Using Hierarchical Modeling to Assist Effects Based Planning and Assessment

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Overview

- Effects-Based Operations (EBO)
- Air Force Institute of Technology (AFIT) EBO Research Stream
- Dimensionality and EBO
- Course of Action (COA) and EBO
- Risk Filtering, Ranking, and Management (RFRM) Methodology
- Guiding Principles
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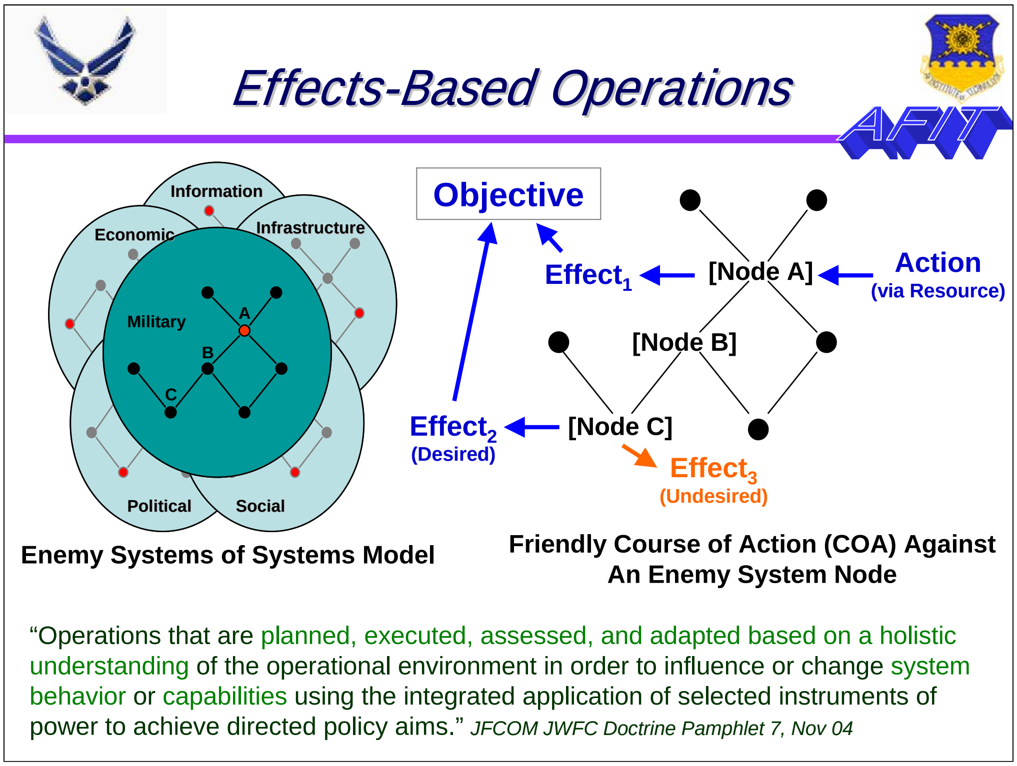
In recent years, effects-based planning and assessment has moved from doctrinal debate to operational implementation in the United States (US) military. Although effects-based operations (EBO) implementation strategies vary among our combatant commands and services, each faces the difficult task of planning and assessing their operations. Operations in Afghanistan and Iraq have clearly demonstrated the challenges associated with planning and assessing military operations in a real-time environment.

To support the implementation of EBO planning and assessment in the US military, numerous efforts have been undertaken to develop methodologies and field software to assist planners and assessment teams. Of note are efforts sponsored by the Air Force Research Lab (AFRL), Office of Naval Research, and Joint Forces Command (JFCOM). From these efforts, several operations research (OR) methodologies have been proposed and tested to handle parts of the EBO planning and assessment problem (e.g. Dynamic Bayesian Networks, Influence Networks, Petri-Networks, Social Network Analysis, System Dynamics, Value-Focused Thinking, and Multi-Criteria Decision Making).

