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Effects-Based Operations: A historical perspective for a Way Ahead[1]

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Abstract

Since the Gulf War, there has been a technology-driven rapid enhancement of military capabilities across a spectrum of disciplines. At the same time, the concept of Effects Based Operations (EBO) has been evolving and gaining acceptance as a better way of thinking about military planning, execution, and assessment. In this paper, we review what the research and development community has done to support this change. We investigate methods, tools and techniques that have been developed to enable the warfighters in the theater and the civilian and military leadership to analyze the complex situations, determine desired effects, and develop alternative courses of action that can be compared and evaluated. Our purpose is to focus on the directions that the R&D community should take to provide this needed capability to the operator. This is, unfortunately, a case of the R&D community not leading, but trying to catch up to the operator's needs.

1. Introduction

During and after the end of the first Gulf War, stories circulated about a different way of planning and evaluating missions. Col Dave A. Deptula (now Maj Gen) wrote an early working paper [4], widely briefed, in which he described the basic ideas of what is now called "effects based operations". In early 1999, a formal brief within the Air Staff defined Effects Based Operations. The term appeared also in the Global war game at the Naval War College in 1999, but actual attempts to incorporate that approach in the course of action (COA) development, in planning and in evaluation did not take place until Global 2000 and 2001. The other word that became closely associated with EBO is capabilities. Both terms raise the whole issue at a higher level of abstraction: from targets and weapons on targets to effects and capabilities needed to achieve the desired effects.

After this slow beginning, both terms are now major drivers of DOD transformation. Gen. John Jumper, the Chief of Staff of the Air Force, has taken desired effects and the capabilities for achieving these affects as the cornerstones for transforming the Air Force. Indeed, recent military actions from Bosnia, Kosovo, Afghanistan, to Iraq illustrate clearly the focus on achieving

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effects, or outcomes, and not simply on the means, or the weapons and platforms, or the targets these platforms attack. For some, effects-based operations (EBO) constitutes a new strategy option for commanders; for others EBO reflects a method of achieving strategic objectives that is richer in informational content than traditional targets-based, or even objectives-based approaches.

Many writers [3, 10, 13, 15] agree that EBO is not a totally new concept. Good military leaders and statesmen have always focused on actions that will cause the adversary to think and act in desired ways. Of course, in war, this may include defeating the adversary's forces, but it can also include many other actions across the political, social, economic, and military domains. One piece of EBO, then, is the close link between COA development and analysis with Intelligence Preparation of the Battlespace (IPB). It is also recognized that not only must we concentrate on the adversary, we must also work to shape the attitudes and behaviors of allies and neutrals, sometimes on a global scale. This driving factor means that classic IPB must expand to include the analysis done across many agencies and indeed nongovernmental and private organizations. These concepts span the levels of conflict from peace, to crisis, to war, to restoration of peace. A primary advantage of an effects-based approach to COA development and analysis is reducing the uncertainty of plans by better prediction of the anticipated outcomes from the execution of those plans. This is accomplished by building a causal model that explicitly expresses the causal linkage between action and effect. Some call that causal linkage 'mechanism,' or the explanation of why the predicted action planned will result in the planned effect.

As EBO concepts evolved, the different services began developing their own set of definitions. The Air Force EBO CONOPS [1] defines it as a method for planning, executing and assessing operations to attain the effects required to achieve desired national security objectives. (AFDD 1) The Joint Forces Command developed its own CONOPS for EBO and has tested these principles in experiments and exercises. Smith, in his recent book [13], defines Effects Based Operations as coordinated sets of actions directed at shaping the behavior of friend, foes, and neutrals in peace, crisis, and war.

The ability to employ the EBO concept has been enhanced by the rapid advancement of technology as well as new organizational constructs within the military and across other government departments. The advances in information technology, weapons with precision attack capabilities, intelligence, reconnaissance, and surveillance systems that provide accurate location of targets, and stealth technology that greatly reduces the requirement of defensive support systems to protect striking weapons, enables selective components of adversary systems to be struck with precision to achieve desired effects with minimum risk and destruction. Non-lethal actions also contribute to overall effects. We have the ability to consider alternatives to the concept of maximum destruction attrition warfare. By focusing on the overall effects needed to achieve objectives and considering a spectrum of lethal and non-lethal actions, COAs can be formulated that use precision intelligence and strike capabilities to inflict the minimum collateral damage while achieving objectives. To do this, one must understand and develop a set of effects that, if achieved, will result in the overall objectives and then determine the best set of actions to take, *along with their timing*, to achieve those effects. In modern coalition operations, such actions include not only traditional military attrition based operations, but a spectrum of actions across all the instruments of national power employed by coalition partners to influence and

persuade an adversary to change his behavior and at the same time maintaining cohesion within the coalition.

These concepts evolved over the past decade and were refined in both the research and development and the operational warfighting community. It is easy to point to the new weapons systems (both lethal and non-lethal), sensor capabilities, networks, and knowledge management capabilities that enabled many aspects of effects based operations. The operators responded by putting these capabilities together in new ways and coordinating them in unprecedented ways to achieve the effects and objectives at hand. A tougher challenge is to provide methods, tools and techniques to enhance the capabilities of warfighters in the theater and the civilian and military leadership in analyzing the complex situations, determining desired effects and developing alternative courses of action that can be compared and evaluated to support planning, execution and assessment.

It is the purpose of this paper to focus on the directions that the R&D community should take to provide this needed capability to the operator. Our approach is first to look backwards, to the developments that have already taken place over the past decade. Indeed, in doing so, we see that in some ways the R&D community led the efforts to define and refine Effects Based thinking. But the operators also tested and refined new concepts, procedures, and processes that embrace the effects based approach to the command and control of resources. They succeeded in employing their resources using an effects based approach without many of the potential modeling and analysis tools and techniques that the R&D community is trying to develop. To accomplish our goal of providing direction for the future R&D efforts, we first look back in Section 2 at several developments and extract the key and relevant features of those developments. In Section 3, we examine briefly the operational concepts that are evolving in experiments and wargames and state some of the lessons that have been noted. Finally, in Section 4, we combine the two areas and provide a framework for guiding future R&D efforts to provide the full capability to employ effects based command and control.

2. The Evolution of Technology to Support Effects Based Operations

This section examines three technologies developed over the past decade; the first two developed for reasons rather different than an effects-based approach to military operations. The first is the influence net approach that evolved out of the need to assess socio-political influence strategies. It turns out that the concepts used to solve that problem apply directly to the problem of effects based operations. The second development is the use of architecting techniques including the use of executable models to relate stimuli to reactions in the decision making/command and control system of an adversary. The third is the merging of these two techniques into causal analysis tools for course of action (COA) development and evaluation.

