D facilities	OL initiates diplomacy via third party
	Increased terrorist attacks in US/Coalition allies	OL launches TBM into own territory	Increased heavy equipment traffic in/out of WMD facilities	
	Terrorist attacks in neighboring countries			

Table B.14 ODF Desired Effect 2.2, WMD R&D Indicators at D+3

$s^m_{WMD\ R\&D}$	s^0	s^e
State Description	Little or no change to system function.	System unable to perform mission.
Indicators	Increased heavy-equipment traffic to and from facilities	Local blackout around R&D facilities
	Increased security at WMD R&D facilities	Lights stay out at R&D facilities while power returns to surrounding area
	Mobile SAM IVO WMD R&D facilities	Decreased traffic to facilities
		Explosions, fires at R&D facilities

Table B.15 ODF Desired Effect 2.3, WMD Deployment Indicators at D+3

$s^m_{WMD\ Dep}$	s^0	s^1	s^e
State Description	Little or no change to system function.	System functionality affected.	System unable to perform mission.
Indicators	Increased heavy equipment traffic at WMD deployment sites	Increased cell phone use	Fires and explosions at WMD deployment sites
	Increased traffic out of/ decreased traffic to WMD deployment sites	Increased radio use	OL forces evacuate WMD deployment sites*
	OL forces garrison at WMD deployment sites*	Increased SATCOM use	
		OL use courier to communicate*	

* unmeasurable indicator

B.4 ODF at D+4

Tables B.16 through B.17 present the observed indicators for ODF at D+4. For *Objective 1*, assessors see for Desired Effect 1.1 (Table B.16) that the OLTO airspace continues to be affected by civilian aircraft even as the SAFIRE threat appears to be neutralized. Assessors determine the OLTO airspace to be in state s^1 and the IADS (Table B.17) to be in the desired state s^e. Therefore, the state vector for *Objective 1* is assessed to be (1,2).

Table B.16 ODF Desired Effect 1.1, OLTO Indicators at D+4

s^m_{OLTO}	s^0	s^1	s^e
State Description (Given IADS neutralized)	OL a/c able and willing to contest coalition forces.	OL a/c contest Coalition forces indirectly.	OL experiences complete loss of air sovereignty and coalition forces have freedom of access for follow-on persistence forces.
Indicators	Increased sortie rates	Civilian a/c engage in unscheduled or unexpected flights	No SAFIRES
	OL a/c engage Coalition forces	Civilian a/c fly unusual flight patterns	No airborne OL a/c
		Mobile SAMs positioned near high-priority assets	Coalition forces uncontested in OL airspace

Table B.17 ODF Desired Effect 1.2, IADS Indicators at D+4

s^m_{IADS}	s^0	s^1	s^e
State Description	Little or no change in IADS capability or behavior.	IADS undergone a significant change.	IADS threat to coalition forces neutralized.
Indicators	Guided SAFIRES	Decrease in SAFIRES	No SAFIRES
		Decreased radar emissions	Ballistic SAFIRES
		Decreased comm. emissions	No radar emissions

In Desired Effect 2.1 (Table B.18), assessors observe OL launching TBMs at neighboring countries and within OL territory. Assessors also observe the continued use of civilian aircraft and the exploitation of civilians through propaganda. Since three of these indicators belong to state s^1, assessors determine the OL leadership to be in s^1.

Table B.18 ODF Desired Effect 2.1, OL Leadership Indicators at D+4

s^m_{OL}	s^0	s^1	s^2	s^e
State Description	Little or no change to system function.	System functionality affected.	Little bit better..	System unable to perform mission.
Indicators	OL launches TBM at Coalition forces	OL civilian a/c used as WMD (flying irregular patterns/times)	OL emplaces civilians IVO WMD sites	OL issues a demarche against US
	OL launches TBM at neighboring countries	OL publicizes civilian consequences (blackouts to hospitals/schools, casualties etc.)	Military defenses relocated to WMD R&D facilities	OL initiates diplomacy via third party
	Increased terrorist attacks in US/Coalition allies	OL launches TBM into own territory	Increased heavy equipment traffic in/out of WMD facilities	
	Terrorist attacks in neighboring countries			

At D+4, assessors see a significant change in the achievement of Desired Effect 2.2 (Table B.19). Due to OL reconstitution efforts, assessors now see the return of electrical power to the WMD R&D facilities. Along with the reconstitution efforts, assessors observe increased traffic of both heavy equipment and regular traffic at the R&D facilities. These indicators place the WMD R&D facilities in the initial state s^0. However, for Desired Effect 2.3 (Table B.20) assessors observe fires and explosions at the remaining WMD deployment sites, which places the WMD deployment facilities in the desired state s^0. Therefore, the state vector for *Objective 2* is assessed to be (1,0,2).