Each of these OR methods can aid in EBO planning and assessment but the complexity of the planning and assessment process makes it impracticable to represent the entire process with a single OR model. Instead, the authors discuss and recommend an approach to planning and assessing EBO that relies on techniques developed and proven effective in the field of risk analysis namely that of hierarchical modeling. Central to the methodology is the overlapping of various OR models to utilize the strengths of various models while minimizing their weaknesses. This presentation details the authors' hierarchical modeling methodology and also provides a critique of the use/applicability of several OR models to accomplish EBO planning and assessment.



The reader should keep in mind that the definition of "EBO" has evolved as the concept of EBO has developed. For many, the definition of EBO has been a moving target. For this presentation, the authors use the EBO definition in JFCOM JWFC Doctrine Pamphlet 7 "*Operational Implications of EBO"* as defined above.

With the publication of Pamphlet 7 in November 2004, the effects-based methodology has fully evolved from a linear strategy-to-task approach to a system of systems baseline to develop relationships (or linkages) between effects, nodes, and actions. System of systems analysis or SoSA provide a holistic understanding of the enemy environment (Figure above, left side). Within each of the six interrelated political, military, economic, social, infrastructure, and information (PMESII) systems, "nodes" represent a functional component of the system (person, place, or thing) and "links" represent the relationships (behavioral, physical, or functional) between the nodes.

In the effects-based planning method described in the pamphlet, an adversary SoSA output determines the direct and indirect linkages across the PMESII that can be exploited by friendly actions. SoSA results become the input for the development of a linkage between enemy nodes and friendly objectives, effects, actions, and resources (Figure above, right side).

Understanding these relationships allows commanders to choose from a set of effect-node-action-resource (ENAR) options. In the figure above, direct relationships exist between adjacent enemy nodes A and B as well as between nodes B and C. Indirect relationships exist between nodes related through another node, in this case between nodes A and C. A friendly action is taken against node A to change its state (i.e., to produce a desired effect) that will lead to the obtainment of a friendly objective. This action also intentionally produces a change of state (another desired effect) at node C. An undesired effect (generally unpredicted) is shown at node C because of an action at node A. This undesired effect could have an adverse impact on the friendly objective.

AFIT EBO Research Stream

Effort Description

Explore *quantitative* and *qualitative* modeling methods for EBO with an emphasis on causal modeling and uncertainty analysis

- Quantitative models are data intensive and can cause skepticism of model validity among operational planners
- Qualitative methods do not require precise numerical information, but are viewed as less accurate

Effort Duration

2-year effort for the Air Force Research Laboratory's Information Directorate

Products:

- Interim Technical Report (Oct 05)
- Final Technical Report (Jun 06)

