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Title: **Integrating Effects-Based and Attrition-Based Modeling**

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Abstract

The concept of Effects-Based Operations (EBO), enabled by Network-Centric Warfare (NCW), is developing rapidly as diplomats and war planners move to confront global threats in the new millennium. Modeling the NCW EBO process attempts to codify the belief structure and reasoning of adversaries and their cause-effect relationships with US and coalition actions, including mitigating undesired effects. A systematic EBO approach requires modeling, simulation, and evaluation tools to quantify the expected effects for different Courses of Action (COA). The problem with realizing a systematic approach is that typically the tools used at the strategic level are different than the tools used at or close to the tactical and operational level. This paper proposes a new method for bridging the quantitative measures provided by these toolsets. The paper describes an end-to-end process for developing the higher-level effects-based model, selecting and interfacing the attrition-based models with the EBO model, and performing evaluations using the combination of the different-level models. This illustration shows where the interfacing can be done between the models as well as how additional events or effects can be added to quantify performance parameters at the interface boundary.

1 Introduction to models

The research described in this paper is motivated by at least two challenges in Effects-Based Operations (EBO) modeling. The first challenge concerns the validity of the elements of a high-level EBO model; the second deals with determining details for the actionable events in such models. One builds these high-level models by employing three basic model-design factors. They are: a structure for interconnecting the cause/effect nodes with linkages; the values assigned to probability parameters that need to be included in the model; and, temporal information, which includes when the actionable events occur as well as the time delays associated with the nodes in model. Subject Matter Experts assist with determining the elements of these three model-design factors, generally with subjective methods. One of the concerns in this modeling process is the validity of the elements that are incorporated into the models.

We hypothesize that use of more detailed modeling improves the derivation of the elements of the higher-level EBO model. In particular, high fidelity simulations can provide more accurate values for the conditional probability values and the time delay information that the higher-level models use as input. A second motivation is that in the strategic level modeling of an EBO approach, actionable events often represent a broad grouping of actions. Determining the set of these broad actions and their timing that might achieve the desired effects is one of the main purposes of EBO modeling. Once selected, one must decompose these broad groupings into specific actions that comprise the plan for execution. Using the higher fidelity simulations is a standard way of testing out these more detailed sets of actions.

The work documented in this paper extends previous research [Wagenhals, et al., 1998] by developing a method for linking higher fidelity attrition models into higher-level Effects-Based Models created using probabilistic modeling techniques. Additional research has employed Effects-Based Operations (EBO) to model related actions in a battle plan to overall effects [Wagenhals and Levis, 2002]. A George Mason University team has developed a prototype toolset called CAESAR II/EB (Computer-Aided Engineering for Architectures/II Effects Based). The toolset supports static analysis of the influences amongst events in a battle plan, and it also supports an analysis of the dynamics in the timing of the events. Timing is governed by delays inherent to each of the events as well as the times for Courses of Action [Levis, 2000] that might be applied to a battle situation. The sequence of these analysis phases is summarized in Figure 1. Our new work proposes a method to model a portion of the analysis with an attrition-based engagement model, which at a lower level provides greater accuracy.

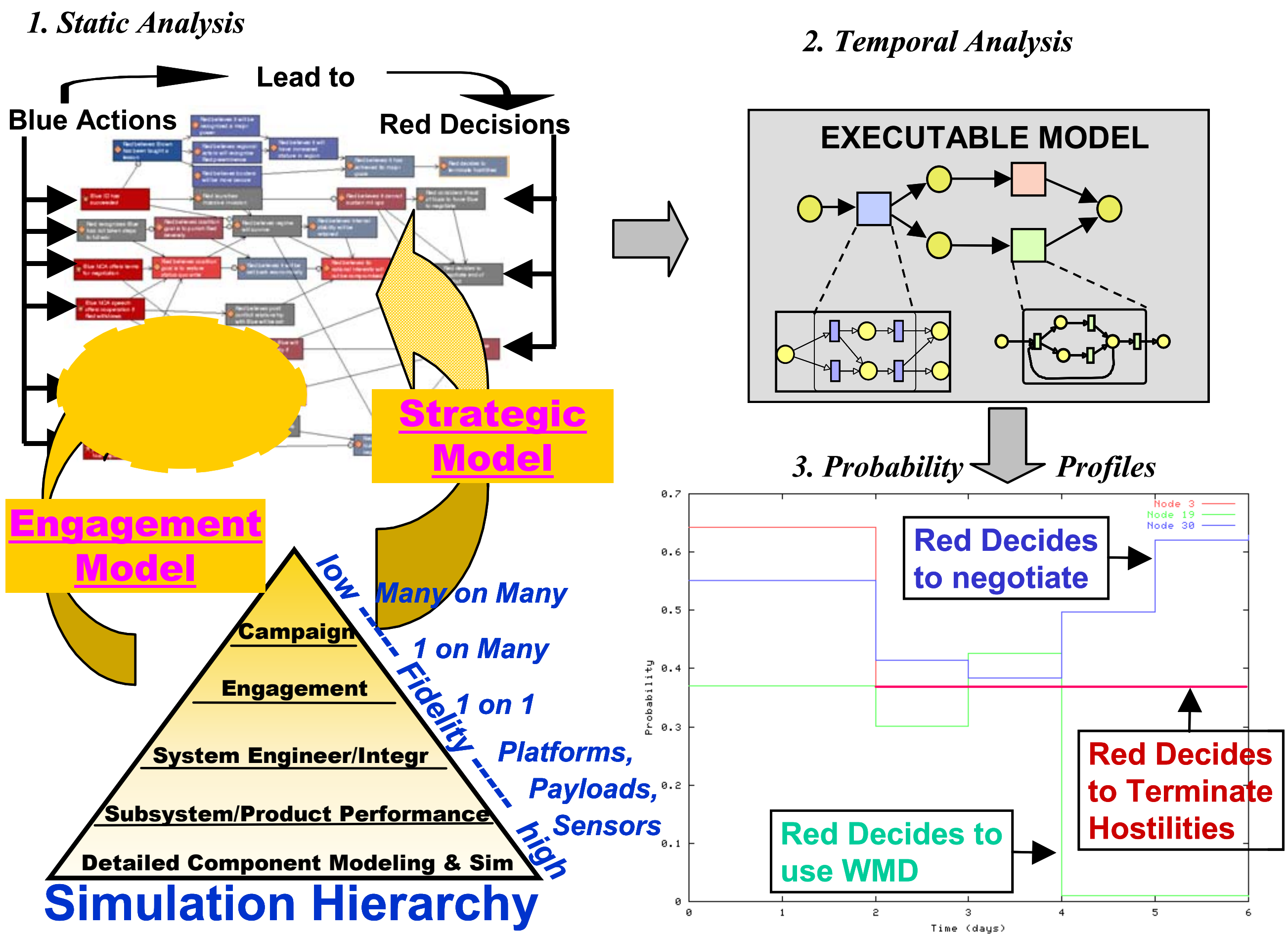

Figure 1 Effects-Based Modeling for Higher Levels of the Simulation

The prior application of the CAESAR II/EB toolset has been at the higher levels of campaign modeling, both at the planning level and in quick-reaction modeling to support the execution of war games [Wagenhals, et al., 2002]. This toolset models **events**, which can consist of actions, effects, beliefs and decisions. Figure 1 shows this prior application as a "Strategic Model." The CAESAR II/EB toolset utilizes a probabilistic modeling technique called an **influence net**. The influence net, shown in the "*1. Static Analysis*" portion of Figure 1, is created first to capture a probabilistic characterization of the influence relationships between these events. **Actionable event** is a term that refers to those events on the left side – events that Blue Forces can take (actions) to achieve the desired effects on the right-hand side. Typically, the analyst first works solely with the static model, adjusting parameters and refining the events and dependencies until the influence net model behavior (regardless of timing for the events) exhibits behavior that seems consistent for a range of possible combinations of the actionable events.

As shown by "*2. Temporal Analysis*" in Figure 1, the analyst next transforms the influence net into an **executable model**. The CAESAR II/EB toolset automatically builds this executable model, using colored Petri net methodology. (Wagenhals, et al., showed that Bayesian Influence Networks can be converted into a mathematically equivalent Colored Petri Network.) The executable model introduces the element of time, and for each event the analyst assigns a time needed for that event to complete. The CAESAR II/EB toolset also asks the analyst to define possible **<u>Courses of Action (COA)</u>**, which defines the occurrence (or non-occurrence) of each actionable event and its commencement time. When the executable model is run, the CAESAR II/EB toolset produces a probability versus time profile for each of the events in the model. These probability profiles, one being illustrated as "*3. Probability Profiles*" in Figure 1, indicate how long it might take for a specific COA to achieve desired effects. This indicates possible problematic time windows where probability of effects may reach undesired levels; what is important are the general trends (for each COA) and not necessarily the absolute probability values or times. The analyst can then vary the influence probability values in the influence net, the event durations and the COA values to improve achievement times or to reveal time windows where a risk of acceptable probability effects might occur.