In 1994, DARPA funded a project for the development of a modeling tool for the assessment of socio-political influences on potential adversaries. The objective was to extract empirical expertise and knowledge about adversaries and place it in an analytical framework. Within this framework, influence strategies and their operational implementation could be examined. This tool, SIAM, was developed at SAIC by a team led by Julie Rosen and Wayne Smith [11]. As Rosen and Smith analyzed the requirements for their tool, they decided that it must possess at least four characteristics. The first was that it must be model based. Building such models would require elicitation of knowledge from different communities of expertise, each with its own definitions and vocabulary. Thus, the tool would need to foster a collaborative approach to

model building, and the model would have to facilitate communication among the domain experts. The second characteristic was that two approaches were generally used to perform this type of analysis. The first approach was the seminar workshop in which subject matter experts would discuss and debate attributes of the situation and possible adversary courses of action and responses to blue actions. The second approach was more mathematical, where computer based models and simulations were used to attempt to estimate current and future states of "physics based" systems. Both techniques are unlikely to yield accurate predictions of an adversary's reaction to actions taken. However, approaches using probabilistic reasoning such as Bayesian nets could be useful in analyzing complex cause and effects relationships. The third characteristic was that while many of the subject matter experts may appreciate that Bayesian approaches and probability theory are a useful approach to assessing the impact of complex cause and effect relationships, they did not have the experience needed to use the available Bayesian tools. Furthermore, even those users with such knowledge and expertise did not have the resources or information needed to define complete conditional probability transition matrices. Finally, it was clear that the modeling technique must provide an intuitive understanding of the complex interaction of cause and effect relationships to decision makers who would select courses of action based on the analysis.

Based on these characteristics, Rosen and Smith determined that the technique for analyzing causal relations of complex situations required a tool that provided a graphical method of model construction and a foundation in Bayesian mathematics for rigorous analysis of the models. To address these needs Rosen and Smith introduced influence nets by combining some ideas from Bayesian Nets [7] and from Influence Diagrams. [6] The Influence Diagrams fostered the concept of the graphical influence net topology. An influence net is a graph, composed of rectangular nodes and directed arcs between nodes. The domain experts create these influence nodes and inscribe text in each that defines an influencing event or proposition that is part of a cause and effect relationship. The analyst also creates influence links between cause and effect nodes that graphically illustrate the causal relationship between a pair of events. The causal relationship can be either promoting or inhibiting. A promoting relationship is one in which an increase in the likelihood of a cause will also increase the likelihood of the effect occurring while an inhibiting relationship means that an increase in the likelihood of the cause will decrease the likelihood of the effect. The type of relationship, promoting or inhibiting, is illustrated graphically by the use of the terminator on the link. An arrow head means the relationship is promoting and a ball means the relationship is inhibiting. Figure 1 illustrates this

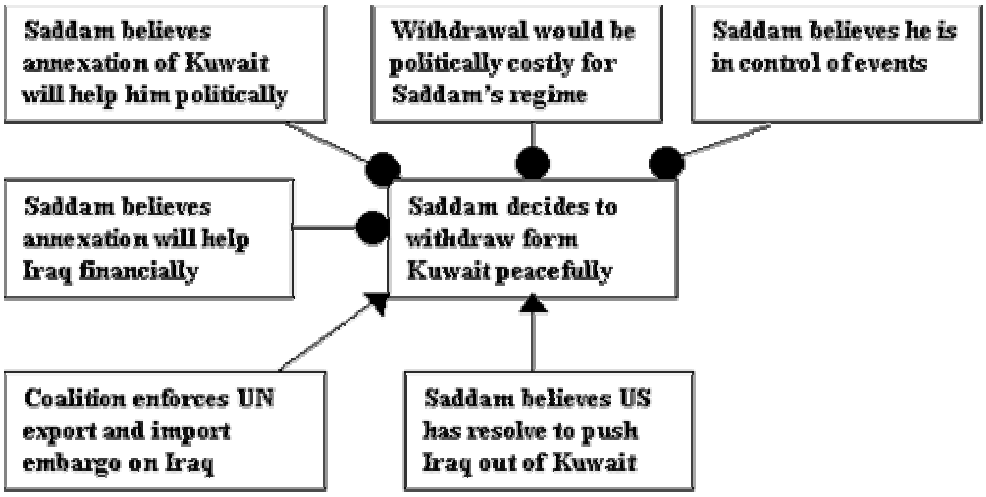

Figure 1. Influence Net Topology

influence net topology. This graphical depiction of complex cause and effect relationships was deemed to be effectively intuitive and could be created collaboratively enabling different aspects (military, political, religious, etc.) to be integrated into one model.

The influence net graphical representation contains a lot of information that can be mapped to textual descriptions of cause and effect relationships in situations, however it is a static representation. By incorporating an underlying Bayesian mathematical model, it could be the interface for rigorous causal analysis. To do this, additional information would have to be provided by the domain experts. The traditional method for creating a Bayesian network requires that analysis provide a set of conditional probability values for each node that has one or more parents. This can be challenging, particularly if a node has several parents. Because of the difficulty in obtaining these values, Rosen and Smith incorporated an algorithm developed by K C Chang et al. at GMU [2] that required the analyst to specify only two parameter values for each influencing link. The domain expert expresses the "strength" of the relationship to indicate if the cause is true what the impact on the effect will be and also if the cause is false what the impact will be. The algorithm then converts these assessments into an estimate of the complete set of conditional probabilities. Thus, the experts are asked to provide a relatively small number of value assignments that gets expanded into the full Bayesian model.

Once the topology of the model is created and the influencing strengths are provided, the underlying Bayesian model can be executed to indicate the probability values of all the nodes in the net given that probability values have been selected for the input nodes of the model. The input nodes, which are nodes with no parents, generally represent actionable events that are candidates for actions in an influencing strategy. The graphical interface to the analytical model included a simple form with slider bars to input the influencing strength parameter values and a color scheme to indicate the probability of the events represented by the nodes in the model. Thus the domain experts and decision makers could observe not only the structure or topology of the logic involved in relating actions to effects, but could also see the consequences of taking sets of actions on those effects. SAIC added several analysis routines to the tool that allowed analysts to determine the sub set of actionable events that gave the best opportunity for having the desired "effect" event occur.

The SIAM tool has evolved a lot since 1995 and is used for a variety of applications. Most of these applications address National and Military Strategic questions and focus on the perception and behavior aspects of the subjects (countries, adversaries, regimes, etc.) of the investigation. But the fundamental concepts of the influence net modeling are at the heart of tool development for EBO. Needed is a modeling technique that can be done collaboratively, that explains how actions will cause effects, and can be understood by both domain experts and decision makers. We will return to these characteristics in Section 4.