Potential Methods for Exploration

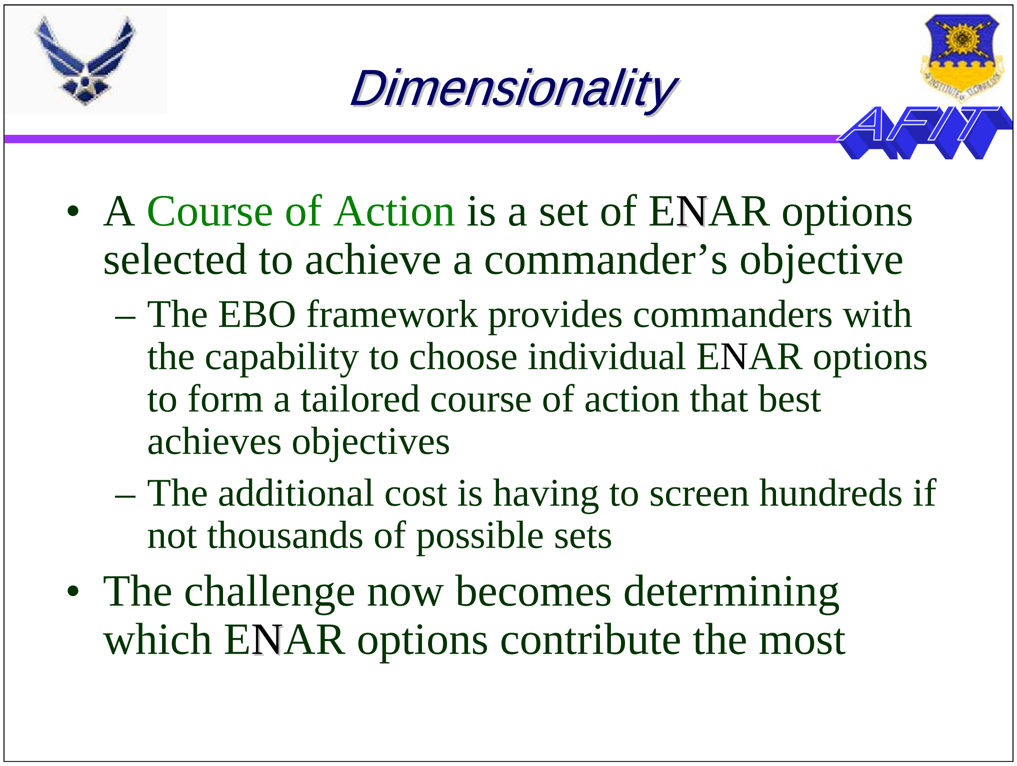
Dynamic Bayesian Nets	Value-Focused Thinking
Influence Networks	Multi-Criteria Decision Making
Petri Networks	Social Network Analysis
E-calculus	Risk Analysis
Qualitative Probabilistic Nets	Event/Fault Tree Analysis
Game Theory	Simulation
Fuzzy Set Theory	System Dynamics
Dempster-Shafer Theory	Complexity Theory
Possibility Logic	

Approach

- Study, compare, and contrast potential quantitative & qualitative methods for applicability to EBO's COA and SoSA modeling
- Determine the practicality, usability, accuracy, limitations, benefits, and shortcomings of various methods
- Document results and recommendations

Comparisons of the relative strengths and weakness of the methods to perform EBO will be based on a list of criteria. A tentative list is as follows:

- Accuracy of the method
- Applicability of the method to deliberate and crisis action planning & assessment
- Applicability of the method to kinetic (e.g. combat) and non-kinetic (e.g. stability) operations
- Applicability of the method to analyze operations at each level of warfare (strategic, operational, tactical)
- Ability of the method to perform sensitivity analysis
- Ability of the method to perform predictive analysis
- Ability of the method to handle temporal issues
- Usability of the method in an JOC/AOC environment
- Data requirements for the method



While the effects-based framework outlined in Pamphlet 7 is relatively straight forward, the number of possible ENAR options can grow very rapidly making course of action development, evaluation, and selection problematic. The primary driver will be the number of nodes to influence in the PMESII system. However, an important secondary driver will be the number of possible diplomatic, informational, military, and economic (DIME) actions available to influence a single enemy node.

Taken together these drivers lead to a dimensionality problem in effects-based planning and assessment. With just a few enemy nodes and a few friendly actions the number of ENAR options can grow rapidly. For example, with four enemy nodes and four friendly actions on each node (one for each DIME instrument) there would be sixteen possible ENAR options. Investigating these options four at a time, the number of possible courses of action (sets of ENAR options) combinations is 256! If the number of nodes in the PMESII is in the hundreds or thousands, as should be expected in a typical military operation, the problem of selecting the "optimum" course of action to take quickly becomes unmanageable.

The EBO framework provides commanders with the capability to choose individual ENAR options to form a tailored course of action that best achieves objectives, but with the additional cost of have to screen thousands of possible choices. The challenge now becomes determining which core ENAR options contribute the most to achieving the operation's objectives.