Figure 1 indicates that Engagement Model simulations with higher fidelity potentially may be used to model a portion of the campaign model. This presents a challenge since Engagement Models typically are not modeled with influence nets or Petri-net executable models or with combinations of them. Representation at these lower levels of the simulation hierarchy usually employs physics-based attrition modeling methods (as well as ISR modeling and Communications modeling). In attrition models, individual engagements are simulated in terms of participant positional (x,y,z) and temporal (t) parameters. Explicit interactions, such as range of detection or firing accuracy, are modeled in more and more detail as one progresses to lower levels of simulation. Attrition modeling itself spans a wide range of fidelity, ranging from gaming methods with easier-to-use setup and exercise to fidelities that are very detailed, such as a 1:1 missile firing, which are highly accurate but of a focused scope. *Jane's® Fleet Command™* [Sonalysts, 1999] simulates naval tactical engagements, and in doing so it employs many of the typical physics-based methods used by the lower-level simulators. Its representation of detail can provide improved modeling of engagement event timing, and *Jane's Fleet Command* allows a user to invest greater involvement in the simulation in return for improved accuracy of details. Because of its general similarity to many attrition-level tools, a demonstration of its interfacing to a high-level tool like CAESAR II/EB brings forth many of the challenges faced in integrating "war-gaming participant" models across simulation hierarchy levels.

2 Case Study Overview

We used a case-based method to examine the hypothesis that it may be possible to develop relationships between the high level EBO models and the higher fidelity attrition models. The Persian Gulf War is a good candidate for use as a case study. It is well documented, and much unclassified information about it is published. Many of the situations encountered there are still significant today. We used documentation from Desert Storm to create first a high level EBO model and then a related set of attrition models. We attempted to discover how the higher level model can foster the development and analysis of the lower level model and how, in turn, the lower level model results can impact the higher level model. By using a known situation it is possible to validate model results and to test the postulated interfaces between the models that were developed. This also provides a base to generalize our findings.

This paper offers new methods, and our desire is to retain a focus on the novel work without becoming overburdened by the vehicle used as a demonstration. It is important to remember that the purpose is <u>to illustrate a method for integrating</u> effects-based and attrition modeling. We modeled the Desert Storm portion of the Persian Gulf War in its entirety using the EBO modeling techniques, which has not been done previously. We also chose to derive detailed engagement information from the higher-level documentation that was more readily available. While greater accuracy for the lower level modeling might be possible from extended work with more detailed sources, our derivation approach allowed us to maintain a focus on the primary purpose of using past history.

The library facilities at the Naval War College in Newport, RI, as well as other libraries and the internet, yielded much material on which we built our EBO model of Desert Storm. A single document, though, provided a particularly authoritative view backed up with some specific detail for the Persian Gulf War, and in particular about Desert Storm. "*Conduct of the Persian Gulf War: Final Report to Congress*" [DoD, 1992], produced under the direction of the Office of the Secretary of Defense, was used extensively for the base of our case study. The document presents major objectives at the strategic levels, and it traces their flowdown to the strategic theater military and operational campaign objectives. It also identifies the major tactical components for each of the campaigns. Its 900+ pages give a broad base of information, which includes strategic outlooks that allow for development of a high-level effects-based model, while also giving some combatant and timing specifics needed for the attrition models. The Final Report to Congress has major sections dealing with Desert Shield and Desert Storm; only Desert Storm is considered here.

3 EBO Approach to Case Study

To prepare an effects-based model based on this report following previous methods [Wagenhals and Levis, 2002], we identified over 52 items in the Final Report to Congress that seemed appropriate candidates for events used to build a model. Generally, these were objectives or activities stated as "bulleted" items in the Final Report to Congress. The Final Report to Congress also provides insight for a structure for interconnecting these items. Figure 2 shows a structure of how the higher-level objectives stated by the President flowed down through the coalition command planning. (The numbers in Figure 2 are used for later reference within the 52 events, which are discussed in Figure 3 as they are arranged into a CAESAR II/EB model.)

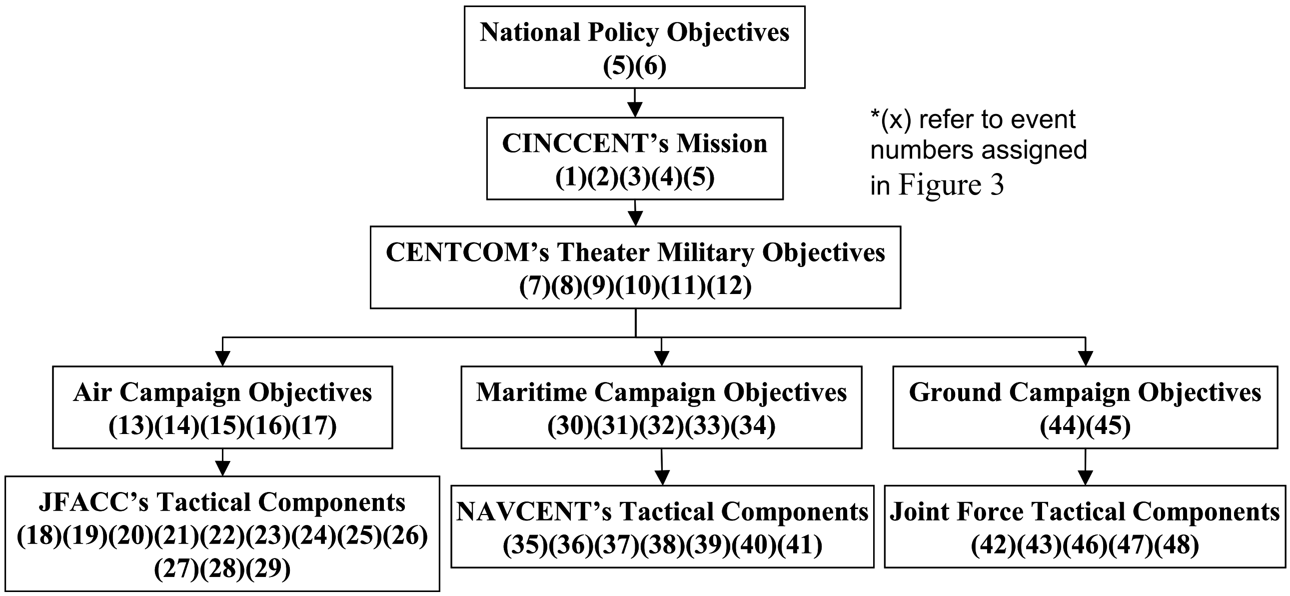

Figure 2 Flowdown of Persian Gulf War Objectives

Wagenhals and Levis [2002] outline a method for developing an effects-based model. This method identifies steps for an analyst/team to follow in building a model, beginning with the following guidance:

> *...first is to relate effects to actionable events. In this problem, we need to define the set of desired and undesirable effects* [i.e., model events] *on the adversary, and then, working backwards from effects to causes, arrive at the actions* [i.e., actionable events] *that we have at our disposal for achieving these effects.*

We chose to identify all of the items in Figure 2 "model events", and then we sought a structure for their interconnect. The flowdown structure of Figure 2 provides a method of "working backwards." With this insight, the influence net should have the structure of Figure 2 that has been rotated clockwise by 90°.

The CAESAR II/EB tool was used to capture the influence net. With the complexity of the model and the desire to tie the model via references back to the Persian Gulf War Final Report to Congress, we found it better to work with CAESAR II/EB's influence model augmented by a PowerPoint representation of the same influence net. Figure 3 shows the PowerPoint version of the influence net of the Persian Gulf War based on the Final Report to Congress. (It is emphasized that the actual modeling was done with the CAESAR II/EB tool, which gives an executable model.) The PowerPoint version depicts a full presentation of the event names, and we can trace each event by its "*(x) Event Name*" back to the page number of the Final Report to Congress for reference to further details if desired[1]. The influencing links of Figure 3 also have been numbered, allowing these dependency numbers to be referenced in subsequent discussion.

[1] These cross-reference pages are not included in this paper due to page limitations.

