Tools for Effects Based Course of Action Development and Assessment

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Abstract

Software tools are now available to assist the Air and Space Operations Center (AOC) with effects based Course of Action (COA) development, analysis, comparison and selection. In 2001, the Information Directorate of the Air Force Research Laboratory (AFRL) initiated an advanced technology demonstration program in the area of effects based operations. The program set out to develop new concepts and a software toolset to meet the AOC requirement for effects based targeting and campaign assessment. At the core of the toolset are the Strategy Development Tool (SDT) and Causal Analysis Tool (CAT). The Strategy Development Tool guides the user through the development of effects based COAs. During the initial planning phase, the Causal Analysis Tool predicts the probability of achieving commander's intent for the effects based COAs. During execution, the Causal Analysis Tool acts as a campaign assessment tool by incorporating accrued evidence provided by a multi-intelligence fusion component. An attrition-based campaign level wargaming tool was also developed to supplement COA analysis The goal is to transition the software tools to AOC strategists to help them achieve an effects based approach to the COA development process described in Joint Publication 3-30, "Command and Control for Joint Air Operations." Though focused on air operations, the tools can be used at the Joint Force Command level as well.

1.0 Introduction

Effects Based Operations (EBO) are "actions, taken against enemy systems, designed to achieve specific effects that contribute directly to desired military and political objectives" [1]. EBO complements rather than replaces conventional approaches to strategy development. It applies across the entire range of military missions from humanitarian relief operations, peacemaking or enforcement operations, to conventional war. EBO is not platform specific and applies whether kinetic or non-kinetic force is used. It is a critical capability for information operations such as psychological operations, electronic warfare, cyber attack and direct attack. An EBO approach starts from a systems perspective and explicitly seeks to understand, trace and anticipate direct and indirect effects as they course through the enemy system. As such, it applies an understanding of oneself, the adversary, and all elements that interrelate, interconnect or otherwise are interdependent.

This paper describes how AFRL has evolved the EBO concept into practical tools and technology for eventual warfighter use. The effort started four years ago based on a vision presented in a white paper written by the Joint Strategy and Concepts Development branch at the Pentagon [12]. Little did we know then that this was just the first step in a long journey to enable EBO by marrying information management technology with Command and Control decision aids. While this paper describes the beginning of AFRL's efforts to help warfighters conduct EBO more effectively, much more research and development is still needed. The Air Force, as well as the Department of Defense, still needs to go a long way to achieve the complete vision for effects based operations.

The program was kicked off with a warfighter analysis workshop to ensure that warfighter requirements were accurately addressed. This workshop was sponsored by the Air Force Command, Control, Intelligence, Reconnaissance, and Surveillance Center (AFC2ISRC) and hosted by the Command and Control Battlelab. The result was an operational concept document that provided focus to the program. The conceptual approach is based on overlaying a dynamic and continuous effects based planning, execution and assessment process on the joint air tasking cycle defined in Joint Publication 3-30 [7].

Section 2 of this paper provides a brief summary of EBO terms, definitions and characteristics that we have based our tool development efforts on. Also included is a discussion of the effects based joint air tasking cycle derived from Joint Publication 3-30. Section 3 provides an overview and screen captures of the EBO software tools. Section 4 is a short discussion of plans for technology transition to operational users. Section 5 addresses technology challenges associated with EBO tool development. This provides an indication of the technical way-ahead to improve the tools based on lessons learned, emerging technology and concepts, and warfighter feedback. Section 6 provides a short summary and challenges for the future.

2.0 Characteristics, Definitions, and Process for Effects Based Operations

2.1 Characteristics and Definitions for Effects Based Operations

According to the Air Combat Command (ACC) White Paper, the EBO methodology entails "planning, executing, and assessing operations designed to attain specific effects required to achieve desired national security outcomes" [1]. It encompasses both objectives-based and target-based approaches and is not a replacement for them. EBO stresses modeling the enemy as a system, or more appropriately as a system of systems. It is also characterized by an explicit focus on desired effects as opposed to tasks (see Figure 1). Definitions of several types of effects and terms are given below.

The AFRL EBO program standardizes on the ACC White Paper as the source for EBO terminology and definitions. It defines effects as the "outcomes, events or consequences that result from a specific action". Types of effects include indirect, cumulative, collateral, and cascading. Indirect effects are effects "created through an intermediate effect or mechanism**."** Cumulative effects are the "aggregate result of many direct or indirect effects against an adversary." Collateral effects are the "outcomes that result when something occurs other than what was intended." Cascading effects are **"**indirect effects that ripple through an adversary system, often affecting other systems" [1].