Soon after the first version of the SIAM tool was released, the Air Force Information Warfare Center began looking for tools to help assess alternative courses of action for information operations. The GMU team developed a modeling approach based on the system engineering techniques for designing and evaluating information system architectures. This architecting approach was used to design DOD C4ISR architectures. The concept was that if enough information was available, an architectural model of an adversary's command and control and decision making processes could be created and evaluated based on the actions that Blue forces would take that would stimulate the Red C4I system and cause it to generate certain responses. The modeling and analysis techniques were well established. Either structured analysis or object

oriented modeling techniques could be used to analyze the adversary C4I system. The information contained in that description was converted to an executable model, a Colored Petri Net for logical and behavioral analysis. The set of actions and their sequence comprised alternative COAs, and the executable model provides the outcomes (reaction of the C4I system) for each alternative courses of action.

As a proof of the concept, a scenario was devised in 1996 that included the hypothetical nation of Witmania that had weapons of mass destruction (WMD) and sponsored terrorism. The objective was to formulate an offensive information operations COA that would cause Witmania to array its defenses in such a way as to enable a surgical military strike against the WMD facilities without having to penetrate air defenses. While it was not phrased this way at the time, the effect that we were trying to achieve was to get the adversary to change the location of some of its key units. Using surrogate intelligence analysts, information was gathered to enable an object oriented approach to building an architecture of the Witmanian C2 process. A Class Diagram, including classes with attributes and operations and relationships between classes, was created. An abstract view of the Class diagram is shown in Figure 2. An activity model was created to show the interactions between classes and their operations. Rules were formulated to specify each of the operations. From these static models, a Colored Petri Net model was synthesized. Figure 3 is the top level page of the Colored Petri Net. The inputs for the executable model were initial conditions that represented different elements of potential COAs. After trying various combinations of actions, a set of actions was found that would cause the Witmanian C2 process to change the location of its defensive forces in a manner that was favorable to the objectives of the Blue forces. The results were presented in the form of a tactical map showing the location of Witmanian forces and facilities before the information operation COA was

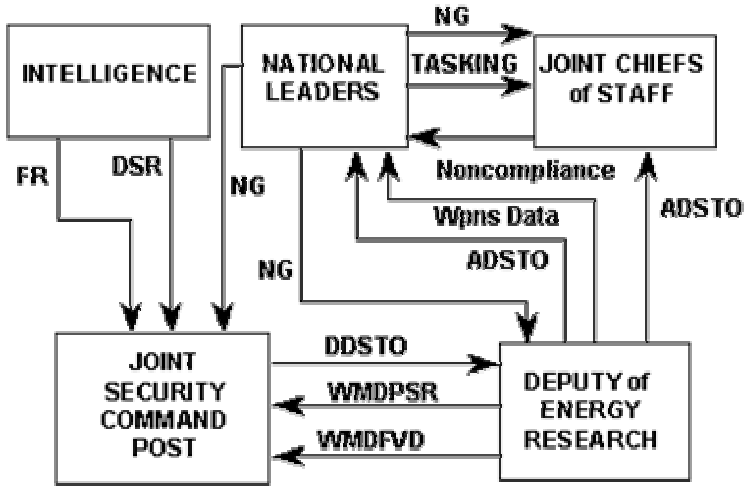

Figure 2. High Level Class Model of the Witmanian C2 Process

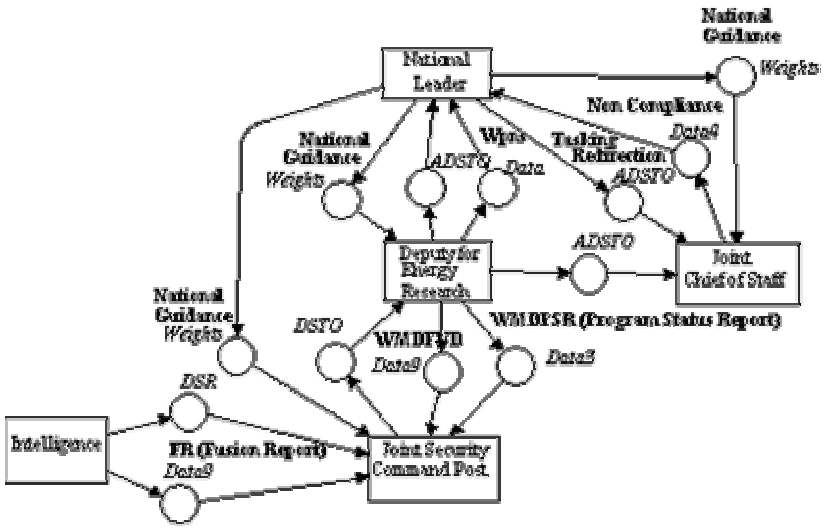

Figure 3. Colored Petri Net Model

implemented and the changed locations after the COA was executed (Figure 4).

It should be noted that the temporal analysis of the Colored Petri Net was not exploited for this demonstration. More information about the processing and decision making timing would have been required to include temporal information in the model. However, it was recognized that adding the timing information would have enabled the analysts to observe the impact of the timing of the actions in the alternative COAs. Such timing analysis could indicate critical windows of vulnerability and opportunity that could not be determined from the untimed model.

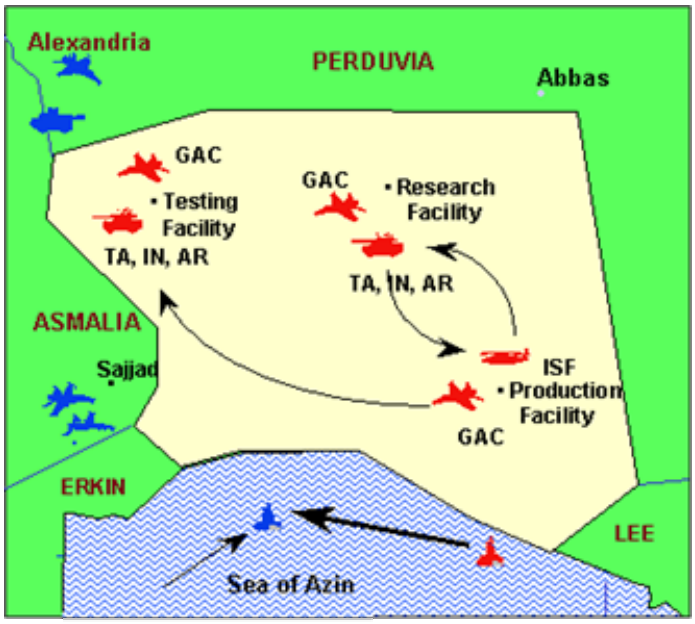

Figure 4 Effect of IO COA on Witmania

While the approach showed promise, it was clear that it required a great deal of knowledge about the procedures the adversary uses and how the adversary makes decisions. It was postulated that in many cases this level of detail would not be available. In addition, the process of building the set of models that comprise the architecture and converting them to the executable model was labor intensive and time consuming.