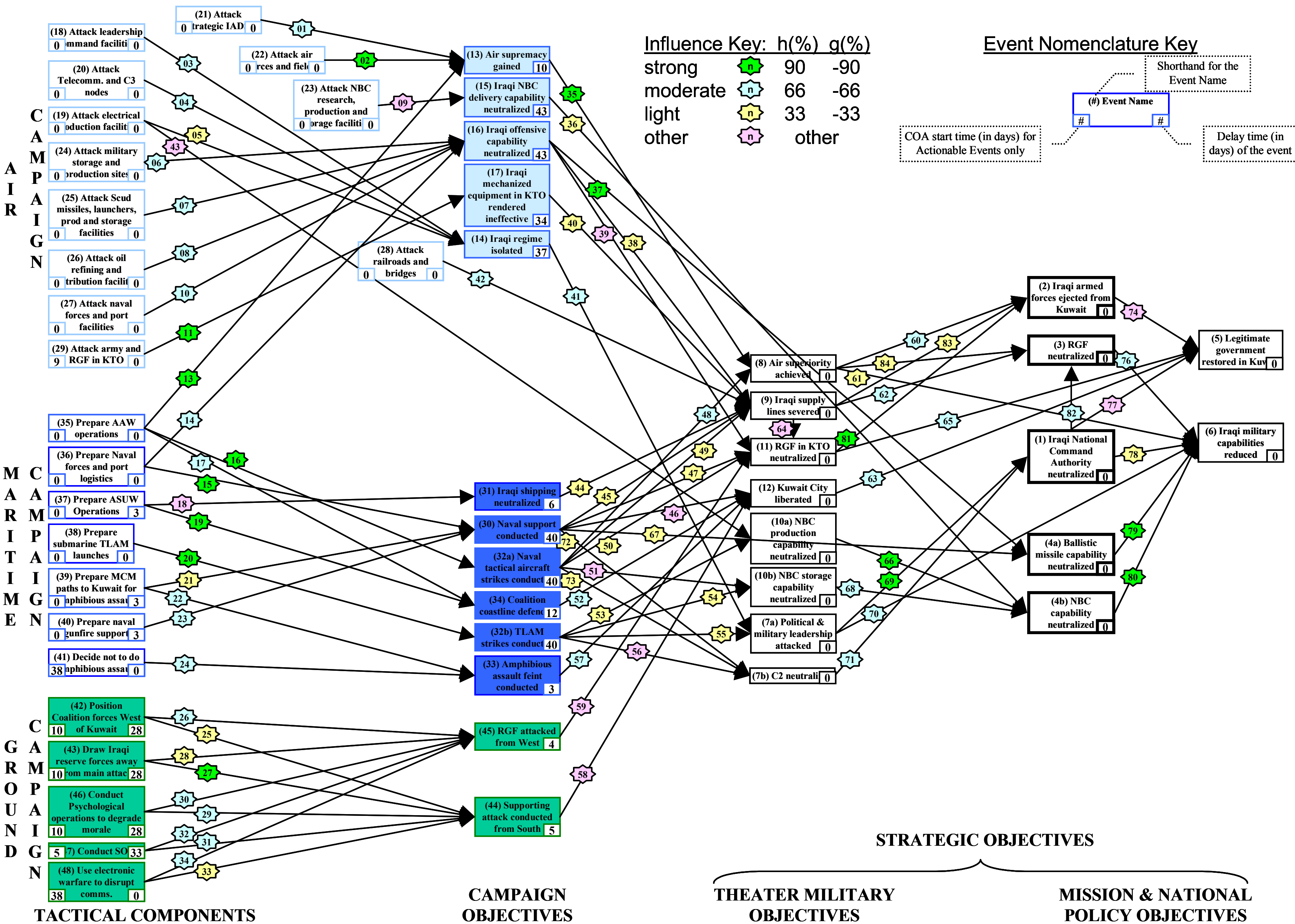

Figure 3 Influence Net of the Persian Gulf War (PowerPoint Version)

Each influencing link of Figure 3, i.e., the connector between the nodes, has an associated parameter pair called the influence (h, g) parameters, which are part of the CAESAR II/EB toolset. A heuristic algorithm called Causal Strength or CAST logic [Chang, et al., 1994; also Rosen and Smith, 1996] converts the set of h and g values to a conditional probability table that relates how influencing events affect dependent events. This conditional dependency is set by the analyst, and its setting assumes independence from other events outside of the event pair being considered. Each influence shown in Figure 3 is given an (h, g) pair value.

The definition of h and g in terms of a parent/child dependency is:

> **h:** *A value between [-1, 1] that, given that the parent event is true, gives the influence that the child is also true (h = 1) through no influence at all (h = 0) to the child is false (h = -1).*
> **g:** *A value between [-1, 1] that, given that the parent event is false, gives the influence that the child is true (g = 1) through no influence at all (g = 0) to the child also is false (g = -1).*

Intermediate values between [-1, 1] are permissible, and they indicate lesser degrees of influence of the parent on the child. The team developed a method to simplify the setting of these (h, g) parameter pairs, which is summarized by the annotation of the Influence Key table shown in Figure 3. This restricted set of values proved to accommodate desired model performance while at the same time simplifying their selection. The Influence Key table includes a color-coding technique so that each influence in Figure 3 conveys the selected values for (h, g).

The validation of this model concentrated on its overall behavior vis-à-vis the choice of values for the (h, g) parameters, since its structure and timing more were directly derived from the Final Report to Congress. As a minimum, model behavior must be that changes in input actionable events are manifest in reasonable changes throughout the net as well as changes at the overall effect nodes (Mission and National Policy Objectives). Such behavior insures that event probabilities are not unintentionally or prematurely forced to limit values, a behavior that would cloud proper predictions for realistic combinations of input actionable events. With a total of 24 actionable events in Figure 3 and for expediency without compromise in thoroughness, we examined behavior of the influence net largely by setting groups of actionable events to True or False rather than individual combinations. The Final Report to Congress decomposed the (typically joint) Desert Storm operations into the Air, Maritime and Ground campaigns. By exercising the model (with a candidate set of (h, g)'s) for the eight possible extremes of combinations of these 3 campaign groups, we obtained confidence that the set of (h, g) shown in Figure 3 are sufficient to insure a base for further checkout of the premises of this paper. The results of this behavioral analysis are shown in Table 1.

Actionable Event Group			Probability of Effect						
Air	Maritime	Ground	(5) Legitimate government restored in Kuwait	(6) Iraqi military capabilities reduced	(2) Iraqi armed forces ejected from Kuwait	(3) RGF neutralized	(1) Iraqi National Command Authority neutralized	(4a) Ballistic missile capability neutralized	(4b) NBC capability neutralized
no	no	no	0.01	0.02	0.01	0.01	0.15	0.04	0.12
no	no	yes	0.04	0.02	0.05	0.01	0.15	0.04	0.12
no	yes	no	0.05	0.11	0.05	0.29	0.35	0.09	0.28
yes	no	no	0.04	0.78	0.20	0.71	0.64	0.91	0.34
no	yes	yes	0.35	0.11	0.30	0.29	0.35	0.09	0.28
yes	no	yes	0.52	0.78	0.86	0.71	0.64	0.91	0.34
yes	yes	no	0.33	0.95	0.55	0.90	0.84	0.96	0.65
yes	yes	yes	0.94	0.95	0.98	0.90	0.84	0.96	0.65

Table 1 Outcome of Influences for a Set of Actionable Event Groups

Table 1, which presents here the conditional probabilities only for the two Mission and National Policy Objective and five Theater Military Objective events, demonstrates how the model behaves for the baseline of our case study. This table shows:

- The coverage from no involvement of any campaigns to all three being involved sends the primary desired effects (events (5) and (6)) from 1-2% to 94-95%, extreme values that make sense
- While events (5) and (6) are successful, event "*(4)b neutralizing NBC capability*" is less successful
- No campaign by itself was able to realize event "*(5) restoring a legitimate government in Kuwait*", although the Air Campaign by itself did have a significant influence (78%) on event "*(6) reducing Iraqi military capabilities*"
- Together, the Maritime and Air Campaigns (without the Ground Campaign) had a strong influence (95%) on event "*(6) reducing Iraqi military capabilities*", but without the Ground Campaign, the Maritime and Air Campaigns only had a moderate (33%) influence on event "*(5) restoring a legitimate government in Kuwait*"
- Alone, the Air Campaign had by far the most significant impact on event "*(3) neutralizing the Republic Guard Forces*", much more than either the Ground or the Maritime Campaigns did by themselves

In addition to these hypothetical discussion points and examination of the final objectives only, we also examined selected other event combinations and also the behavior of the interior nodes of the influence net to assure credibility of the case study baseline.

The preceding discussion, focusing on the static behavior of the CAESAR II/EB model, lays the groundwork for proceeding to the dynamic exercise of the model. One part of doing this requires setting a delay value for each event in the influence net. The second part requires the setting of the initiation time for each of the input actionable events, that is, a COA for the model. Again, information from the Final Report to Congress provided the basis of doing this. The PowerPoint representation Figure 3 shows the delay and start values used in the CAESAR II/EB model of the Persian Gulf War.

The Final Report to Congress provided a good description of the overall timeline for key wartime activities. We strived to subjectively capture those times for each of the events. All of the time variations were placed in the Tactical Component and Campaign Objectives categories of Figure 3. Upon completion of the Campaign Objectives, then, the higher-level Theater Military Objectives and Mission and National Policy Objectives are realized with a delay time of 0 days. The time span covered in total is from H-hour to G+4, the cessation of combat activities. The resulting output from the CAESAR II/EB model for the probability of achievement of the Mission and National Policy Objectives of Figure 3 is shown in Figure 4.