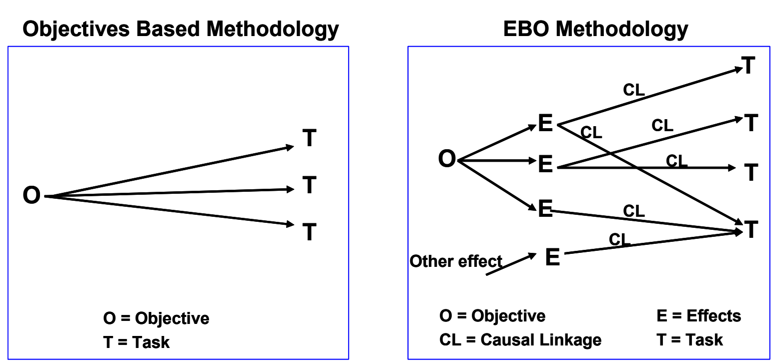

Figure 1: Comparison of Objectives Based and Effects Based Methodologies

Figure 1 illustrates the differences between the objectives based and EBO methodologies. With the objectives based approach, there is a specific focus on the tasks that need to be achieved to reach the objective. Higher echelons state the objectives and lower echelons determine the tasks that are required to meet these objectives. With the EBO methodology, there is a specific focus on the desired effects that will achieve the objective. Tasks and actions are then specified that are necessary to achieve the desired effects. There is also explicit representation of causal linkages. "Causal Linkages explain why planners think the proposed actions will create desired effects" [1]. They also explain the causality of unintended effects which could be positive or negative. Actions can then be taken if necessary to mitigate the undesired effects. The explicit representation of causal linkages has the added benefit of helping determine the overall probability of success since probability values can be assigned to them. CAT uses these probabilities to determine the overall probability of achieving commander's intent.

Figure 2 illustrates the representation of an effects based COA as a causal model. This hypothetical COA has the objective of stopping weapons of mass destruction (WMD) activities by a fictitious country called Orangeland. The arrows represent causal linkages and it is easy to trace these causal linkages all the way from targets through objectives. All important to EBO is the specification of indicators, such as "More than 5 R&D Facilities Destroyed" in the figure. Indicators are "observable or unobservable manifestations of action, cause or result" [10]. They are used to signify if an effect has been achieved or a task has been accomplished.

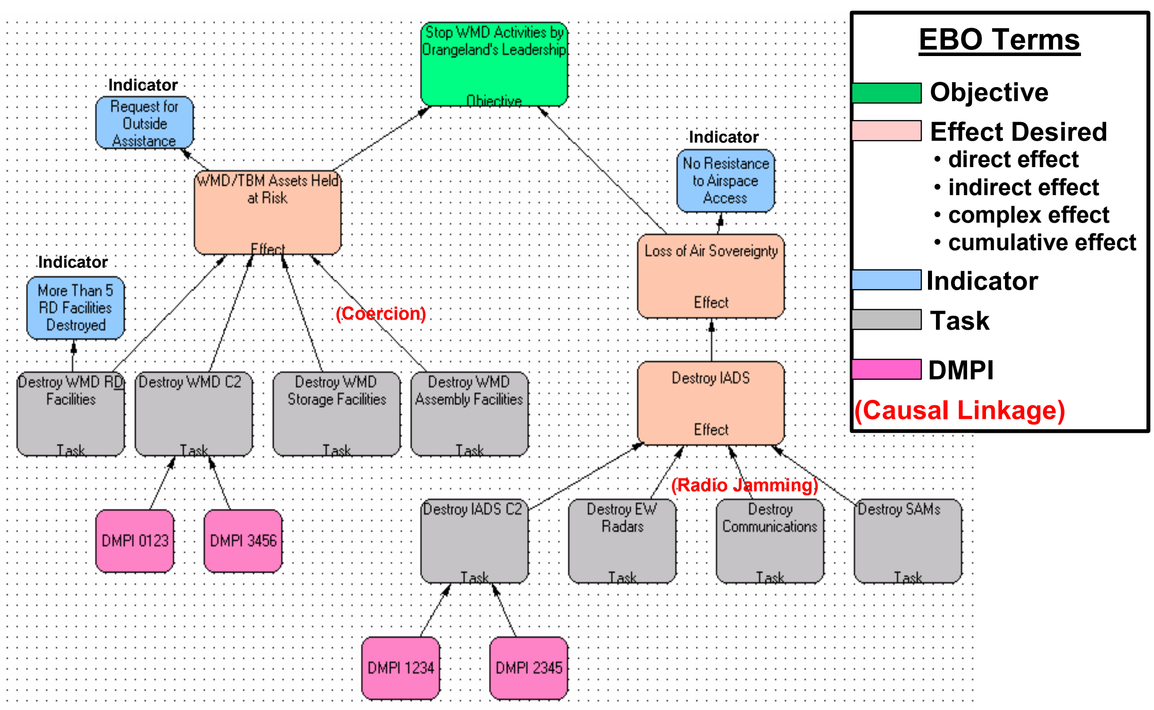

Figure 2: Use of a Causal Model to Represent an Effects Based COA

2.2 The Effects Based Joint Air Estimate Process

EBO tool development at AFRL is grounded in doctrine, with a particular emphasis on Joint Publication (JP) 3-30. This document defines the Joint Air Estimate Process (JAEP) and the Joint Air Tasking Order (JATO) Process (see Figure 3). The current AFRL EBO tools fit predominantly into the JAEP portion but do provide some support to the JATO process.