Because of the collaboration with SAIC on the SIAM model, it was proposed to AFRL that SIAM be used as the front end to the development of the model and the selection of the actionable events. The influence net contains a more generalized view of the situation and can take into account the uncertainty associated with the decision making processes that the adversary uses. With its Bayesian mathematical analysis engine, it can be used to select the combinations of actionable events that give acceptable level of probability of achieving desired effects. After building and analyzing the influence net model, it would be converted to an executable model in Colored Petri Nets as we had done with the static architecture based models of the adversary. The latter would be used to simulate alternative courses of action. Initially the conversion of the influence net of the Colored Petri net was done by hand. Later, an algorithm was formulated that made the conversion process automatic and therefore transparent to the user.

The conversion of the influence net to the Colored Petri Net provided an added dimension to the analysis of alternative COAs. Instead of just determining which set of actions contribute the most to achieving the desired effects, one could visualize the impact of the timing of the actions in the COA on the effect over time. We moved from evaluation based on static equilibrium models to the temporal analysis of a dynamical system. It became much clearer that the timing of some actions is critical in achieving success. Of course, this type of analysis requires additional information for the model. We need to add estimates of the communications and information processing delays of the adversary as actions unfold over time. We also need to know what are the timing constraints on the actions being evaluated.

The approach proved successful and over the next six years, step by step, the tools were improved and the resulting software system, CAESAR II/COA, was used for the development and evaluation of courses of action. Much of this work has been reported in a series of papers in CCRTS. [15]

In the Spring of 1999, when the call started being heard for effects based operations, it became apparent that these tools could be used not only to address socio-political and information operations, but also to encompass military actions. An enhanced version of the software, CAESAR II/EB, was created and applied to this class of problems. This version had a new architecture in that the executable model was placed behind a browser interface eliminating the view of the Colored Petri Net for the analysts. Instead, analysts would interact with the Colored Petri Net via a series of forms in a browser, and the server-based executable model would run behind the scenes and provide probability profiles to the analyst as pop-up windows in the browser. The architecture enabled an analyst to access influence net models in executable form from anywhere the analyst had access to the network.

In parallel with the CAESAR II/EB developments, at AFRL/IF, John Lemmer and Maris "Buster" McCrabb were developing a new tool, the Causal Analysis Tool (CAT), that was based on Bayesian networks for use in campaign assessment. The initial version of CAT contained a graphic user interface to build models of situations in a fashion that was similar to SIAM. However, the tool used a different method of obtaining the conditional probability values from partial information provided by the analysts. In addition, CAT had some new features that made it more attractive for use in effects based operations planning. A collaborative effort between AFRL/IF and GMU led to the inclusion in CAT of the influence net algorithms developed by GMU. In addition, a version of CAT was incorporated in CAESAR II/EB.

In 2001, the Air Force Research Lab/IF division at Rome, N.Y. began its Effects Based Operations Advance Technology Demonstration (EBO ATD). The objective was to develop and integrate a set of technologies to support Effects Based Operations for Air Components. Several contracts were awarded to create the various "pieces" of an overall capability. A series of demonstrations are planned over the three-year period of the ATD. This ATD is designed to demonstrate to users the capability to plan, execute, and assess air campaigns using the EBO construct. Successful demonstration should lead to full scale development of the systems to support EBO. The target system is the Air Operations Center, so this ATD is focused primarily on the operational level.

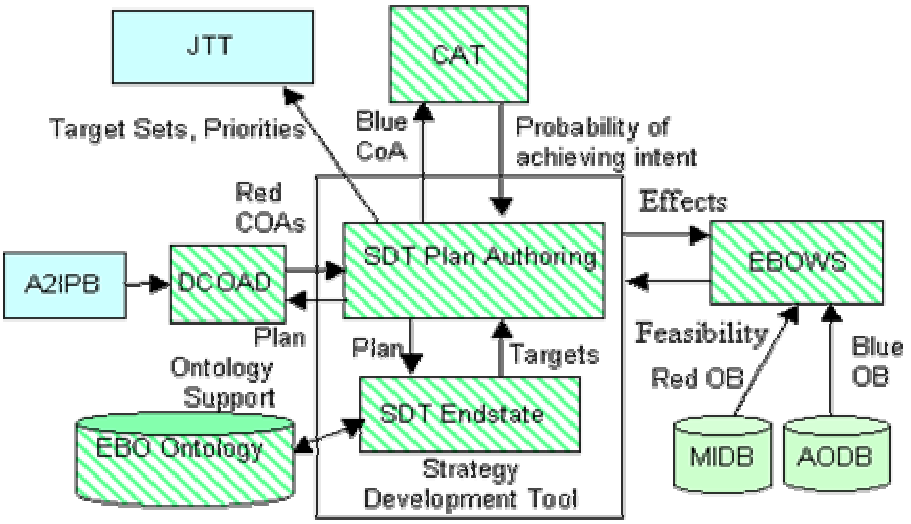

Figure 5. AFRL EBO ACTD

Figure 5 shows the components of the ATD and interactions between them. The main components include the CAT tool, a Strategy Development Tool (SDT), an Effects Based Operations Wargaming System (EBOWS) and the DCOAD (Dynamic COA Decision aide). The CAT tool provides the modeling and analysis capability developed and demonstrated with CAESAR II/EB. It provides the gauge for measuring the effectiveness of alternative COAs. The COAs are fleshed out in more detail using the SDT that is composed of two components, a COA authoring piece, and a target systems analysis piece. It is with the SDT that the actions defined in the COA are converted into timed plans. The timing of the plans involves determining resources and their constraints to carry out the actions. It also incorporates a more detailed analysis of the target systems that make up Centers of Gravity. Candidate plans are evaluated using the wargaming capabilities of EBOWS. The final plans are provided to the Joint Targeting Toolkit (JTT) for detailed targeteering and then to detailed resource allocation tools to do the final target-weapon-platform pairings.