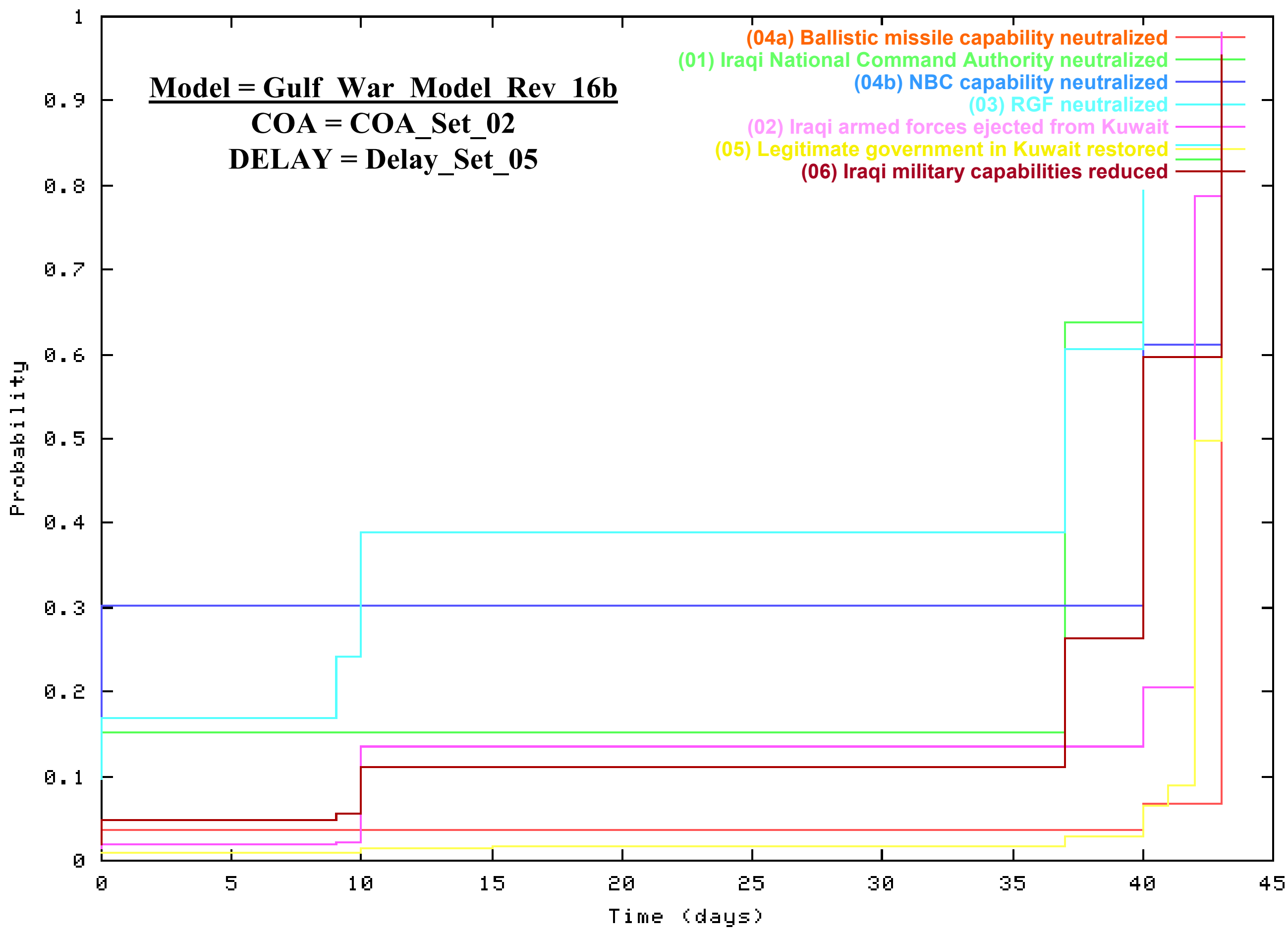

Figure 4 Outcome Probabilities for Original High-Level Model

Such graphs, where CAESAR II/EB computes the timing of all events in the EBO model, are a rich source for analysis. For this case, such analysis shows that for this model probability of realizing the Theater Military and Mission and National Policy Objectives grows with time. Furthermore, the first major influences occur at day 9 due to the completion of the events "*(28) Attack railroads and bridges*" followed by event "*(31) Iraqi shipping neutralized*." At day 10, transitions are due to events "*(13) Air supremacy gained*" and "*(8) Air superiority achieved.*" Other major transitions occur at day 37 due to event "*(14) Iraqi regime isolated*" and then in days 42 and 43 with a combination of the events "*(16) Iraqi offensive capability neutralized*", "*(45) RGF attacked from West*" and "*(44) Supporting attacks conducted from south*." These behaviors, together with the results of Table 1, extended our confidence in the basic EBO model and in building upon this as a base model for our case study.

4 Integrating Attrition

To test the concept of using attrition models to supplement the high-level model, we needed to identify specific engagements within the campaigns for modeling with physics-based tools. The Final Report to Congress discussed many such engagements, and it provided varying levels of detail about them. One can evolve to these specific engagements by one of two methodologies: 1. top-down; and, 2. bottoms-up. The first method is more appropriate when the wartime objectives have been set and planning is underway to explore alternative engagements to assess what their impact might mean on desired effects. In doing so, modeling work might be expedited if one has available a "library" of similar engagements previously modeled and analyzed. Interestingly, the second method (bottoms-up) is one way to build such a library of engagements. We choose this second method to build our test cases for the case study as it also illustrated how such libraries might be developed.

For a campaign-level naval warfare simulation of engagements, our research used a modified version of *Jane's® Fleet Command*™. [Sonalysts, 1999] This tool has been used in military war-gaming, and it is typical of other engagement tools in its manner of employing physics-based measures of effectiveness. It models both naval and air operations so that we could cover both the Maritime and Air Campaign aspects of Desert Storm. It also can model direct support of Ground Tactical Component activities such as Naval Gunfire Support (NGFS).

We used this tool to model three specific engagements of Desert Storm, which we show here as test cases to illustrate their integration into the EBO model. Clearly, their inclusion and integration represents the modeling of only a small portion of the total tactical component activities for Desert Storm. As such, we retain all events of the baseline EBO model since at the high level they also cover these other campaigns. The characteristics of the three engagements that we selected are quite different in order that we can test that our premise might be applicable to a wide number of situations. We cover in the following discussion one of these engagements in greater detail, and then the other two in a more cursory manner, discussing only their salient features.

An extract from the Final Report to Congress describes one of the larger Persian Gulf War events that fits the criterion for modeling with *Jane's Fleet Command*:

> *"The next day [30 January], a large force of Iraqi combatants based at Az-Zubayr and Umm Qasr attempted to flee to Iran, but was detected and engaged by Coalition forces near Bubiyan Island in what was later called "the Battle of Bubiyan." This battle lasted 13 hours and ended with the destruction of the Iraqi Navy. With P-3Cs providing target locations, helicopters, ASR aircraft on alert, and other aircraft diverted from strike and CAP missions conducted 21 engagements against Iraqi surface combatants. By the end of the Battle of Bubiyan, one FPB-57 missile boat and two TNC-45 missile boats were heavily damaged. An additional three Osa missile boats and possibly a third TNC-45 were damaged. Three Polnocny amphibious ships were damaged, two of them heavily, along with one T-43 minesweeper. Only two damaged ships, an Osa II missile boat and a Polnocny amphibious ship escaped to Iranian waters."*

We used this and other descriptions of this engagement from the Final Report to Congress to build a model with *Jane's Fleet Command*. When the model is executed, *Jane's Fleet Command* creates for the analyst several displays that show movement in space of all parties to the simulated engagement. Those displays evolve in movie-like fashion, continuing (if the analyst wishes) until all adversary participants are eliminated. Figure 5 is a screen capture of a snapshot (in time) typical of the attrition-based simulation used to model the Bubiyan Island engagement. The lower-left panel shows the 2D overall view of the engagement, a portion of which is enlarged in the upper panel to show better detail of those participants. The center lower panel provides a 3D birds-eye view for any one of the selected combatants, and the lower right panel gives detailed information of that participant currently under the cursor location. To gather data for this integration illustration, we ran the simulation in the computer-only.[2] At the end of the engagement, its output is a spreadsheet (not shown) of the timeline events for each participant. Several runs of an engagement (same set-up, but different performance due to the statistical nature of these models) were made for a given set-up. This provides averaged data for use in the timing of events in the higher-level CAESAR II/EB model.