Table B.19 ODF Desired Effect 2.2, WMD R&D Indicators at D+4

$s^{m}_{\text{WMD R\&D}}$	s^0	s^e
State Description	Little or no change to system function.	System unable to perform mission.
Indicators	Increased heavy-equipment traffic to and from facilities	Local blackout around R&D facilities
	Increased security at WMD R&D facilities	Lights stay out at R&D facilities while power returns to surrounding area
	Mobile SAM IVO WMD R&D facilities	Decreased traffic to facilities
		Explosions, fires at R&D facilities

Table B.20 ODF Desired Effect 2.3, WMD Deployment Indicators at D+4

$s^{m}_{\text{WMD Dep}}$	s^0	s^1	s^e
State Description	Little or no change to system function.	System functionality affected.	System unable to perform mission.
Indicators	Increased heavy equipment traffic at WMD deployment sites	Increased cell phone use	Fires and explosions at WMD deployment sites
	Increased traffic out of/ decreased traffic to WMD deployment sites	Increased radio use	OL forces evacuate WMD deployment sites*
	OL forces garrison at WMD deployment sites*	Increased SATCOM use	
		OL use courier to communicate*	

* unmeasurable indicator

Appendix C OPERATION CLOSE GAP Data

Appendix C presents the data used to make the assessments in the OPERATION CLOSE GAP (OCG) scenario in Chapter 4. The daily cumulative actions accomplishment and the observed indicators are presented here for the campaign at 6 months and the campaign at 12 months.

C.1 OCG at 6 Months

Figure C.1 details the actions accomplishment for OCG at six months. After six months of actions, only the action to develop the early childhood TV series is completely accomplished. The mean accomplishment is just over half-way at 51 percent. Particularly lagging is the construction of new schools, providing all schools with potable water and sanitation facilities, and the enrollment of out-of-school children in accelerated learning programs, all of which have only been just over 20 percent accomplished.

Tables C.1 and C.2 illustrate the observed indicators at six months for OCG *Objective 1* (Improve quality and access to education). For Desired Effect 1 (Table C.1), assessors observe students earning higher grades and an increase in regular attendance. However, the overall enrollment has not necessarily increased. Since approximately 33 percent of the indicators for the initial state s^0 have been observed compared with 20 percent of the indicators for state s^1, assessors determine that the student enrollment is in s^0. For Desired Effect 2 (Table C.2), assessors observe indicators for states s^0, s^1, and s^2. Since 50 percent of the indicators for state s^2 have been observed, which is greater than the other two states, then assessors determine the Education Infrastructure to be in state s^2. Therefore, at six months, the state vector for *Objective 1* is assessed to be (1,2).