COA through the EBO Prism

- Currently planners develop a COA theme and then develop tasks that go with the theme
- The EBO framework does the reverse – actions are first developed to achieve the desired result, matched with resources, and then packaged into a COA
- A new approach is introduced to reduce the number of ENAR options to a manageable level and aid in COA development, evaluation, and selection
  - This approach is based on work in the field of risk analysis

It is important to note that it is necessary to complete the SoSA and ENAR linkages discussed in pamphlet 7 before beginning to develop, evaluate, and select courses of action (COAs). Currently planners generally develop a COA theme and then develop tasks to go with that theme. Conversely, the EBO method does the reverse. Actions are first developed to achieve the desired result, matched with resources, and then packaged into a course of action. In decision analysis terms, the SoSA and ENAR processes produce the "structure" for the COA decision. Using the ENAR option, the result is a much larger and potentially flexible number of COAs than the proverbial "air COA", "ground COA", or "mix of both."

The current effects-based planning processes provide the structure to develop COAs, but additional aids are needed for COA evaluation and selection. A new approach is introduced to reduce the number of ENAR options to a manageable level and aid in COA evaluation and selection. This approach is based on the risk filtering, ranking, and management (RFRM) methodology developed by Yacov Haimes and associates.

In the RFRM methodology, risk is evaluated from the standpoint of identifying "what can go wrong" scenarios along with the scenarios' associated likelihoods and consequences. Analysis of real world problems can produce thousands of these risk scenarios. For example, consider the multiple failure modes of a nuclear power plant. The RFRM methodology assists decision-makers in establishing priorities among the large number of risk scenarios to determine the most important contributors to risk.

The techniques of filtering and ranking can also be used to assist military planners in the development, evaluation, and selection of COAs. Such a methodology would enable planners and commanders to focus on the set of actions that would potentially provide the greatest impact on desired effects and objectives at the lowest possible risk to friendly forces.

RFRM Methodology

- Eight Phases to Risk Filtering, Ranking, and Management (RFRM) method
  1. Scenario Identification
  2. Scenario Filtering
  3. Bicriteria Filtering and Ranking
  4. Multicriteria Evaluation
  5. Quantitative Ranking
  6. Risk Management
  7. Safeguarding Against Missing Critical Items
  8. Operational Feedback

Likelihood / Effect	Unlikely	Seldom	Occasional	Likely	Frequent
Catastrophic					
Critical					
Serious					
Moderate					
Marginal					

Low Risk | Moderate Risk | High Risk | Extremely High Risk

1. *Scenario Identification*. Identify all "as planned" or "success" scenarios and and all "risk" scenarios. The result of identification is the creation of a number of risk scenarios hierarchically organized into a set and subsets. Identification will probably contain hundreds if not thousands of risk scenarios.
2. *Scenario Filtering*. The risk scenarios identified in Phase 1 are filtered according to the responsibilities and interests of the current user. Typical filtering criteria are the decisionmaking level, the scope, and the temporal domain.
3. *Bicriteria Filtering and Ranking*. The remaining risk scenarios identified in Phase 2 are further filtered using qualitative likelihoods and consequences. This step uses the ordinal version of the USAF risk matrix (likelihood, consequence pairings). Risk scenarios falling into the low "severity" boxes of the matrix are filtered out and set aside for later consideration.
4. *Multicriteria Evaluation*. In this phase, the remaining risk scenarios are evaluated on more detailed consequence criteria. These criteria allow a more detailed effect assessment of the consequences derived in Phase 3. Each criteria is scored such that a higher value indicates a higher consequence.
5. *Quantitative Ranking*. In this phase, the likelihood of each scenario is quantified based on the totality of relevant evidence available. Calculating the quantitative likelihoods avoids possible miscommunication when interpreting qualitative likelihoods such as "seldom" or "occasional".
6. *Risk Management*. Having filtered the risk scenarios by likelihood and consequence, a much smaller set of risk scenarios has been identified constituting most of the system risk. In this phase, options for dealing with the risk scenarios are identified and a comparison of the cost, benefits, and risk reduction of the proposed options is conducted.
7. *Safeguarding Against Missing Critical Items*. Reducing the risk scenarios to a smaller set may have filtered out scenarios that seemed minor but could become important if the options developed in Phase 6 are implemented. In this phase, the performance of the Phase 6 options are evaluated against the previously filtered scenarios.
8. *Operational Feedback*. Using the experience and information gained during option implementation to refine the scenario filtering and decision processes of earlier phases.