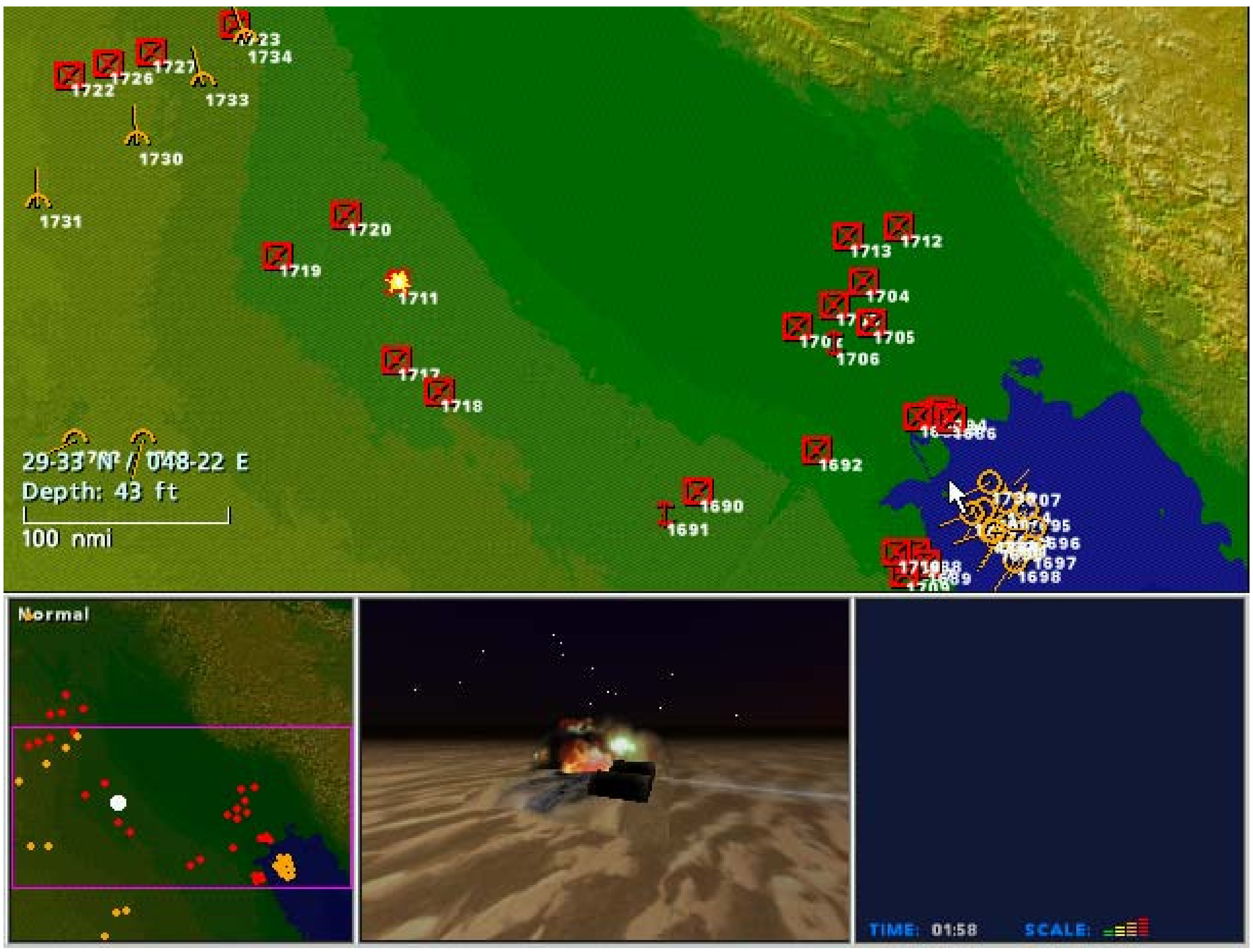

Figure 5 Attrition Modeling of the Bubiyan Island Engagement

The Bubiyan Island Engagement was primarily a naval engagement. Following bottoms-up reasoning, we treated its interfacing needs to be predominantly subsets of the Maritime Campaign Objectives. This leads to Figure 6, which shows just the portion of Figure 3 we identify as those events that may have a direct connection with the Bubiyan Island Engagement. (Other influences unimportant to this discussion are omitted.)

[2] Other modes include man-in-the-loop and computer versus man.

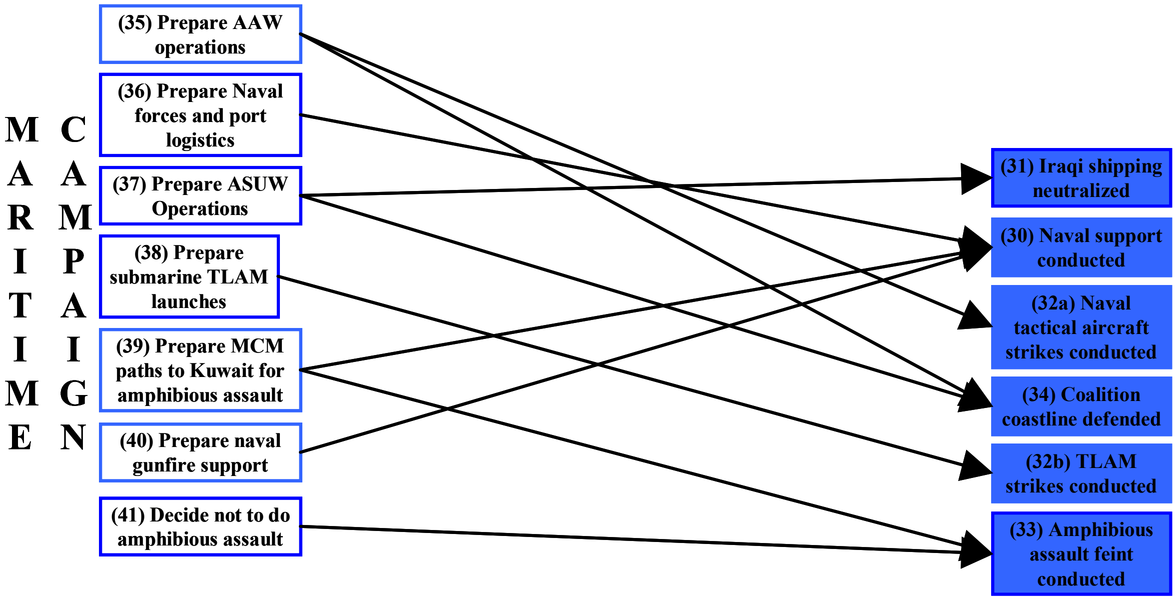

Figure 6 Identify a Sub-Net for Integration

The attrition-based *Jane's Fleet Command* provides quantitative measures of effectiveness (% killed) of the engagement participants versus time. Thus, the effect(s) of the attrition model are events that reflect achievement in progress for the neutralization of adversarial participants. We propose that such events become the vehicle for interfacing information from the lower level to the EBO model, as is shown in Figure 7. We also found it helpful to include an addition precursor event (also shown), which proved helpful in setting the event time delays needed by the CAESAR II/EB model.

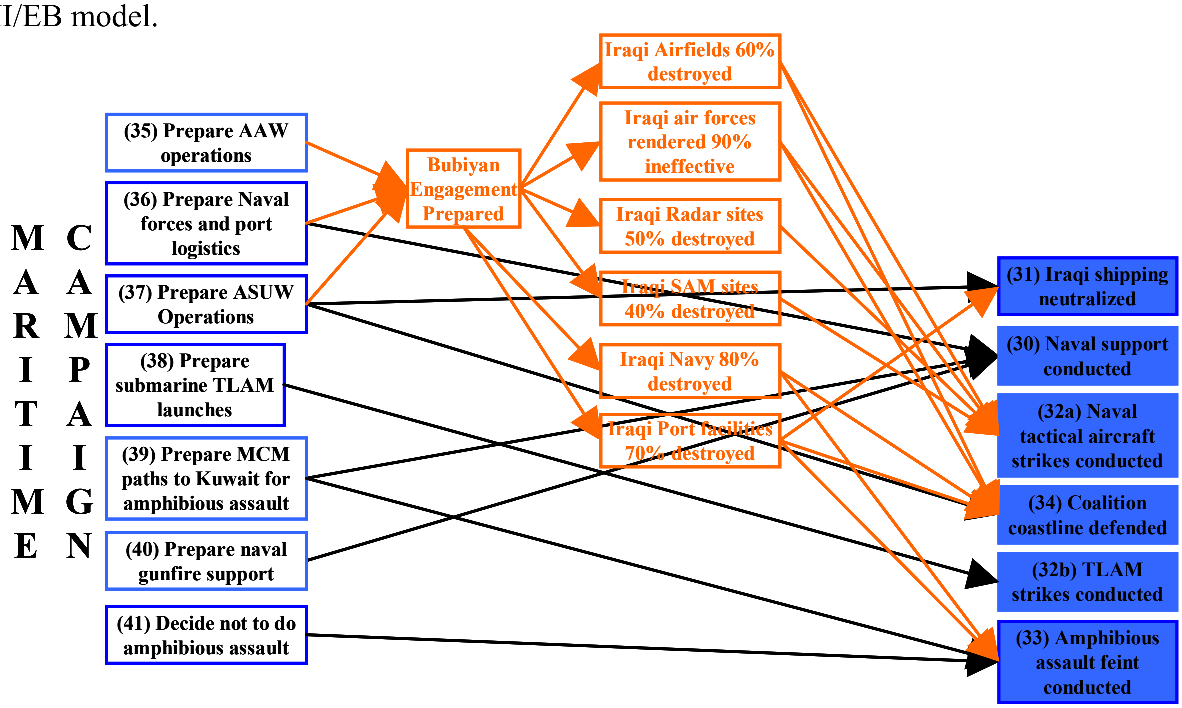

Figure 7 Placeholder Events Added For Interfacing Attrition Result

These additional attrition events derived from the attrition model are integrated into the EBO model by adding influence links from high-level events that have a role in the higher fidelity engagement model. As shown in Figure 7 only three of the (actionable) Maritime events should have an influencing role, and the Bubiyan Island engagement should impact only three of the Maritime Campaign Objectives. This, then, determines the structure of the interfaced addition to the high-level model for this engagement.