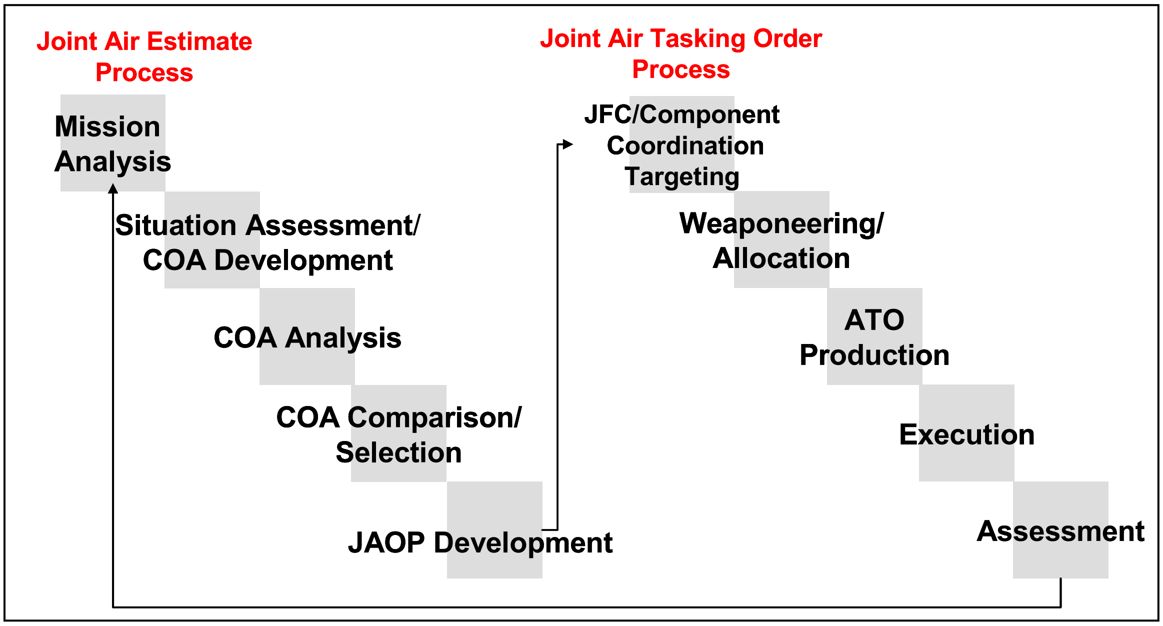

Figure 3: JP 3-30 Joint Air Estimate and Air Tasking Order Processes

Relative to the JAEP, SDT provides the ability to record Mission Analysis starting with commander's intent. Commander's intent is then broken down into specified and implied tasks. SDT has provisions to record all this information as well as the mission statement, rules of engagement, desired effects, etc. Situation Assessment is critical for plan development. Within SDT, this information is obtained from Intelligence Preparation of the Battlespace (IPB) applications. The result is a better understanding of the adversary's capabilities and potential actions which facilitates building a Blue COA to counter those actions. For the COA Development portion of the JAEP, SDT provides a structured and organized interface to guide the user in building effects based Blue COAs.

The COA Analysis phase of JP 3-30 typically consists of wargaming to determine strengths and weaknesses of each COA. AFRL is using CAT as a COA analysis tool, however CAT does not perform a wargaming function. CAT uses the probability of achieving commander's intent as a method of determining the "best" COA in the COA Comparison phase. The COA with the highest probability of achieving commander's intent would be selected in the COA Selection phase. Because we are using probabilities to accomplish this analysis, the user is cautioned that this method is used for relative comparison of one COA versus another.

Moving to the JATO phase of the process, SDT supports target development by recording non-kinetic targets, associating tasks and effects with targets, and specifying "do not effect" and "do not strike" targets. CAT supports the Assessment phase of the JATO process by performing campaign assessment. Once execution starts, information from multi-intelligence sources is accrued and fused. This evidence is fed back into CAT for recalculation of the probability of achieving commander's intent. In this way, the overall operation can be assessed to determine whether or not the COA requires adjustment.

It is important to recognize that the process drives the tool development and not the other way around. As work continues, additional tools will be developed to provide support to phases of JP 3-30 that are currently unsupported. The existing tools will ultimately be enhanced to provide increased capability and functionality.

3.0 Software Decision Aids for EBO

3.1 Strategy Development Tool

Presently, the effects based operations toolset consists of working prototypes covering initial strategy development and assessment. SDT supports development of an effects based COA by explicitly focusing on desired effects and actions. An SDT COA is broken into phases. Each phase consists of objectives, effects, causal linkages, tasks and targets (see Figure 4). COAs can be created manually, augmented with pre-defined templates, or built using adversary models with associated Blue interventions.

SDT includes a library of doctrine-based templates and supports custom template construction. Strategists choose and modify the templates based on commander's intent. The library of strategy templates includes those for attrition, denial and strategic paralysis. The mission template library includes offensive counter-air, defensive counter-air, suppression of enemy air defense, air interdiction, close air support, combat search and rescue and tactical intra-theater airlift. These libraries are being augmented as a result of our Joint Expeditionary Force (JEFX) 2004 participation and will continue to expand as strategists develop and save additional templates.