Up to this point, the R&D community evolved a procedure for creating a model of a situation in which uncertainty plays an important role, and that can be used to develop, analyze, and select a course of action, defined as a timed set of actionable events designed to achieve an overall effect or objective. We had developed a set of tools and techniques that support this COA evaluation and selection process. The next challenge was to determine how to incorporate these techniques into existing, real world command and control environments. The research that developed the concept for modeling model-based development and evaluation of Courses of Action (COA) and a suite of tools to support these concepts was accomplished without testing the concept and tool suite in a realistic environment. While realistic models were created to test the concepts, the use of the tool suite within a working command and control structure had only been postulated. The goal was to the use the war gaming experiences to formulate operational concepts from which operational and system architecture views could be developed to guide the development of future systems that support EBO analysis.

As has been described in past CCRTS [15] GMU had the opportunity to use the CAESAR II/EB in Global 2000, 2001, and Millennium Challenge 2002. In addition, an enhanced version of CAT was used by the Air Force Studies and Analysis Agency (AFSAA) in support of more current issues. These operational experiences taught us a great deal about the nature of EBO. One overall observation is that while EBO is highly desirable, it is a complex undertaking.

3. Lessons Observed Toward a Way Ahead

These past efforts taught us a lot about the possibilities of this approach and of its limitations. There is a host of challenges that the R&D and analytic [3] communities need to address to bring suitable, useful tools to the hands of planners and operators in command centers who have to trade off hard and soft kills, choose a proper mix of kinetic and non-kinetic weapons, and of course embed military action in the context of political, diplomatic, and social actions. Furthermore, there are technical issues associated with the temporal aspects of effects based operations – latencies between causes and effects and latencies in observing the effect itself.

To try and set a course for future R&D efforts, we look to three areas. The first is the observations that we derived from our experience in developing the technology and from the participation in wargames and experiments. We also turn to a new CCRP book on the subject by Dr. Edward Smith [13] that provides insight into the needs of the operational community.

As the R&D community developed the CAESAR II/EB and CAT technology, several technical issues have yet to be solved. These include issues with the temporal aspects of the models, the analysis techniques that can be applied to the models, and the interaction and exchanges between different modeling disciplines.

As describe in Section 2, an algorithm was implemented in CAESAR II/COA (Wagenhals et al., 1998) that converts an influence net into a discrete event dynamical system. The particular mathematical model used is that of Colored Petri Nets and its software implementation in Design/CPN (Jensen, 1997). The nodes in the Influence net become transitions in the Petri Net and the places hold tokens that carry the marginal and conditional probability values. Since the Influence net does not contain temporal information, it must be provided as an input to the Petri Net.

In general, there are four types of temporal information associated with the Petri Net representation of the Influence net; one associated with the input scenario and three with the model itself.

The input scenario can be described in terms of the actions in the Course of Action (COA) and the time at which these actions occur. The actions are modeled as events, which means that they occur instantaneously. An action can be repeated an arbitrary number of times (e.g., re-target a particular physical asset on a periodic basis to undo repairs – as is the case with air strips or bridges). An example of a COA scenario is shown in Figure 6.

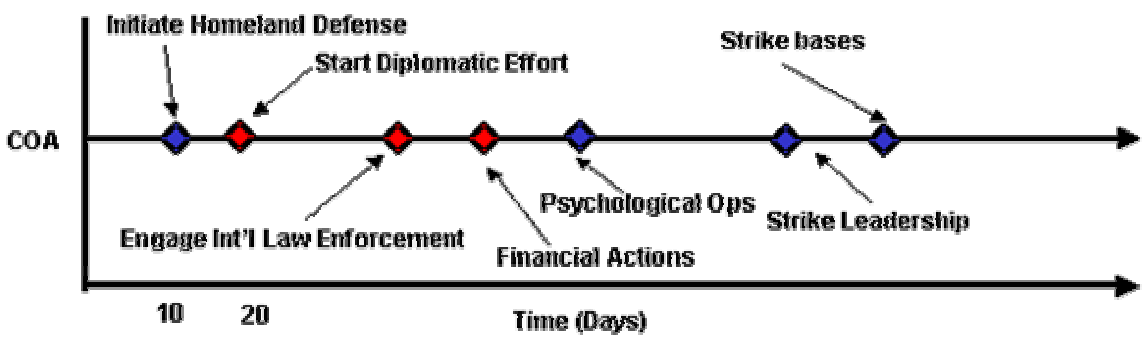

Figure. 6 A COA example: Time-phased sequence of actions

Because influence nets assume the independence of causal influences, it is possible to associate time with the arcs of the influence net. These times represent the amount of time it takes for knowledge about a change in the status of any variable to be propagated by some real world phenomenon to the node that is affected by that change. Thus, we associated time delays with the arcs representing the influence in the influence net. The update in the marginal probability of a node occurs immediately after the time delay. This is the second type of temporal information and the only type currently implemented in CPN. (Associating time delays with nodes instead of or in addition to time delays associated with arcs is only a variant and does not require a different type of temporal information.)

The third type of temporal information that can be used is the *duration* of an action. For example, the implication of the COA events in Figure 6 is that we initiate Homeland Defense ten days after time 0, but we maintain it from then on. One may think of it as a step input occurring

at time t = 10. However, we may decide to initiate psychological operations on day 20 and maintain them for 50 days or until the air campaign starts. This type of input needs two pieces of temporal information: the initial time and the final time, or the initial time and its duration. The underlying model is that of a pulse. At this time, the problem is being explored using temporal logic (Zaidi and Levis, 2002).

The fourth type of temporal information is sometimes referred to as *persistence*. This is the time interval over which an effect is manifested. The underlying assumption is that effects may not last forever. Striking an airstrip once may make it inoperable for several days (effect: no flights in or out) but not forever. The duration "several days" of the example is the persistence. It should be noted that the issue of persistence is more complex because it is rarely described by a Boolean variable (on – off). Even in the simple case of the airstrip, small aircraft may be able to take off after two days, but may take a week for larger aircraft to use the runway, i.e., the effect may decay over time.

The hard underlying problem is that these kinds of phenomena require that they be modeled using hybrid dynamical systems, namely, systems that are both time driven and event driven.

So far, only the first three types of timing information are implemented in CAESAR II/EB and CAT. Neither approach fully handles persistence. Inclusion of a proper model of persistence is important; it is one of the technical problems that the R&D community is and should be addressing.

While it is a challenge to create Effects Based influence net models, a second challenge is given that such models are constructed, what analysis techniques can be applied to answer key questions. Clearly, one key question is what is the best or at least a good set of actions to take to achieve the desired effects. That question is followed by the question of what is the best sequence and timing of those actions. SIAM, CAESAR II/EB, and CAT have analysis tools to address the first question. The second question is still addressed by trial and error processes rather than by a prescriptive or normative analysis approach.