Guiding Principles

- Qualitative-based filtering of ENAR options is required to solve the dimensionality problem
- All sources of evidence must be applied
  - Professional experience, expert knowledge, statistical data, and common sense
- Must answer (as a minimum) four questions?
  1. What ENAR options are supportable with resources?
  2. What is the likelihood that a given set of ENAR options will accomplish the desired effects?
  3. What are the consequences of executing a given set of ENAR options to our force?
  4. What impact will current decisions have on future options?

The RFRM framework is based on three guiding principles. First, due to time and resource constraints, it is often impractical to apply quantitative methods to thousands of risk scenarios. Hence the use of qualitative filtering methods first in Steps 2 (*Scenario Filtering*) and 3 (*Bicriteria Filtering and Ranking*) of the framework. In the application to EBO, the number of potential ENAR options is extremely high as previously demonstrated. An initial qualitative step to narrow the options will help focus the decision-making effort.

Second, all sources of evidence such as professional experience, expert knowledge, statistical data, and common sense should be harnessed to assess the significance of the risk source. In the EBO methodology all of these “sources of evidence” will be important in the evaluation and selection of a set of actions to achieve the desired effects of a given operation.

The third guiding principle is a set of six questions that combine risk assessment with risk management. To develop, evaluate, and select COAs from an effects-based plan, the authors reduce this to four questions:

• What ENAR options are supportable with resources?

• What is the likelihood that a given set of ENAR options will accomplish the desired effects?

• What are the consequences of executing a given set of ENAR options to our force?

• What impact will current decisions have on future options?

To answer these questions, our COA development, evaluation, and selection process takes place in six steps.

COA Development, Evaluation, and Selection Process

AFIT

1. ENAR Option Identification
2. Resource Filtering
3. Phase & Scope Filtering
4. Quantitative Evaluation, Ranking, & Filtering
5. Risk Filtering
6. Safeguarding Against Missing Options

Develop (1–3)

Evaluate (4–6)