To show that this integration procedure applies also to other situations, we identified from Desert Storm two additional engagements driven by Intelligence, Surveillance and Reconnaissance (ISR). Today some of these situations would rely heavily on resources like Global Hawk and Predator. Within the realm of the Persian Gulf War, the documentation of the Final Report to Congress identified engagements using earlier systems such as Pioneer for Naval Gun Fire Support (NGFS):

> *"On 4 February, USS Missouri, escorted by USS Curts using an advanced mine avoidance sonar (a modified hull mounted SQS-56 sonar), threaded through a mine cleared channel and unlighted navigational hazards to a position close to the coast (FSA RK2). With Marines providing fire control direction, USS Missouri's 16-inch guns fired 2,700-pound shells onto Iraqi C_3 bunkers, artillery emplacements, radar sites, and other targets. Between 4 and 6 February, USS Missouri fired 112 16-inch shells, 12 five-inch shells, and successfully used an Unmanned Aerial Vehicle (UAV)* [Pioneer] *in support of combat missions ... near Ras Al-Khafji."*

And in the spirit of today's integrated ISR resources, the Final Report to Congress reported on developmental systems, such as JSTARS, used at a very early stage in support roles prior to their full deployment:

> *"This ended the ground engagements of the battle of Al-Khafji, but a lesser known aspect had taken place that night, 30-31 January, farther north, inside occupied Kuwait. During the daylight hours of 30 January, while Coalition aircraft conducted tactical strikes on Iraqi forces in contact with Coalition ground forces, manned and unmanned reconnaissance, and intelligence assets gathered a clearer picture of what was going on behind the leading Iraqi elements. New reconnaissance technologies such as the TR-1, Joint Surveillance Target Attack Radar System (JSTARS), and Navy and USMC unmanned aerial vehicles played an important role. For eight hours, throughout the night, Coalition air power systematically attacked and decimated the two divisions; by daybreak the divisions were retreating in disarray. If they had been able to attack into Saudi Arabia in good order, they might have precipitated a large-scale ground engagement and caused significant Coalition casualties. Instead, they were repulsed. III Corps suffered numerous casualties and lost a substantial number of tanks and an undetermined number of other vehicles, according to combat unit and intelligence reports."*

In a manner following the preceding discussion for Bubiyan Island, attrition results from *Jane's Fleet Command* modeling these ISR Engagements yielded similar interface events that quantified the neutralization of adversarial participants. As expected, they interconnect to high-level events (some the same, some different) with influence links to provide an integrated EBO structure. The result of integrating these three attrition models is shown in Figure 8.

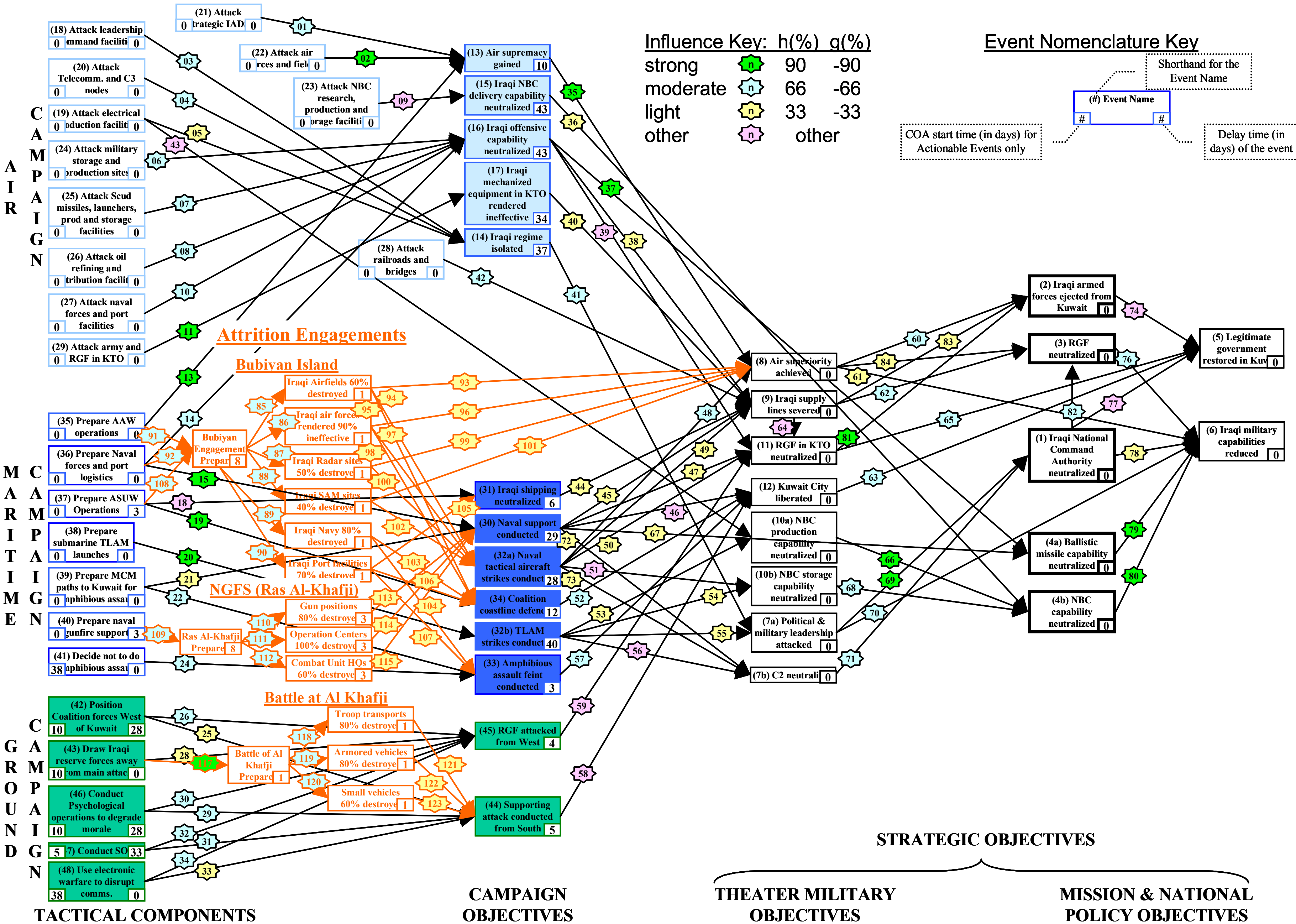

Figure 8 Integrated Influence Net of the Persian Gulf War (PowerPoint Version)

With an integrated attrition model, we can now extend our influence links beyond the original ones where steps additional to those listed above may be warranted to improve the fidelity of the original model. This is illustrated in the final form of Figure 8 by the Bubiyan Island Engagement, which contains additional dependencies beyond those developed in Figure 7. We added the influences #93, #96, #99 and #101 to illustrate that the analyst, for this model, realized that the air achievements marked by completion of the Engagement events

- *Iraqi Airfields 60% destroyed*
- *Iraqi air forces rendered 90% ineffective*
- *Iraqi Radar sites 50% destroyed*
- and, *Iraqi SAM sites 40% destroyed*

really have no explicitly evident connection with the original five Campaign Objectives 30-34. Thus, four influencing links were added to make the event "*(8) Air superiority achieved*" show this dependency more explicitly. This demonstrates that inclusion of more detailed information by the lower-level attrition model allows for improvement of the original model. A similar case is shown in Figure 8 by the added influencing links #104 and #107, both of which an analyst might consider adding so that the event "*(33) Amphibious assault feint conducted*" can show a dependency on the attrition simulation of destruction of a large part of the Iraqi Navy.

In our case, the insertion of the attrition model should not change the overall behavior of the original high-level effects-based model. This is intentional since the focus of this work is to develop a generalized method, which once established allows the analyst to vary the parameters further and cause different outcomes if desired. Table 2 shows the outcome event probabilities for the same events presented in Table 1, from the high-level effects-based model. Comparison of the results of these two tables show that inclusion of the attrition models has preserved the behavior insofar as the coarse level afforded by setting to True or False each of the input tactical component actionable events as a campaign group.

Actionable Event Group			Probability of Effect						
Air	Maritime	Ground	(5) Legitimate government restored in Kuwait	(6) Iraqi military capabilities reduced	(2) Iraqi armed forces ejected from Kuwait	(3) RGF neutralized	(1) Iraqi National Command Authority neutralized	(4a) Ballistic missile capability neutralized	(4b) NBC capability neutralized
no	no	no	0.01	0.02	0.01	0.01	0.15	0.04	0.12
no	no	yes	0.04	0.02	0.05	0.01	0.15	0.04	0.12
no	yes	no	0.05	0.12	0.07	0.31	0.35	0.09	0.27
yes	no	no	0.04	0.76	0.19	0.69	0.64	0.91	0.34
no	yes	yes	0.33	0.12	0.30	0.31	0.35	0.09	0.27
yes	no	yes	0.52	0.76	0.85	0.69	0.64	0.91	0.34
yes	yes	no	0.30	0.95	0.52	0.90	0.83	0.96	0.64
yes	yes	yes	0.94	0.95	0.98	0.90	0.83	0.96	0.64

Table 2 Outcome of Integrated Influences for a Set of Actionable Event Groups

With the inclusion of additional modeling structure based on the attrition models, some adjustment may be required for the element delay times downstream from where the attrition models are integrated. Figure 8 illustrates two methods for doing this. For the events of Bubiyan Island and

NGFS engagements, influencing links #16, #17 and #23 were dropped and effectively replaced by the inserted events representing the attrition-based models. To preserve their original 40-day delays, the delays of events "*(30) Naval support conducted*" and "*(32a) Naval tactical aircraft strikes conducted*" were reduced to adjust for the delay times assigned to the inserted events.