Center of Gravity (COG) analysis is used to guide development of Blue COAs. To facilitate the process, the "COG Articulator" portion of the tool enables the strategist to build light-weight COG models that outline characteristics and capabilities of enemy COGs such as leadership, infrastructure, system essentials, etc [15]. The user can also interject possible interventions that would prevent the adversary from achieving their objective. Once the strategists are content with the models and interventions, a causal chain can be exported from the COG Articulator into the plan editor. The entire model can also be exported to CAT for analysis of the probability.

The SDT "Target Set Tool" assists the users with populating direct and indirect targets for achieving each of the effects in the plan. The user can manually browse the target systems and enter targets by selecting them directly or by querying the information relative to links and target set category codes. The SDT "Option Generator" can automatically select targets based on an analysis of the "affect" targets in the plan. The present generation of heuristic algorithms to select targets is limited to the electrical power and petroleum oil lubricant target sets.

AFRL has several other research efforts examining methods for capturing relevant target systems knowledge to assist the strategist with effects based decisions. The Athena program focuses on understanding target system cross-dependencies and the development of models for representation and analysis. The EBO COG-Analysis Tool will enable planners to rapidly pull together information from a vast array of sources and assist in developing an operational view of the environment. It will focus on easing the tasks of manipulating the views, incorporating additional knowledge, and augmenting new beliefs and assumptions while also creating machine readable structures. AFRL is also working with an Air Force intelligence reach-back organization to develop an understanding of their target system analysis processes and how it can be incorporated into the EBO strategy process.

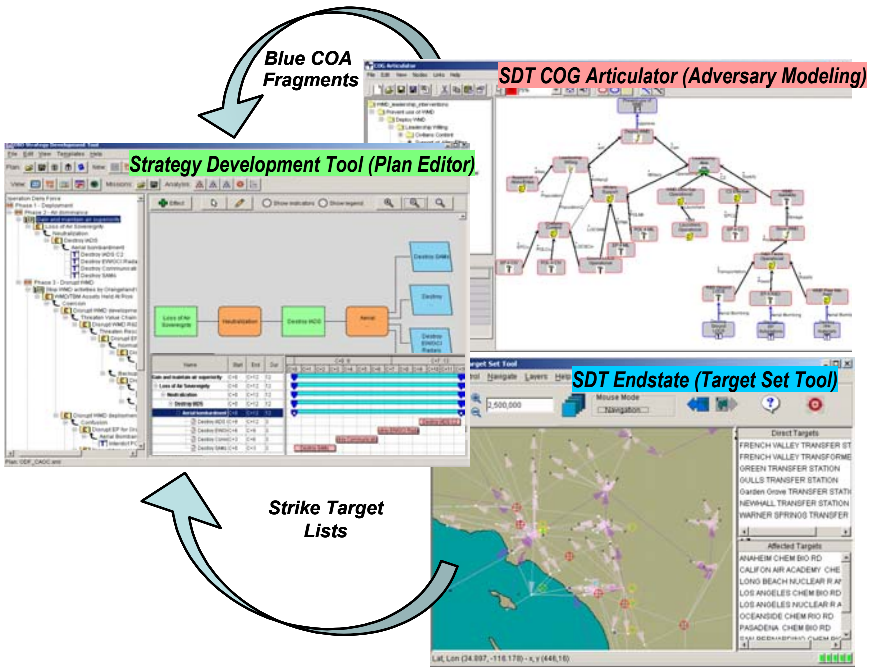

Figure 4: Strategy Development Tool

3.2 Causal Analysis Tool

As planners assemble the various COA options, the temporal reasoner and assessment functions within CAT will provide a priori assessment of the likelihood that the initial COA will achieve the desired effects. This tool uses Dynamic Bayesian Networks (DBNs) to determine the likelihood of a course of action obtaining the desired goal. The models within the tool allow the planner to describe causal relationships between actions and effects. Users can inject the probability of individual actions in the model over time and iteratively refine the model as necessary and compare different options. One of the advantages of CAT is the ease and speed at which models can be created, used for inference and modified if required.

A CAT model consists of a hierarchical graph of objectives, effects, tasks and indicators that are connected by causal linkages that describe how COA elements are causally related. The work area within the tool is broken down into two main sections, the plan layout area and the probability profile viewing window, shown in Figure 5. The user can easily draw the elements and causal links in the plan layout workspace within CAT. Probability profiles of several courses of action can be plotted on the same graph for comparison. The user can drill down into each of the elements and links to assess the COA at each level.

The DBN is used to estimate the states of the decisions over time. To start the process, leak, group and alone probabilities along with persistence and delay times are inserted into each of the actions. Leak probability is the likelihood that an event will occur due to outside causes. Group probability is when a number of causes work together more effectively than each working singularly. Alone probability is the likelihood that an action will cause an event with no other causes acting upon it. Temporal aspects are included by first entering the start time of the action followed by the persistence and delay. Persistence is how long the effect will last after it has been initially caused. Delay is the amount of time that it takes for the effect to occur after an action has been taken.