The first analysis method that can applied to the Influence net is Sensitivity Analysis. Consider the Influence net that has six actionable events (Blue's actions) and three overall effects. We can compute the change in the probability of each effect due to the change in the probability of occurrence of one of the Blue actions, with all other input probabilities held constant. For example, the sensitivity coefficient of Effect 3 to changes in the probability of Action 1 is given as the percent change in the probability of E_3 occurring divided by the percent change in the probability of A_1 occurring:

$$S_{31} = \Delta E_3/E_3/\Delta A_1/A_1$$

The sensitivity analysis is carried out to determine which actionable events, alone and in combination, appear to produce with the highest (or acceptable) probability the desired effects. It should be noted that Influence nets are static probabilistic models; they do not take into account temporal aspects in relating causes and effects and they do not consider effects due to interactions between causes . However, they serve an effective role in relating actions to events and in winnowing out the large number of possible combinations. The result of this step is the determination of a number of actions that appear to produce the desired effects and an estimate of the extent to which the goal can be achieved.

The second analysis problem is more difficult to solve. Not only do we need to determine the set of actions to take, but we also need to select the best sequencing and timing of those actions. In addition, we may not be free to select any timing and sequence of actions due to the constraints on the resources that are needed to carry out the actions. The problem is one of not only considering the actions and their timing that will yield the best probability profile for effects, but one that is feasible from the point of view of resource availability.

There is some theoretical work on the Colored Petri Net model of the influence net that supports the selection of timing and sequence of actions [10]. The algorithm is not yet implemented in the tools nor tested in the operational environment. This is an area that should be explored by the R&D community.

A third area of analysis involves using the models to explain how certain COAs lead to the desired effects. Listing a set of actions and their timing and then displaying the probability profile does not explain the features of the probability profile. It could be enlightening to be able to highlight certain portions of the probability profile and have a visualization tool to describe the actions and timing that are causing that feature to occur.

In addition to the technical challenges to be solved in the COA analysis tools that allow them to more precisely model the timed relationships between actions and effects, our experience in the war games using the CAESAR II/EB tool provided additional insights into the needs of the operators. We have made the following observations.

1. The EBO concept is a complex one spanning multiple echelons and disciplines.

2. A model based approach to relating actions to effects is appropriate.

3. Even with a tool that supports the modeling of actions and effects and provides a static and dynamic analysis capability, building the models is a challenging task. Our limited experience shows that the majority of individuals have difficulty initially in creating good models on their own. In general, no single person can build the models; it takes a team of domain experts to work together to create good modes.

4. Models have been built that support COA development at the Strategic and Operational levels. We have yet to determine if the CAESAR II/EB approach will be valuable at the tactical level where the concentration is more on the specifics of actions against targets.

5. We have observed at least two tempos in operations that impact model development and evaluation. During a pre-crisis stage and even in the early phases of a crisis there is a considerable amount of time available to create, vet, and analyze the models. These models tend to frame the broad courses of action that may be taken, if the crisis deepens into conflict. During conflict, there is a need for rapid development of models. In general, no one model remains informative as time goes on. Thus, during high tempo operations, new situations and questions arise and models have to be developed on the fly, if they are to be useful. This means that the time available to build these new models is limited compared to the time available during pre-crisis planning. Tools and techniques must support the rapid morphing of existing models as well as the assessing of the new information that is needed to build new models. Part of the challenge is obtaining the team of experts needed every time a new model is required. Tools that support web based collaborative model development may facilitate the tool building with a geographically distributed team of domain experts. Such an approach has already been taken successfully by the current version of SIAM.

6. To be effective, the modeling and the models must be incorporated into the overall planning, execution, and assessment process. This means that the strategy and planning cells, current operations cells, and commander and staff must be aware and support the modeling efforts. The output of the models must be part of the COA development and the planning processes. Having a separate stand alone EBO modeling activity is not very effective. We will discuss process in more detail shortly.

In addition to these observations, we have found the description of EBO in Smith [13] to be useful in formulating the way ahead. Dr. Smith participated with the GMU team in using CAESAR II/EB in the Global 2000 and 2001 games, and many of the observations in his book are similar to ours. Some of our key observations are as follows

1. Actions cause effects. In addition, it is certain characteristics of actions that affect the effects. Some of these characteristics include focus, type of force used, scale of the action, scope, timing (speed, duration), and visibility of the action.
2. Effects occur to objects of the effect. The object of an effect can be a physical thing or a psychological entity. Dropping the span of a bridge with a bomb affects a physical object. Demoralizing a company of adversary troops affects a psychological object.
3. This leads to the observation that effects are physical or psychological.
4. Effects cascade from one effect to another. One action or a set of actions against a single object can result in a chain reaction of effects. The chain can go from physical to physical, physical to psychological, psychological to physical, or psychological to psychological.
5. Effects can accumulate over time.
6. In the effects based play of the game, there are action - reaction cycles. Blue actions cause effects on the adversary that causes adversary reactions and thus effects. These cycles happen in multiple locations with multiple dimensions in multiple arenas.
7. We need to be able to define objectives in terms of effects and determine desired end-states. The goal is to create a trajectory from the current state to the desired end state through the set of coordinated actions we take. The timing and synchronization of the actions affects the trajectory from the current state to the desired end state; the same set of actions with a different timing can result in a different trajectory.
8. Actions have costs and constraints. It is not sufficient to determine a set of actions and generate orders to carry them out. Only certain resources are capable of carrying out specific actions and, in general, resources are limited. Resources have to be in certain locations to carry out actions, thus the maneuver of resources is also a constraint that must be taken into account.

The design of the CAEASR II/EB and CAT technologies correlates fairly well with these observations. The models link actions to effects (Observation 1). The description in each effect node states not only the effect, but also the object of that effect (Observation 2). Thus the models can handle both physical and psychological effects (Observation 3). The description of the action node can take into account the attributes of the action. The "strength" of the causal link captures the impact of the attributes of the action. The model can show cascading and accumulation of effects (Observations 4 and 5).

The implication of Observations 6, 7, and 8 extend beyond the basic modeling technique. Observation 6 implies the need for multiple models that can be built rapidly – at least fast enough to remain within the action – reaction cycle. These multiple models must be consistent across the various domains. For example, there need to be models at the strategic level that are supported by a set of models at the operational level. The operational level models also can be supported by more detailed tactical models. The more detailed tactical models need not be and usually will not be influence net models. The use of Petri Nets for the executable model of the influence net allows a layered approach in which tactical models are triggered by the Petri net, execute, and return values to the Petri net (see an instance of this approach in Shin and Levis [12]).

The CAESAR II/EB and CAT tools partially support Observation 7. These tools generate the reaction of the adversary in terms of the effects modeled in the tool. The results are described by the probability profile, i.e., the probability of an effect occurring as a function of time. Currently the process of converting the statement of command intent and the desired end state into the effects that are described in the model is manual.