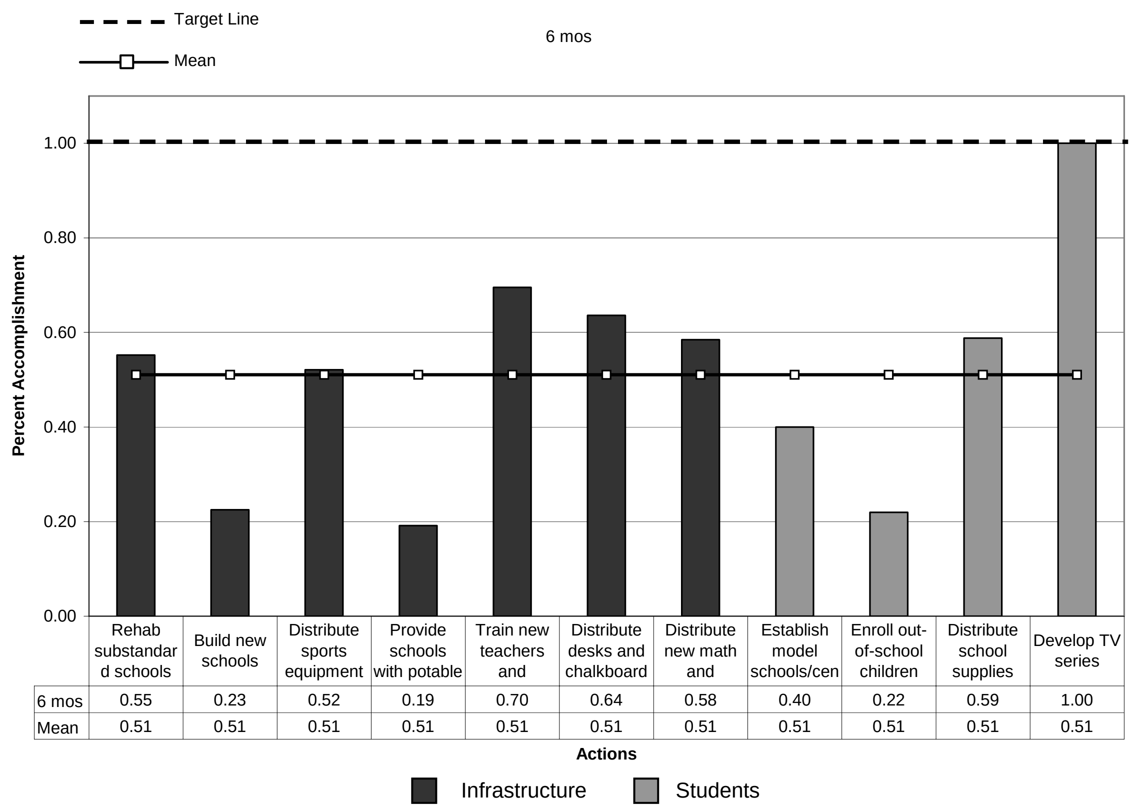


Figure C.1 OCG Actions Accomplishment at 6 Months

Table C.1 OCG Desired Effect 1, Student Enrollment Indicators at 6 Months

S^m_{Students}	S^0	S^1	S^e
State Description	Little or no change to enrollment and attendance.	Noticeable increase in enrollment and attendance.	System at desired levels..
Indicators	Decrease in behavioral problems	Development of sports, clubs, and after-school activities.	Enrollment at desired level.
	Higher standardized test scores	Waiting lists develop for model schools	Attendance at desired level.
	Higher grades	Administrators/teachers hold workshops and seminars to share best practices	Decrease in dropout rates
		Increase in regular attendance	
		Increased enrollment	

Table C.2 OCG Desired Effect 2, Education Infrastructure at 6 Months

$s^m_{\text{Infrastructure}}$	s^0	s^1	s^2	s^e
State Description	Little or no change to system capability.	System capability noticeably increased.	System capability significantly increased.	System able to perform mission.
Indicators	Schools hiring maintenance staff	Interscholastic athletic competitions develop	Increase in attendance in poor metropolitan areas	Schools used as community centers
	Increase in number of teacher and administrator applications	Schools initiate sports programs	Increase in enrollment in rural areas	All Ed facilities fully operational
	Decrease in crime/vandalism in and around schools	Schools develop PE curriculum	Higher math and science test scores	Schools open full time
	Education facilities not in use	Math/science activities develop (fairs, competitions, etc.)	Decrease in preventable illnesses in children	Schools fully staffed
			Increase attendance across the board	Schools at full capacity for students
			Increase in enrollment	

C.2 OCG at 12 Months

Figure C.2 outlines the actions accomplishment at 12 months. Assessors note that the construction of new schools and the enrollment of out-of-school students into accelerated programs are still lagging with just over 50 percent accomplishment each. The mean action accomplishment is progressing, however. At 12 months, the mean accomplishment is 70 percent.

Tables C.3 and C.4 illustrate the observed indicators at 12 months for OCG *Objective 1*. For Desired Effect 1 (Table C.3), assessors observe one indicator in each state. Since the indicator of the desired state is the a measure of the system of interest itself (the student enrollment), assessors determine the system to be in the desired state s^e.