The Causal Analysis Tool can also perform an interactive analysis during execution to determine whether commander's intent is being met. The user must set the observation points within the evidence manager. This consists of the probability that the observation is true as well as the valid time window on each of the nodes in the plan and associated measures of effectiveness (MOE). The requests for evidence can be fulfilled by information gathered via sensor data or high level 'Intel' fusion. The next section will describe in greater detail the AFRL Fusion for Effects Based Operations (FEBO) tool which can semi-automatically fill the information requirements.

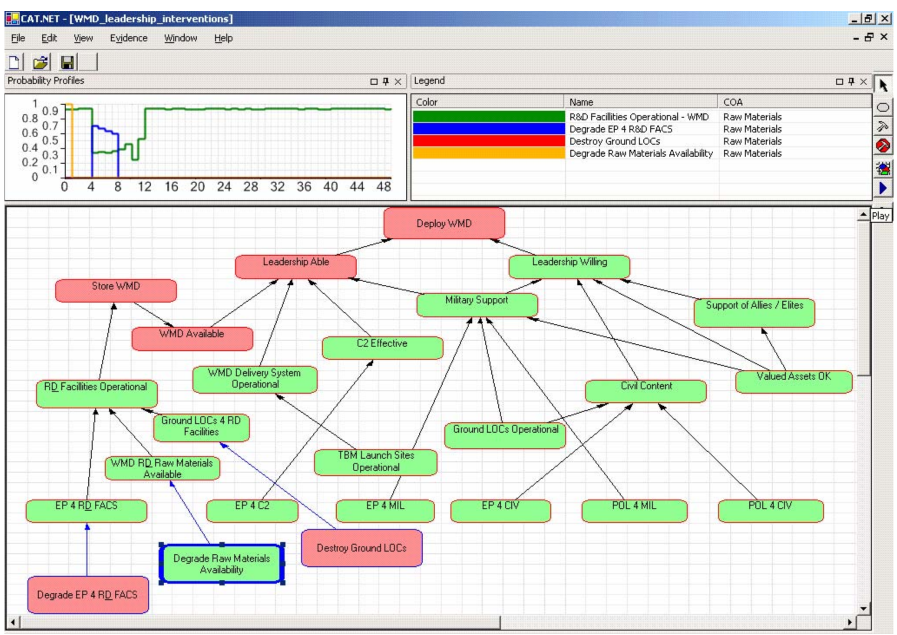

Figure 5: Causal Analysis Tool

3.3 Fusion for Effects Based Operations

Accurate analysis during execution requires information feeds which consist of both specific battle damage assessment and higher level information fusion across different intelligence systems. The FEBO system is designed to interact with strategy and assessment tools. The SDT tool will provide the fusion systems with an Extensible Markup Language (XML) based description of a strategy, indicators and MOEs. The fusion system will translate the indicators and MOEs into a set of information requirements for assessing the strategy. As can be seen in Figure 6, the SDT "destroy radar" indicator is decomposed by the fusion system into a number of measurable points which the various intelligence sources can address.

Gathering of information commences with the generation of necessary Intelligence, Surveillance and Reconnaissance (ISR) requests. As sensor data becomes available it is routed to the appropriate fusion engine for processing. Fusion of the data to answer the indicator requests will initially be done by selecting from a catalog of predefined models. Current work is focused on assessing multiple indicators associated with the integrated air defenses systems and weapons of mass destruction. As evidence is gathered it is provided to the Causal Analysis Tool for assessment.