The implication of Observation 8 is that the R&D community must provide more than what the CAESAR II/EB or CAT technologies provide. The operators in command centers such as a CAOC need a complete EBO capability. The CAEASSR II/EB or CAT tools only provide part of the analysis of an EBO based plan. In addition, we need to be able to perform Center of Gravity and Target Systems analysis to determine the functions and components of the adversary's systems that are vulnerable to actions and thus are potential targets. These components and functions become the objects of effects that are contained, sometimes in an aggregated way, in the causal model that links actions to effects. In addition, we need tools that can identify and schedule the resources needed to carry out the actions and provide feasible time windows when those resources can be available to conduct the actions.

Figure 7 attempts to capture the concepts contained in these observations. At the top of the figure we show Command Intent that is used to provide Broad Actions and Desired End State. The latter is converted to Overall Effects. We also may introduce undesired effects based on Command Intent. An Influence Net model is developed linking actions to the overall effects. Some of the basis of the influence net model come from understanding the Centers of Gravity that our actions can affect to produce the overall effects. Objects within those COGs are selected because of their vulnerability to the actions that can be carried out by resources. A tool that supports the development of plans for the allocation of resources to tasks in both the spatial and temporal dimensions is needed to develop feasible plans. It is important to conduct risk analysis both in terms of undesired effects and potential adversary COAs and their potential effects on Blue. A wargaming capability can support this type of analysis. We have indicated in Figure 7 some of the technologies that are being developed for the AFRL EBO ATD (Figure 5).

From both our development and wargaming experiences we have postulated that one approach to handle the complexity of EBO is to partition the overall problem into five inter-related ones. These problems are addressed as stages of an integrated process. Each problem requires models and algorithms that are specific to that stage.

1. EBO Problem: Relate effects to actionable events. In this problem, we need to define the set of desired and undesirable effects on the adversary. Then, working backwards, from effects to causes, arrive at the actions that we have at our disposal (the application of the instruments of

national/coalition power) for achieving these effects. It is crucial at this stage to explicitly state the causal linkage between actions and effects. While many physical action-effect links are obvious, for example, a bomb striking a bridge causes a span to fall into the gorge, at higher order or behavioral effects, this linkage is rarely obvious. For example, still today there is debate over why Milosevic acceded to NATO's demands over Kosovo in 1999. However, the actions that most likely caused him to settle when he did, that is, with the highest probability of success, were allied airpower attacks on Serbian dual-use (that is, military and civilian) infrastructure, particularly power plants around Belgrade that cut electrical power to the capital. [5]

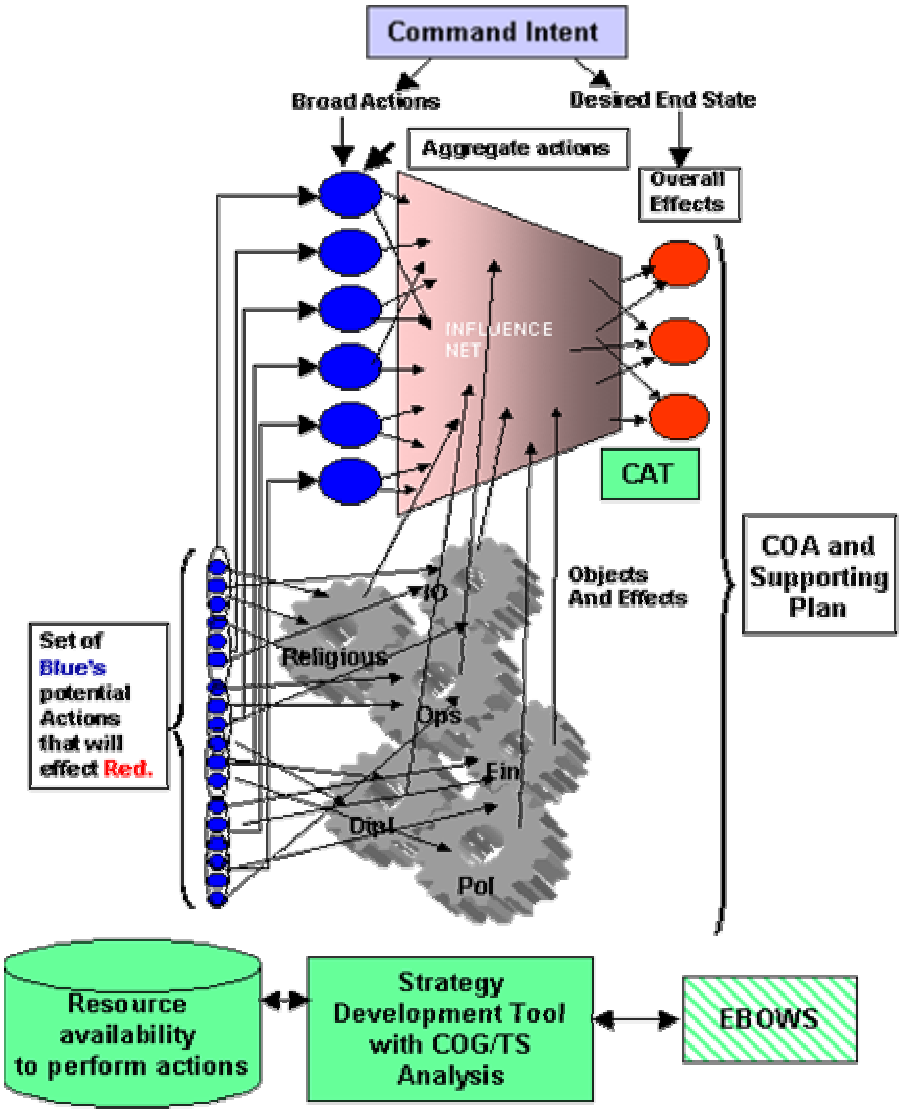

Figure 7. Interaction of R&D tools to Support EBO

2. COA Problem: Select from the set of all actions those subsets that will yield with high probability the effects we wish to achieve (including low probability for undesirable effects). Take into consideration constraints associated with specific actions or combinations of actions. Then sequence the actions in each subset and time-phase them. The result is a set of alternative COAs. This is still at the operational level. When the selected COA becomes a plan, the operational aspects are mapped to system (target) aspects.

3. ISR problem: We need to identify those observables (phenomena that can be observed by our sensors) that either directly or indirectly indicate whether we are achieving the effects or not. This information provides the basis for assigning Intelligence, Surveillance, and Reconnaissance assets to monitor the execution of the operations. Furthermore, this means that by monitoring the progress we are making we will be able to adapt plans in a dynamic manner.