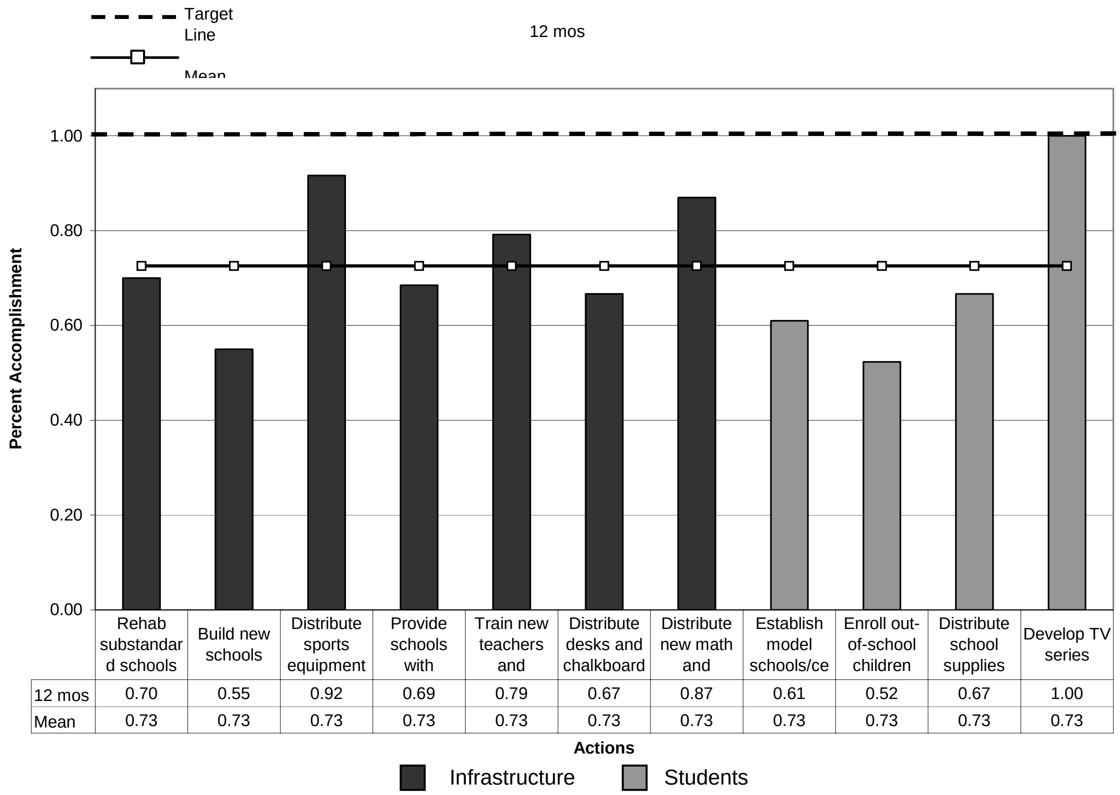


Figure C.2 OCG Actions Accomplishment after 12 Months

Table C.3 OCG Desired Effect 1, Student Enrollment Indicators at 12 Months

S^m_{Students}	S^0	S^1	S^e
State Description	Little or no change to enrollment and attendance.	Noticeable increase in enrollment and attendance.	System at desired levels..
Indicators	Decrease in behavioral problems	Development of sports, clubs, and after-school activities.	Enrollment at desired level.
	Higher standardized test scores	Waiting lists develop for model schools	Attendance at desired level.
	Higher grades	Administrators/teachers hold workshops and seminars to share best practices	Decrease in dropout rates
		Increase in regular attendance	
		Increased enrollment	

For Desired Effect 2 (Table C.4), assessors observe one indicator each of states s^0 and s^1, and two indicators for state s^2. The two indicators for state s^2 account for 33 percent of state s^2's indicators, while one indicator for states s^0 and s^1 account for only 25 percent of those states' indicators. Assessors therefore determine that the Education Infrastructure is in state s^2. Therefore, for *Objective 1*, assessors determine the state vector at 12 months to be (1,2).

Table C.4 OCG Desired Effect 2, Education Infrastructure at 12 Months

$S^m_{\text{Infrastructure}}$	s^0	s^1	s^2	s^e
State Description	Little or no change to system capability.	System capability noticeably increased.	System capability significantly increased.	System able to perform mission.
Indicators	Schools hiring maintenance staff	Interscholastic athletic competitions develop	Increase in attendance in poor metropolitan areas	Schools used as community centers
	Increase in number of teacher and administrator applications	Schools initiate sports programs	Increase in enrollment in rural areas	All Ed facilities fully operational
	Decrease in crime/vandalism in and around schools	Schools develop PE curriculum	Higher math and science test scores	Schools open full time
	Education facilities not in use	Math/science activities develop (fairs, competitions, etc.)	Decrease in preventable illnesses in children	Schools fully staffed
			Increase attendance across the board	Schools at full capacity for students
			Increase in enrollment	

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14. ABSTRACT

In order to bring the doctrine of Effects-Based Operations (EBO) into a fully operational capability, Effects-Based Assessment (EBA) must provide relevant insight to the commander and his planning staff. Assessments of an effects-based plan and execution must include an assessment of the effects of a campaign on the enemy in addition to an assessment of the accomplishment of friendly actions taken to achieve the desired effects. Determining the effects of a campaign requires an analysis of the dynamics of the enemy systems. EBA must be able to recognize the states of the enemy's systems as the system states change over time. This research advances the application of EBA by defining anticipated states of enemy systems, developing indicators to determine those states, and applying progress functions to the states in order to quantify attainment of the commander's objectives. The methodology describes a process for assessing combat and stability operations. The results indicate that the EBA methodology developed in this research works best where the systems of interest cannot be assessed directly.

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