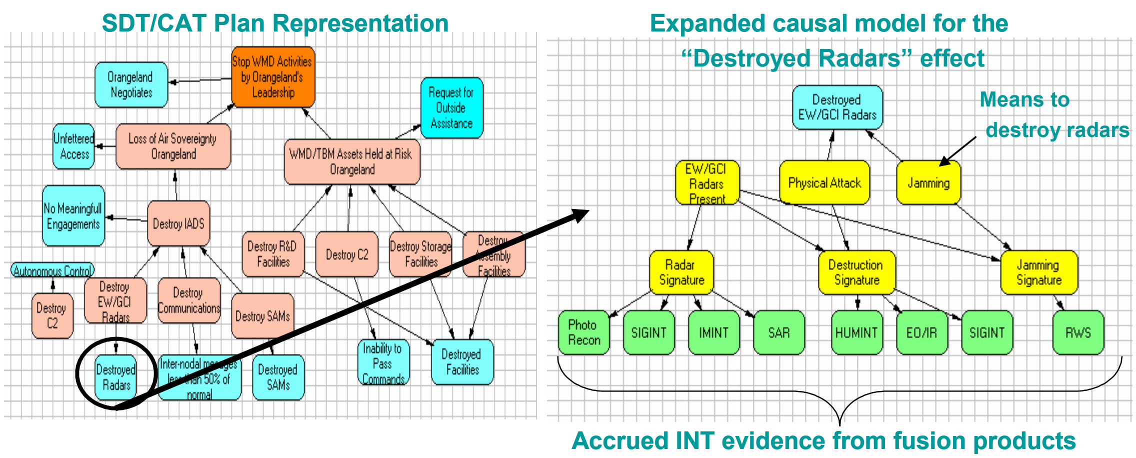

Figure 6: Fusion for Effect-Based Operation Information Decomposition

3.4 Effects Based Operations Wargaming Simulator

The Effects Based Operations Wargaming Simulator (EBOWS) is used for examining the utility and effectiveness of a number of different courses of action at the theater-level. The EBOWS tool can demonstrate the trade-offs between COAs based on a force-on-force engagement level wargaming construct. It differentiates between them in terms of time and materials necessary to achieve the goals and also the risks incurred during their execution.

The COA analysis and comparison phases within JP 3-30 are a key part of the process. These phases involve wargaming each COA against the adversary's most likely and most dangerous COAs. The EBOWS tool brings in knowledge of the adversary to assess the feasibility of each relative to friendly forces, available aircraft, munitions and locations of targets over time. The results of the simulation can be displayed in tabular form as well as by using comparison gauges as shown in Figure 7. The comparison gauges enable the users to quickly compare the relative merits of each course of action.

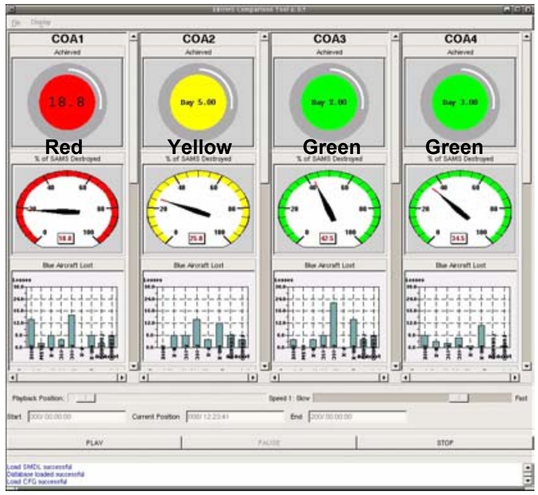

Figure 7: Effects Based Operations Wargaming Simulator Output

4.0 Warfighter Assessment and Technology Transition

The EBO tools are nearly ready to transition to the warfighters. The goal is to transition SDT and CAT as AOC Weapon Systems applications that are interoperable with the Theater Battle Management Core Systems (TBMCS) through web-based information management services. Before transition can occur, warfighter assessment and acceptance is required. AFRL has exercised the tools in a number of warfighter forums including an "EBO Workout", the Checkmate Strategy Conference and ultimately the Joint Expeditionary Force Experiment (JEFX) 2004.

The April 2003 EBO Workout was co-sponsored by ACC/XP and AFC2ISRC. The goal of the EBO Workout was to clearly define the capability required for an effects based integrated approach to strategy development for the JFACC and staff. Retired Lt Gen Heflebower led the strategy cell player team through the effects based planning process while observation and assessment teams documented player interactions. SDT and CAT were used by the observers to shadow the player team as they worked through developing commander's intent, course of action, effects, actions, and causal linkages. One of the lessons learned from the shadow play was the need for a tool to quickly capture notions of what the strategist believes Red is doing and how Blue can intervene. This led to the development of the COG Articulator.

The March 2004 Checkmate Strategy Conference was a three day event for air strategists to identify strategic challenges, exchange leading edge ideas and discuss the finer points of the operational art of war. It was hosted by the Pentagon's Checkmate office (AF/XOOC). Eighty nine select officers from the US Air Force, US Navy and the United Kingdom attended the conference. The core audience consisted of strategy cell leaders responsible for designing air and space strategy in support of combatant command campaign plans. Evaluation copies of SDT and CAT were provided to all attendees. Lessons learned from the feedback will be used to improve the tools.

The AFRL EBO/PBA initiative was selected for inclusion under the key PBA and EBO focus areas of JEFX 2004. During each of the spirals and the main experiment, operators within the AOC Strategy Cell will be using the EBO and PBA tools to work through the JP 3-30 process. Assessors will be examining each step of the operational process along with how the various tools perform each of the functions. Assessor evaluations and 8th Air Force feedback is being used to improve the functionality of the tools.

JEFX 04 will focus heavily on machine-to-machine interaction and the availability of information across the different divisions of the AOC. In addition to the functions outlined above, for JEFX SDT will pull adversarial information from the Automated Assistance with Intelligence Preparation of the Battlespace (A2IPB) tool to facilitate plan development. The A2IPB information will consist of named areas of interest, targeted areas of interest and Red COAs. The objectives, tasks and effects developed by SDT will be passed to the new Strategy Management Service which is part of TBMCS. Once in the strategy repository, the information can be shared with other tools such as the Joint Targeting Toolbox and Information Warfare Planning Capability (IWPC) or viewed by the Strategy Planning Tool. As a result of our participation in JEFX 04, many valuable lessons learned are being obtained which will have a positive influence on the future interaction of our tools and technologies.