4. Evaluation Problem: We need metrics by which we can assess the effectiveness of different COAs. When we have such metrics, it then becomes possible to generate algorithmically the set of preferred COAs that either maximizes a measure of effectiveness (MOE) subject to constraints, or satisfies a set of constraints including MOE thresholds.

5. Execution Assessment Problem: Once the plans that constitute a selected COA begin to unfold, we need to be able to use the models created to address problems 1, 2, and 3 and the metrics of problem 4 to measure and calculate the degree to which the desired effects are being achieved and, if necessary, adjust the selected COA.

The current technology and techniques do a reasonably good job supporting the first three problems. As mentioned above, improvement in temporal algorithms and analysis procedures will enhance the tool capabilities to support these three problems.

We have only begun to develop potential solutions to problems 4 and 5. One technical approach has been to incorporate a "backward" propagation algorithm in the CAESAR II/EB and CAT tools. Such an approach has turned out to be challenging because of several temporal issues. The current algorithms are limited in the number of indicators to which evidence can be applied. The difficulty is that the time to complete the algorithm increases exponentially with the number of evidence nodes that are incorporated. We are addressing the problem by applying heuristic algorithms that can be justified logically and converge to solutions quickly.

4. A Way Ahead

Both the R&D and the operational communities are learning a great deal from their on-going collective experience with EBO. Still, a picture to help determine the future directions for both communities is starting to emerge. The researchers have identified several areas where there tools and techniques need improvement. The operators are evolving new operational concepts for EBO. These operational concepts induce a process that ultimately gets documented in Doctrine and Tactics, Techniques, and Procedures. GMU learned that it is imperative that the tools developed be fully incorporated into the planning, execution, and assessment process, if they are to make a difference.

A systems engineering approach may provide the answers that we are seeking. The effects-based operational concept is refined sufficiently to use it to develop a C4ISR Architecture that supports the development of systems that will enable operators to more effectively carry out Effects Based Operations . Using the C4ISR/DOD Architecture Framework, an Operational Architecture View can be constructed starting with and Activity Model, Data Model, and Rule Model. These models define how the operators expect to carry out the process of creating COAs, developing plans from them, issuing tasking orders to forces (resources), executing the tasks, and assessing feedback from the execution and intelligence, surveillance, and reconnaissance sources. Indeed, these models are being developed by the Air Force and the Navy at this time (Figure 8 shows a portion of an activity model for the Air Force). The activity model indicates the operational activities that the operators expect to perform in an Effects Based Operation. The R&D community can examine the Operational Architecture view to determine the technologies, tools, and techniques they should be developing to support those operational activities. A System Architecture View can be created that shows systems, system components and elements and their interconnections and interfaces. The system functions would be mapped to the operational activities. Activity models based on the system functions can be created that

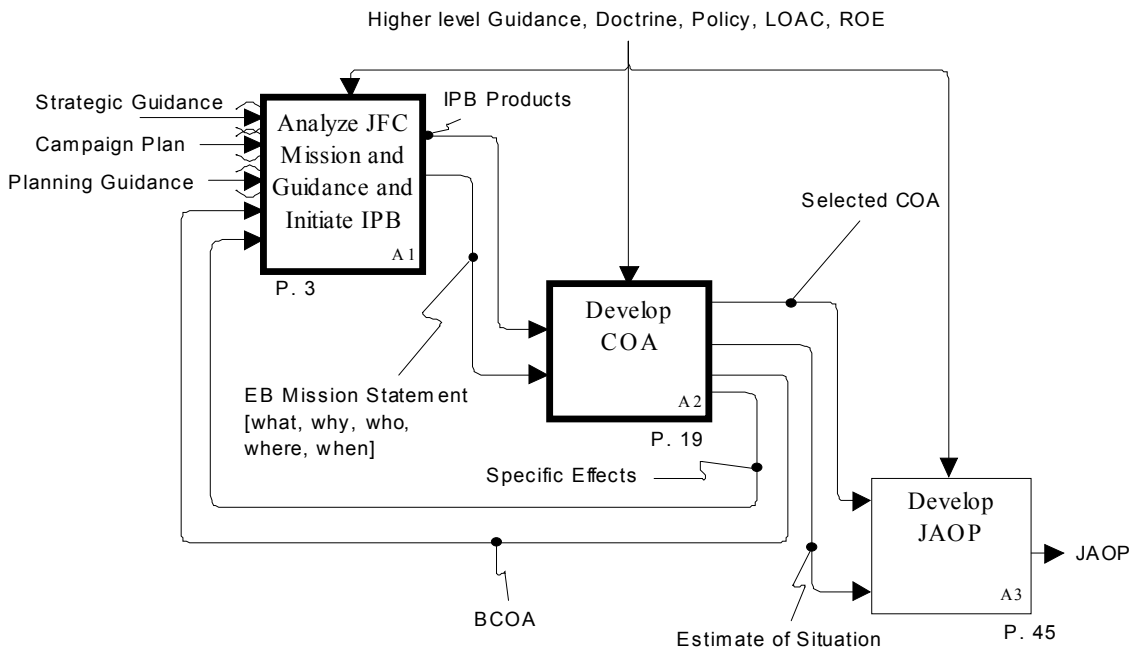

Figure 8. Activity Model for EBO

mirror the operational architecture view activity models. In the case of the AFRL EBO ATD, the tools shown in Figure 5 could be a starting point for the system architecture view. The system architecture view would show the interfaces between the systems that will enable operators to conduct EBO according to their operational concept. The architecture can reveal gaps in technology developments and opportunities for new efforts.

5. Conclusion

As we have discovered, EBO is a complex undertaking with potentially high payoff. Both the operational and R&D communities need to refine their thinking and create new tools and techniques to manage this complexity. Furthermore, the tools and techniques must be incorporated in an overall process that is used for planning, execution, and assessment across domains and levels. If conceptualizing the action-effect relationships is at the heart of EBO, we need to devise better ways to help operators and analysts develop good models rapidly. There is considerable room for improvement in this arena such as the use of templates and approaches for pruning models. In addition, we need ways of rapidly finding information and data that can be used in developing the models and methods for transforming the information into the constructs of the models. Since more than one modeling technique is appropriate, we need to determine how to import the information derived from one model into another. For example, CAESAR II/EB models may support and be supported by more traditional wargaming models. We need to determine what the interactions between these models should be in order to enhance the EBO process.

In this paper, our goal was to show a way ahead. In this regard, we have only partially succeeded. While we are able to suggest many areas for improvement, the clear path is elusive.

As a result, we suggest that the system engineering approach using architectures can provide the vehicle to understand the way ahead.

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