The second method for adjusting downstream time delays is illustrated by the inclusion of the Battle of Al Khafji into the Ground Campaign. This method also highlights a part of our solution that still requires future work to understand and resolve. Following the same rationale for dropping influence links when inserting the attrition modeling, we deleted the influencing link #27 when transitioning from Figure 3 to Figure 8. The delays for the events of the inserted engagement appropriately are small, reflecting the short duration of the Battle of Al Khafji, which the Final Report to Congress indicates commenced on day D+12. As shown in Figure 3, the parent event *"(43) Draw Iraqi reserve forces away from main attack*" completes at day D+38. While that representation of event timing was adequate for the higher level modeling of the Ground Campaign, it is not adequate here for the inclusion of the greater detail of a particular engagement. We partially solved this by changing the delay time of the actionable event *"(43) Draw Iraqi reserve forces away from main attack*" from 28 days to 0 days, which Figure 8 shows. With this change, the model now more accurately represents the start of the Battle of Al Khafji. This solution may not be desirable if other external forces predetermine the timings of the input actionable events and their adjustment is not left to the modeler. This solution, if allowable, also can cause other influences, such as influencing link #28, to act upon its child ("*(45) RGF attacked from West*") at times earlier than intended. This premature influence could have been corrected by adding another event, which only serves as a placeholder delay to restore back the initial timing to the model. This added correction also could be circumvented by another option, which is to employ other modeling tools that incorporate timing delays into the influence representations along with their influencing probabilistic parameters. Our work here shows that a solution is possible and that further work may be needed to provide greater flexibility to the modeler for more accurate modeling.

The adjustment of these onset and delay times, whose results are shown in Figure 9, illustrates different ways that the attrition models can cause the higher level model to be modified or enhanced. This demonstration of integrating effects- and attrition-based models is built around a very high-level view of the entire war. In real application, one probably should deal with a more localized scope of wartime events whenever specific events are modeled in greater detail by including attrition-based findings. In this illustration, three different tactical engagements were placed together here in a single model in order to demonstrate several integration techniques. It may be useful to break the high level model into smaller pieces and study those pieces individually in order to increase the fidelity of a modeling effort.

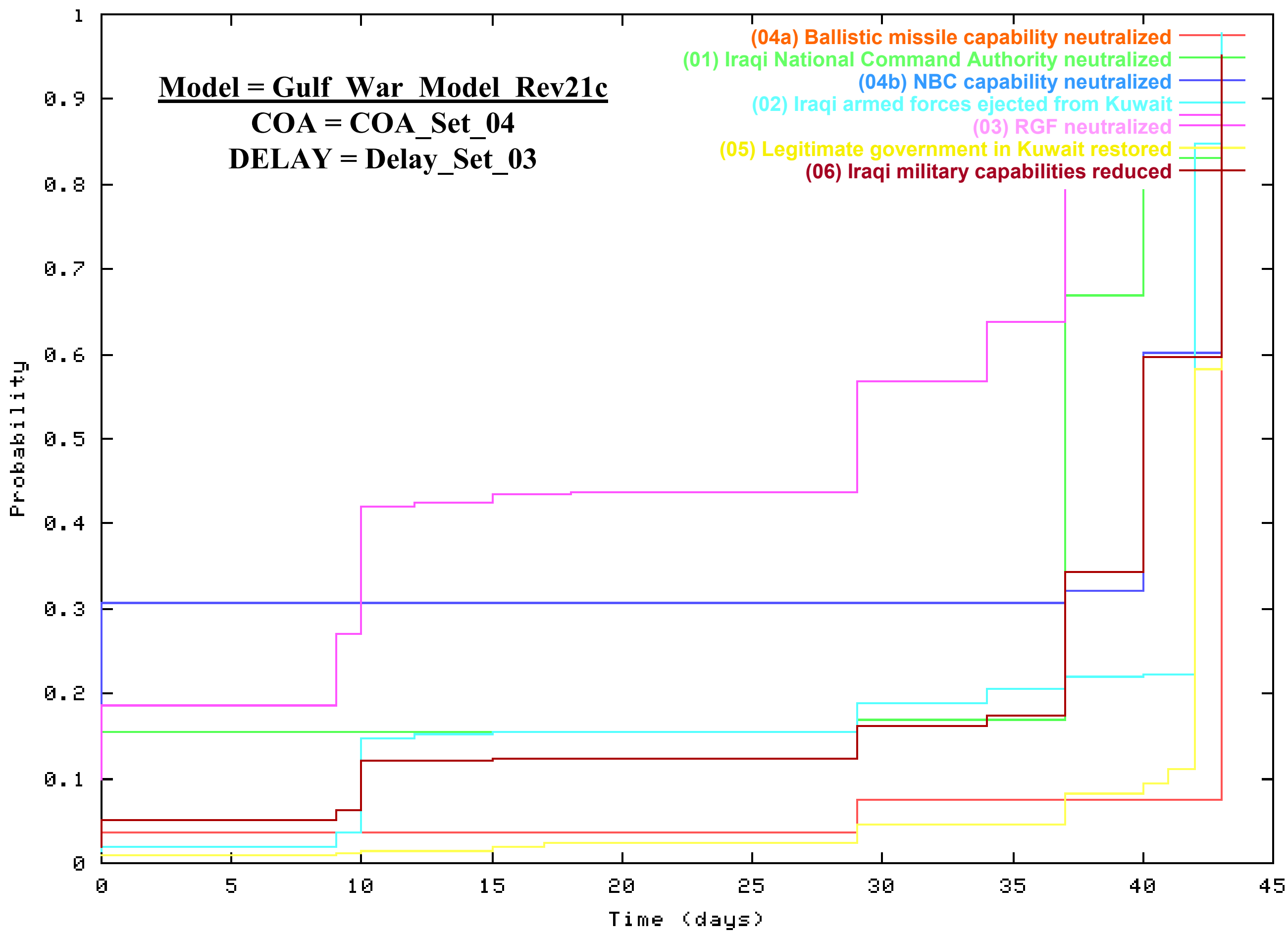

Figure 9 Outcome Probabilities for Attrition Model Integrated with High-Level Model

With the attrition models now included, Figure 9 behaves largely the same as Figure 4. There are slight differences, however. For example, at day 29 the probability for event "*(03) RGF Neutralized*" rises; this is caused by the event delay of "*(30) Naval support conducted*" being 29 days. In setting up the model and as discussed above, this delay was reduced from its original 40 days to 29 days to reflect inclusion of the 11th day NGFS engagement at Ras Al-Kafji; the expectation was that these days would be additive to produce back the original 40 days. Contrary to expectations, the reduced delay becomes visible in any case. This occurs because of influencing link #15. Its (h, g) values were retained at their original setting as strong, and its structure also connects to "*(30) Naval support conducted*" in parallel with the added engagement model. Thus, changing the delay of "*(30) Naval support conducted*" based on the addition of the structure from the attrition model should not have been done because the addition was not the only structure connected to the node. This serves to illustrate that care must be taken when integrating the models, as unintentional side effects can occur.

With the toolset used for this research, delays were confined to values associated with events only. Newer versions of the tools allow delays to also can be associated with the influencing links. With delays on both influencing links and nodes, one must consider whether the additional structure created from using attrition models represents a refinement of the links or the nodes. If the model is refining the link, then the new structure with the time delays derived from the attrition modeling can replace the original link. If the new structure is a refinement of the node, then it is important that the attrition model include incorporate all the incoming influencing links to that node.

Figure 9 also shows more activity at day 34. That activity is caused by event "*(17) Iraqi mechanized equipment in KTO rendered ineffective*" through influence #40. Since the event discussed in the preceding paragraph precedes happenings through influence #40, its higher probability causes the information arrivals through influence #40 to now be visible as they arrive at event "*(9) Iraqi supply lines severed*." This latter event in turn has through influence #62 a moderate influence on event "(3) RGF Neutralized", causing its probability to increase earlier than in Figure 4.

5 Conclusion

Practitioners are beginning to explore the use of Effects Based Modeling tools based on probabilistic methods. Initial efforts have been to use this approach at the strategic level where model fidelity is relatively low and the elements of the models are determined by Subject Matter Experts using subjective methods. The credibility of such models to support decision-making is often a challenge. In addition to these approaches, there are many higher fidelity models that have been developed that can be used for more detailed analysis of courses of action. This paper describes our initial research into developing formal methods for linking or interfacing the higher-level effects based models to the lower level, higher fidelity models.

Using a case study approach we explored a process for relating a high level effects based model with detailed attrition based models. We hypothesized that the there were potentially two benefits from doing this. First, attrition models may be useful in providing a more detailed look at actionable events that are created in the high level EBO model. The attrition model can help planners refine the courses of action selected from analysis of the EBO model. The second benefit is that the attrition models may help refine the EBO model. This could be done in two ways. First, a more refined structure for the EBO model may be obtained from the attrition model and second, conditional probability values and refined timing information for the nodes and the influencing links may be obtained from the attrition models.

Creating these linkages for the case study was labor intensive. We did not discover or develop a method for directly linking EBO models to attrition models. Instead, an analyst familiar with both modeling techniques translated the information in the EBO model into the data needed to set up the attrition model and determined the type of analysis that should be conducted with the attrition model. After the analysis of the attrition model was completed, the analyst determined where it made sense to add additional structure to the EBO model and how to refine the timing information in the EBO model. We discovered that care must be taken when "cutting" the EBO model to incorporate new structure from the attrition models. It is possible that formal rules for this insertion of new structure and the adjustment of timing information can be developed.

We believe that this research represents preliminary steps toward a more formal and tractable approach to relating high-level EBO models with higher fidelity attrition models. The challenge is that the two techniques are very different and not well matched in terms of inputs and outputs.