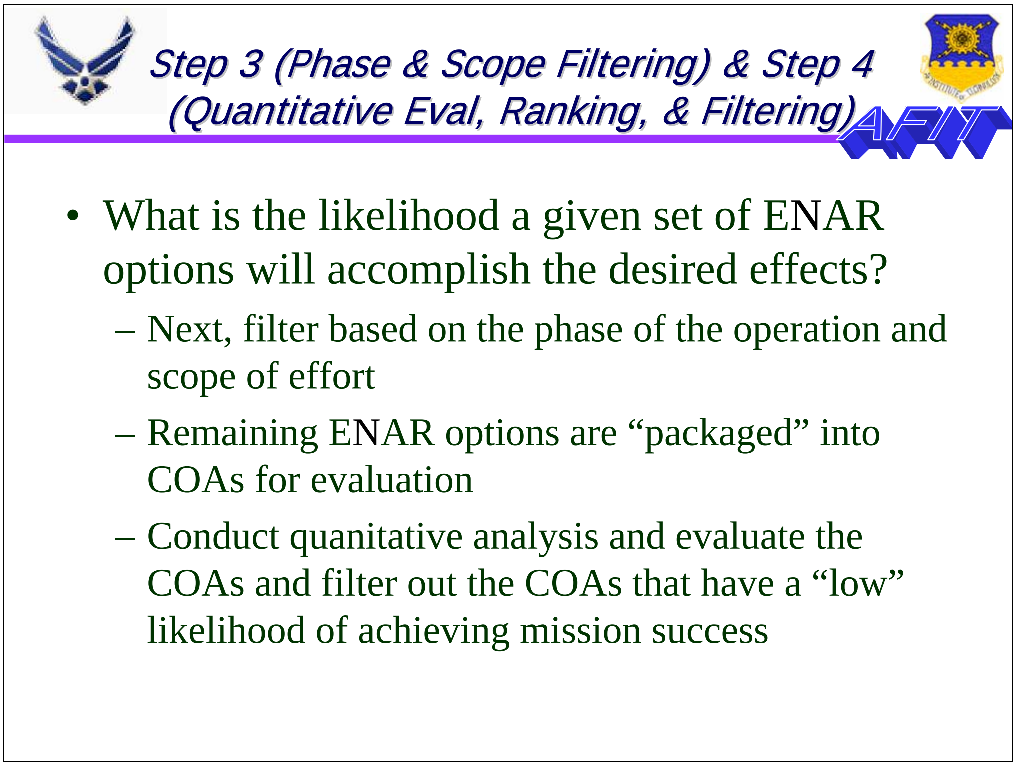
COA Selection

Steps 1 (Identification) & 2 (Resource Filtering)

- What ENAR options are supportable with resources?
  - First a systems of systems analysis (SoSA) analysis must be performed and a set of ENAR options proposed
  - Next, need to determine if the required resources are available to execute each ENAR option

Step 1 (*ENAR Option Identification*). First a system of systems analysis (SoSA) is performed and a set of ENAR options developed by the planners. There will be hundreds if not thousands of potential options for a full SoSA. SoSA is an iterative process and methodology presented here can accommodate these iterations. However, the SoSA needs a level of maturity such that the ENAR options that are proposed represent the "70%" solution. That is, the options are mature enough in their formulation that taken as a complete set, the options have a good chance of achieving mission success (obtainment of mission objectives).

Step 2 (*Resource Filtering*). In theory, the proposed ENAR options have already accounted for the available resources. In reality, development of an ENAR option may define the resources required to accomplish an action, but not necessarily, check to see if the required resources to execute the option are in fact available. For this reason, this step filters ENAR options based on available resources. If the resources are not available, the DIME actions can not be supported. The result of this step is a reduced set of supportable ENAR options.



To answer the above question, two steps are required.

Step 3 (*Phase & Scope Filtering*). In this step, qualitative filtering takes place again, but is now based on ENAR option phasing and scope. For example, if the desired effects are "no enemy aircraft threaten friendly freedom of maneuver" and "no adversary theater ballistic missile launches", ENAR options that support stability operations do not apply to the situation currently and can be filtered (these options will be reviewed again in Step 6 (*Safeguarding*)). Further, if the operation is taking place in Country X, ENAR options that apply to Country Y are also filtered. The result of this qualitative filtering effort is a smaller number of ENAR options that support the desired effects by phase and scope.

This smaller number is then grouped into *sets of ENAR options* based on subject matter expertise and professional experience. Each set of ENAR options becomes a candidate course of action.

Step 4 (*Quantitative Evaluation, Ranking & Filtering*). The next step is to apply quantitative methods combined with commander's guidance, subject matter expertise and professional experience to evaluate the candidate COAs. A varieties of methods are available to quantify the likelihood of success of a given COA. Among these, although not an exhaustive list, are cause and effect modeling, decision analysis, simulation, and systems analysis. Hard methodologies should be combined with soft methodologies (that can support the thinking of groups and individuals).

Ultimately the answer to the question "What set of actions is most likely to accomplish the desired effects?" is not an absolute. There will be too many uncertainties involved. Instead, the result of this step is a ranked set of COAs based on commander's guidance, subject matter expertise, experience, and supported by analysis.

Step 5 (Risk Filtering)

- What are the consequences of executing a given set of ENAR options to our forces?