5.0 Technology Challenges Associated with EBO Tool Development

The Joint Air Tasking Cycle culminates in the development of an Air Tasking Order (ATO). Planning for the daily ATO normally commences 48 hours prior to its execution. In practice, a 72 hour cycle is used with 3 ATOs in various stages of progress at any given time. A 24 hour period for execution is allocated per daily air tasking order. Shortening the 72 hour cycle and a more dynamic and continuous ATO are commonly discussed as means to make air operations faster and more effective. In reality, the 72 hour cycle with thousands of sorties per day works very well and doesn't include extraneous events and activities that can be compressed. However, as illustrated in Figure 8, improvements to the Joint Air Tasking Cycle can be achieved with a built-in continuous effects based assessment and execution cycle, dynamic re-planning, a dynamic time sensitive targeting process and a more fluid "streaming ATO". The following is a discussion of the research challenges associated with developing a more dynamic and continuous effects based COA development, execution and assessment process within the Air Operations Center.

SDT provides the means to record mission analysis. Advanced methods could be developed to automatically parse commander's intent and rapidly extract the tasks and other useful information for mission analysis. The product of mission analysis is a mission statement which explains the JFACC's understanding of the guidance and plans for proceeding with the air campaign. Templates for mission analysis can be developed to provide a starting point for the JFACC and staff.

SDT does an adequate job of assisting the user with COA authoring. It provides a limited adversarial / target system analysis capability to drive Blue COA development. A growing library of strategy and mission templates is also available. Case Based Reasoning (CBR) could be a useful technique to optimize use of the templates. This technique could automatically match attributes from the current operation with data that describes the strategy and mission templates within the library (casebase) of templates. CBR employs what is known as similarity matching to help choose the most appropriate stored entity for re-use, here the entity being a COA, or partial COA.

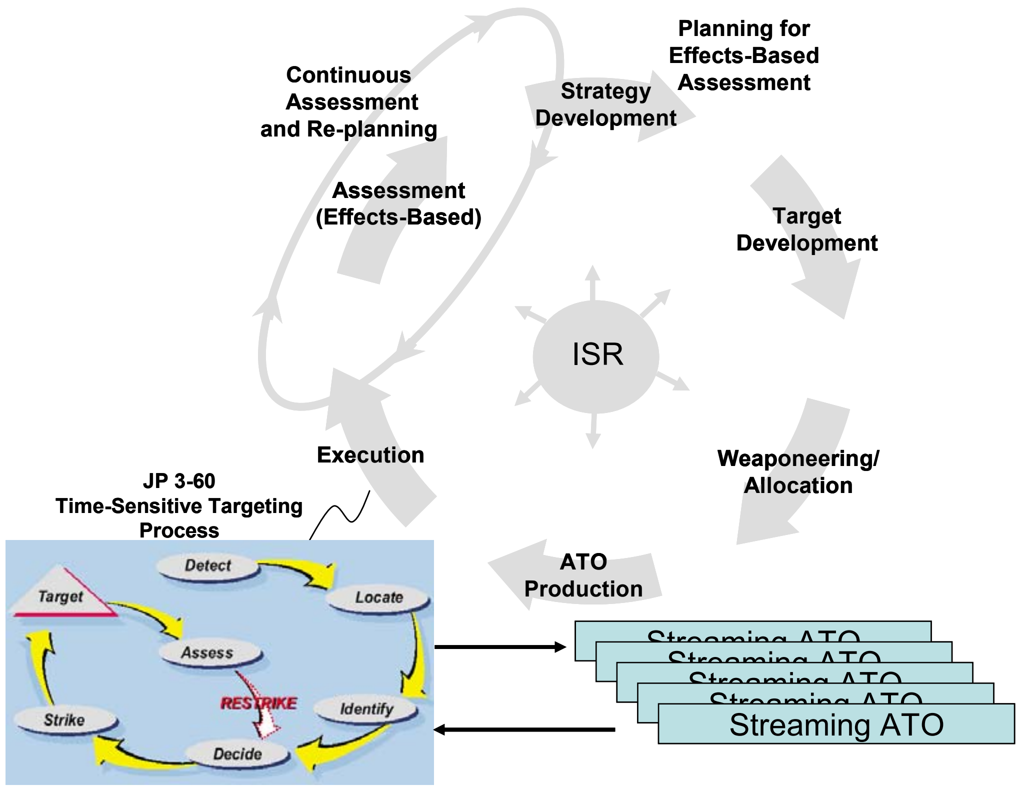

Figure 8: A More Dynamic and Continuous Effects Based Joint Air Tasking Cycle

Results of similarity matching would be presented to the user in priority order for developing a new COA. Also, each time a user creates a new COA or template, they would save it to the casebase so that it is available for use in the future.