Risk To Forces \ Effects Priority	Low	Medium	High
Extreme			High to Extreme Risk, High Priority
High			COA 2 ($P_s \leq .2$)
Medium	COA 1 ($P_s \leq .7$)		COA 4 ($P_s \leq .4$)
Low		COA 3 ($P_s \leq .5$)	
Negligible	Low to Negligible Risk		

P_s = probability of success

Step 5 (Risk Filtering). This step is similar to the "risk to forces" and "risk to mission" evaluations currently used. This multi-criterion assessment is based on the priority of the effects achieved by a given COA and the risk to friendly forces of that COA (see above table). Initially, the ranked COAs from the previous step are distributed into the table based on subject matter expertise and professional judgment. The COA ranked most likely to succeed will not necessarily end up in the "low risk, high priority" section of the table.

COAs in the upper right of the table represent a set of ENAR linkages that have an impact on a high priority effect but also pose a high to extreme risk to friendly forces. For this paper, the definitions of risk in the left hand column of the table are adopted from Kelly.

Negligible: No losses acceptable except those completely unpredictable and unpreventable.

Low: Losses expected at normal training or peacetime attrition rates. Accept only favorable engagements.

Medium: Losses expected at historical combat rates. Accept neutral or disadvantageous engagements; withdraw to preserve forces.

High: Expected losses may render unit unfit for further combat. Accept major losses to achieve objective; Preserve some future capability if able.

Extreme: Losses may result in force annihilation. Accept losses necessary to accomplish mission.

The result of this table is a visual representation of the COAs under consideration that combines the likelihood of success, risk to forces, and the impact on high priority effects. Planners can maintain or eliminate COAs based on any combination of these factors combined with commander's guidance.

Note: During COA development a similar assessment of adversary actions is also made during planning. Typically, this takes the form of "most likely, most dangerous." In other words, what will the adversary most likely do and what is the most dangerous (dangerous to friendly forces) action or actions the adversary could take? The EBO methodologies currently available do not yet address this aspect of operational level planning and decision aids are not yet available. A risk oriented approach similar to the one described in this paper may be applicable to evaluating adversary actions against friendly forces.

Step 6 (Safeguarding)

- What impact will current options have on future options?
  - Previous filtered ENAR options are reviewed within the context of the selected COAs to determine potential impacts

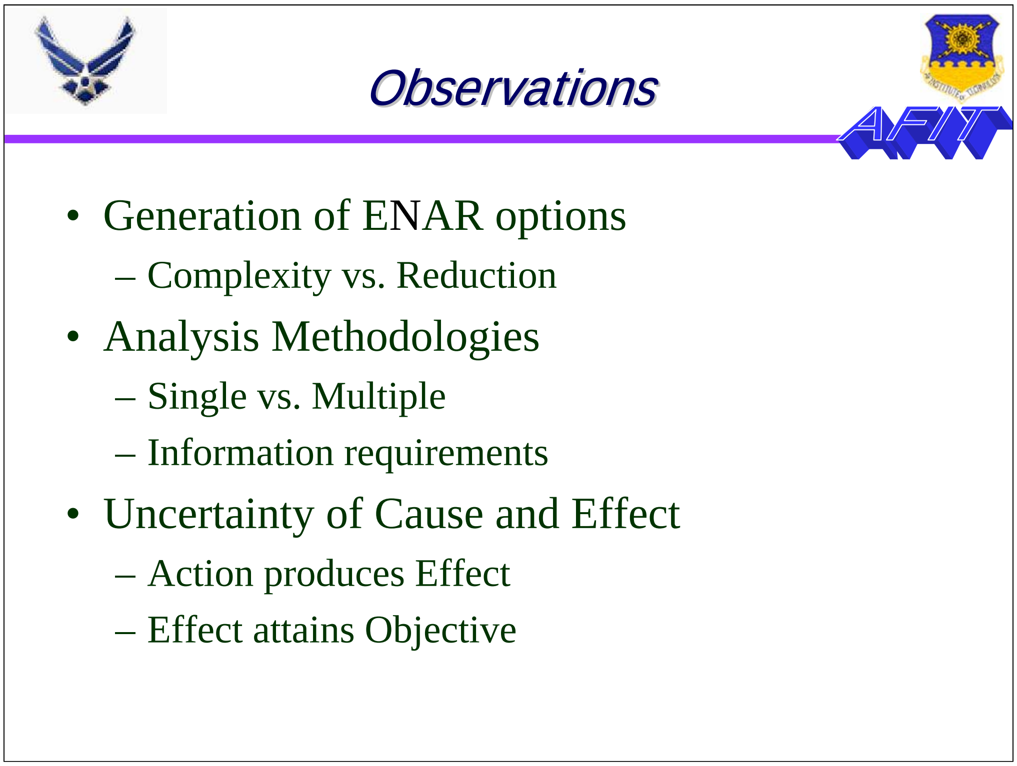
Since a COA, once executed, is expected to influence the PMESII network, filtered ENAR options must be reviewed in an attempt to evaluate unanticipated problems in either time or scope. In this manner, all ENAR options can potentially be managed to achieve a balance between the various phases of a campaign. For example, while a kinetic attack on a dual use power station may achieve the desired effect of cutting the adversary's communications today, it may also increase the risk to friendly forces later when the power station is being rebuilt during stability operations. This is an example of an undesired effect. To mitigate the increased risk (impact of the undesired effect) later, a different set of actions and resources might be developed for stability operations to account for the damaged power station or, the adversary's communications may be attacked through another node today.