Representation and quantification of uncertainty for COA analysis is an area that warrants further investigation. How certain can the strategist be that an action and causal link will lead to a desired effect? One can be relatively confident when estimating the causal relationships from action to physical desired effects, such as destroy. Non-physical, behavioral, indirect effects such as coercion are very difficult to determine and predict. True effects based analysis is highly dependent on adversarial modeling. A grand challenge in the EBO arena is to develop methods that predict how physical actions can lead to behavioral responses on the part of an adversary. As Ed Smith stated in his recent book on EBO [13], "EBO focuses on shaping the adversary's thinking and behavior rather than on simply defeating his forces." So how is it that we can predict and shape what is and what will be in the hearts and minds of our adversaries? A number of research initiatives are underway in the area of adversarial behavioral modeling. Some of the approaches include synthetic cognitive modeling, empirical modeling based on extrapolation of past behavior, empirical modeling based on culture studies, applying complex adaptive system theory and emergent behavior principles, and probabilistic approaches such as Bayesian Networks [5]. A sound approach to behavioral modeling including methods to estimate the uncertainty of action-effect pairs is needed to guide the strategist in structuring effects based plans that will shape the adversary.

COA analysis also involves wargaming each COA against the adversary's most likely and most dangerous COAs [7]. EBO requires real or near real-time operational level wargaming of Blue versus Red COA. A robust, computerized, operational level wargaming tool that can be used in an AOC to help refine COAs is needed. This tool would take Blue COA options such as those generated by SDT and wargame them against Red options generated from some IPB tool or process. Today, COA versus COA wargaming, if done at all, is done on paper using situation and event templates. Most computerized wargaming tools have a force-on-force, target-attrition emphasis. Though they do support and analyze higher level objectives such as *establish air supremacy*, *defeat warfighting forces*, or *disrupt enemy leadership*; they are not adequate to satisfy all EBO wargaming requirements [9].

COG Analysis and Target System Analysis (TSA) are necessary to plan for effects based targeting and require a focus on inter- and intra-dependencies. The strategist needs to be able to trace physical and behavioral effects of various actions throughout the enemy system to understand and plan for effects to take place. A number of constructs exist for defining and modeling enemy COG structures. These include the work of Warden [15], Barlow [2], Strange [14], and the US Joint Force Command's PMESII (Political, Military, Economic, Social, Infrastructure, and Information) developers. Physical system modeling capabilities exist only for individual COGs and Target Systems and focus on how to best destroy or disable them. What is needed is a general purpose tool that can guide the strategist to utilize the constructs listed above in a way that defines what COGs and TSAs should be targeted based on their contribution to achieving direct, indirect, physical and behavioral effects. AFRL has a number of R&D activities underway in this area as mentioned previously.

Once COAs are developed and transitioned into a Joint Air Operations Plan, targets are developed, weaponeered, and ultimately executed as part of the daily Air Tasking Order. An ATO capability is needed that responds to changing execution circumstances or unexpected execution results. The notion of continuous "streaming" ATO cycles, where a number of ATOs are worked in parallel, has been the focus of recent discussions. Due to the nature of time sensitive targets and uncertainty of changing scenarios, there exists a need to develop a streaming ATO that is capabilities-based and stands ready to assign assets to targets in a dynamic environment. The concept of a more fluid "streaming" ATO, working hand-in-hand with near real-time information feeds from distributed networked sensors could lead to a much more dynamic and continuous air tasking order cycle.

When execution commences, effects based assessment needs to take place continuously to determine if the plan is achieving the intended effects or if re-planning is necessary. Presently, combat assessment is conducted to determine if re-attack is necessary in order to destroy targets. A number of R&D tasks are required to support the continuous assessment and re-planning loop depicted in Figure 8 above. When planning for assessment, appropriate indicators and measures of effectiveness have to be specified. A taxonomy of indicators with an intelligent wizard based on case based reasoning or other means should be explored. The CAT development team is researching various evidence accrual algorithms that will take in evidence and determine the new likelihood of COA success. Further research is required to accurately determine which pieces of information to fuse to provide this evidence.

In addition to the challenges related to making the Air Tasking Cycle more effects based and dynamic, a number of other challenges exist in the EBO area. Determining if and how EBO can be applied to countering the asymmetric and all too real threat of terrorism is a topic for research. The use of Net Centric Warfare as an enabler for EBO also needs to be investigated, given its key components of information tools, sensors and communications. [13].

6.0 Summary

There are many benefits to effects based operations and effects based course of action development, including economy of force, reduced collateral damage, prediction of campaign success, and effects based ISR planning. A suite of automated capabilities for planning, executing and assessing EBO is required in order to fully realize the benefits. The tools discussed in this paper mark the beginning of a long road ahead. While significant progress was made towards an initial warfighter capability, a good deal of research and development is still required to meet the vision of a fully computerized and dynamic EBO process. In addition to the tools and technology, the process of EBO is also in its infancy. This poses an interesting and at times daunting challenge for technology developers. Technologists must continue to address the scientific underpinnings of EBO such as behavioral modeling and uncertainty during planning. As warfighters continue to experiment with the EBO process and associated tools, both will continue to mature significantly. AFRL is striving to address the future technical challenges and will continue to do so with a warfighter-focused approach.

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