The result of this step is two to three courses of action that have a high likelihood of achieving the desired effects, an acceptable level of risk to friendly forces, and an acceptable impact on future operations. The final selection of the course of action to pursue is made by the decision-maker.

Deliberate Vs. Crisis Action Planning

- In deliberate planning there is generally time to take both a quantitative and qualitative approach to determine the likelihood of success as well as the impact on future options
- On the other hand, in crisis action planning time constraints are significant. Quantitative steps could be eliminated from the ranking of candidate COAs

The process of filtering, ranking, and evaluating ENAR options to develop, evaluate, and select a COA applies to both deliberate and crisis action planning. In deliberate planning there is generally time to take both a quantitative and qualitative approach to determining the likelihood of success as well as the impact on future options of a given COA. On the other hand, in crisis action planning time constraints are significant. In this case, the quantitative steps could be eliminated from the ranking of candidate COAs; the likelihood of success will be based entirely on professional judgment and subject matter expertise.



Identifying critical or influential nodes is a necessary and critical requirement for developing ENAR options. For large PMESII networks, identification is non-trivial and reduction must be accomplished in some form to make the process of node identification manageable. However, PMESII networks are complex systems. Complexity theory postulates that complex, nonlinear systems can not be decomposed. Specifically, reducing complex systems into component subsystems or pieces does not adequately address the emergent quality of the system as a whole. In fact this emergent quality of a complex system does not exist within component systems, but is generated as a product of their interaction. Methods are needed that reduce the number of nodes to a manageable level while maintaining the fidelity of the complex, non-linear relationships of these complex PMESII networks.

No single methodology or tool can fit all cases and circumstances. The quantitative methods needed to analyze the likelihood of success of a COA rely heavily on data to populate the PMESII network. Perfect information will not be available. Further, the number of nodes in the PMESII network will have a significant impact on the methodology. Even after matching resources and filtering based on time and scope, the number of possible ENAR options available may still be too high to assess each possible combination.

The methods used have to have a capability to handle evidence updates in a rapid manner. Incorrect cause and effect assumptions will be prevalent in any real-world EBO planning framework. The ability of models to handle data updates in a time efficient and systematic matter will be an indicator of a model's capability to survive in the EBO world.

Continuing AFIT Research

- Our research has expanded beyond this initial work to include:
  - Characterization of Uncertainty in EBO Planning and Assessment
  - Complex Systems Analysis of EBO networks
  - Cause and Effect Modeling
  - Multiobjective Analysis of Operational Objectives

End of Using Hierarchical Modeling to Assist Effects Based Planning and Assessment Presentation

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