Each technique can provide answers to different aspects of a larger problem: how to develop, compare and select feasible courses of action that will give a reasonable chance of achieving desired effects in a timely manner. Attrition models help understand the physical nature of EBO while probabilistic EBO models can address the higher level effects that involve the human belief and reasoning processes. The connection is that courses of action use physical actions to influence the reason and belief processes. If methods for linking these two modeling approaches can be refined, we believe that collectively more accurate and useful attrition and EBO models can be created.

References

Chang, K.C., Lehner, P. E., Levis, A. H., Zaidi, A. K., and Zhao, X. (1994). On Causal Influence Logic, Technical Report, George Mason University, Center of Excellence for C3I.

DoD, (1992). "Conduct of the Persian Gulf War: Final Report to Congress," US Government Printing Office, Washington, DC, April.

Levis, A. H. (2000). "Course of Action Development for Information Operations," *Phalanx*, Military Operations Research Society, Vol. 33, No. 4.

Rosen, J. A., and Smith, W. L. (1996). "Influence Net Modeling with Causal Strengths: an Evolutionary Approach," *Proc. Command and Control Research Symposium,* Naval Postgraduate School, Monterey, CA, pp.699-708.

Sonalysts, Inc. (1999). "Jane's Fleet Command," Electronic Arts™ brand; also Jane's Library©, Jane's Information Group Ltd.

Wagenhals, L. W. and Levis, A. H. (2001). "Modeling Effects Based Operations in Support of War Games," 15th International Symposium on Aerospace/Defense Sensing, Internal Society for Optical Engineering, *Proceedings of SPIE* Vol. #4367, Orlando, FL, April.

Wagenhals, L. W. and Levis, A. H. (2002). "Modeling Support of Effects-Based Operations in War Games," Proceedings of the 2002 Command and Control Research and Technology Symposium, 11-13 June 2002, Monterey, CA.

Wagenhals, L. W., Shin, I., and Levis, A. H. (1998). "Creating Executable Models of Influence Nets with Coloured Petri Nets," *Int. J. STIT*, Springer-Verlag, Vol. 1998, No. 2, pp.168-181.

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Integrating Effects-Based and Attrition-Base Modeling

Mr. Edward A. DeGregorio *
Dr. Raymond A. Janssen **
Dr. Lee W. Wagenhals ***
Dr. Richard Messier *

2004 CCRTS
Command and Control Research and Technology Symposium

June 15 -17, 2004
San Diego, CA

OVERVIEW

- Purpose: Examine process and methods of interfacing high-level probabilistic Effects-Based models with higher fidelity attrition-based models and performing evaluations of alternative Courses of Action using the combination of these modeling techniques
- Outline:
  - Effects-Based Challenge
  - Case Study from Persian Gulf War
  - Conclusions

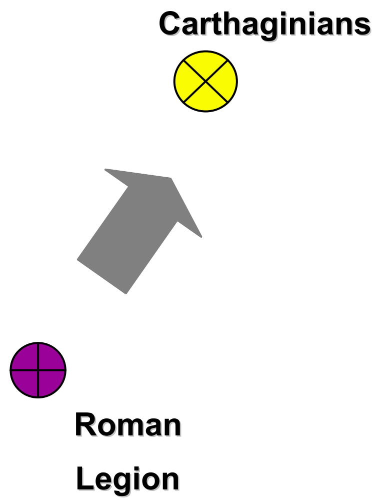
Network-Centric Effects-Based Operations (EBO) … Shaping the Adversary's Behavior

- **JFCOM defines EBO** as ***"a process for obtaining a strategic outcome or effect on the enemy through synergistic, multiplicative, and cumulative application of the full range of military and non-military capabilities at the tactical, operational, and strategic levels".***
- **Network-Centric Operations (NCO) <u>enables</u> EBO**
  - **NCW enabled by 4 technologies:**
    - **Sensors**
    - **IT and Network Architectures**
    - **Precision Weapons**
    - **Stealth Platforms**

EBO is the key to broadening the role of NCO beyond Attrition Warfare

Evolution of Warfare* and Modeling & Simulation Approaches

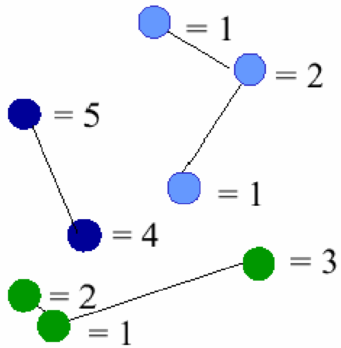
* *Measuring the Effects of Network Centric Warfare, Booz-Allen & Hamilton, 1999*



Single Dimension Warfare

Force N on M

Lanchester's Equations: Attrition Modeling



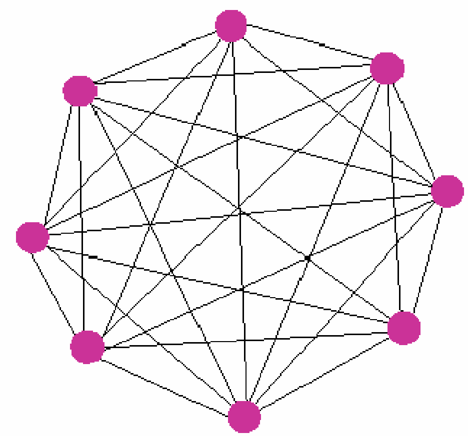
Total Force Value = 19
(N+N+N+N+N+N+N+N)

Platform-Centric Warfare

PCW ⇨ $\sum N_i$

Physics-Based Force-on-Force Attrition Modeling

(Campaign, Engagement)



Total Force Value = 64
(N^2)

Network-Centric Warfare

NCW ⇨ $(N)^n$

Paradigm Shift to EBO requires modeling Physical + Belief + Reason Domains**

** BGEN Deptula, USAF, 2001, on *"EBO: Change in the Nature of War"*

Dimensions of Network Centric Warfare (NCW)*

Information/Knowledge Grid

(Nanoseconds)

** Measuring the Effects of Network Centric Warfare, Booz-Allen & Hamilton, 1999*

Network & Info Technology

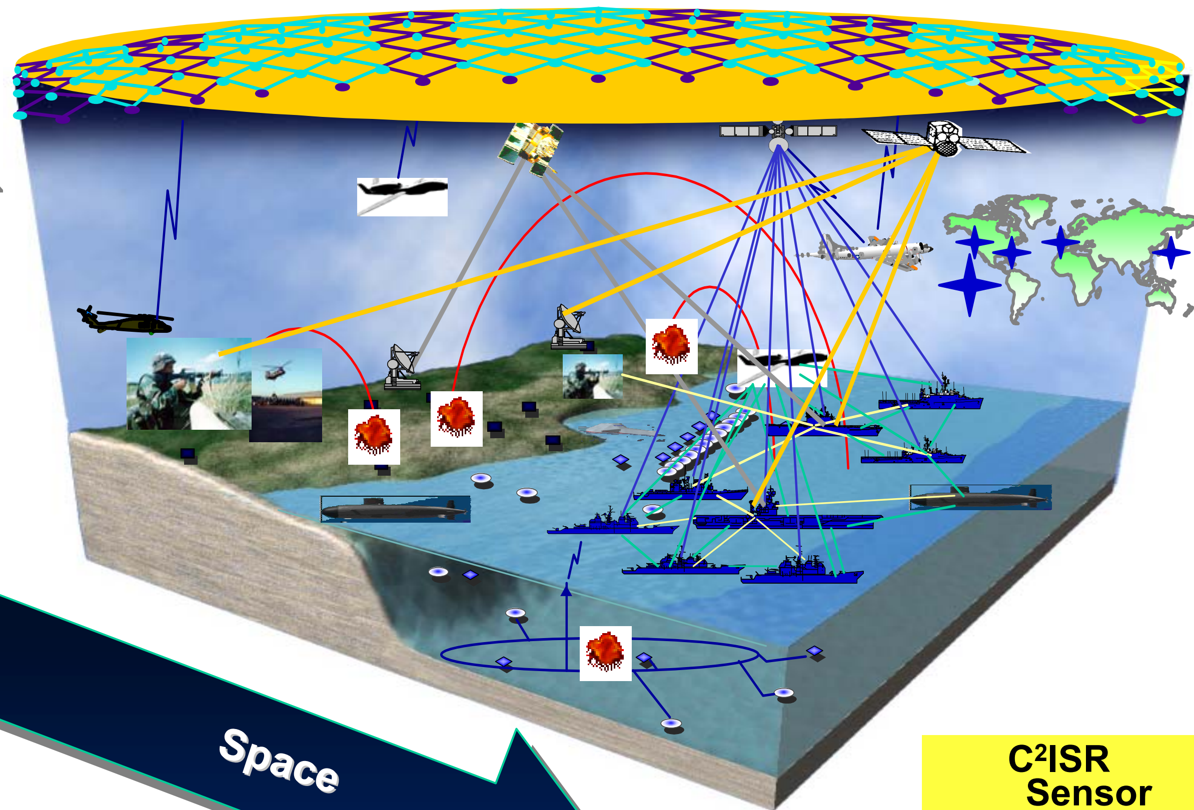
Time

Engagement Grid

(Weeks … Minutes)

Force

Space



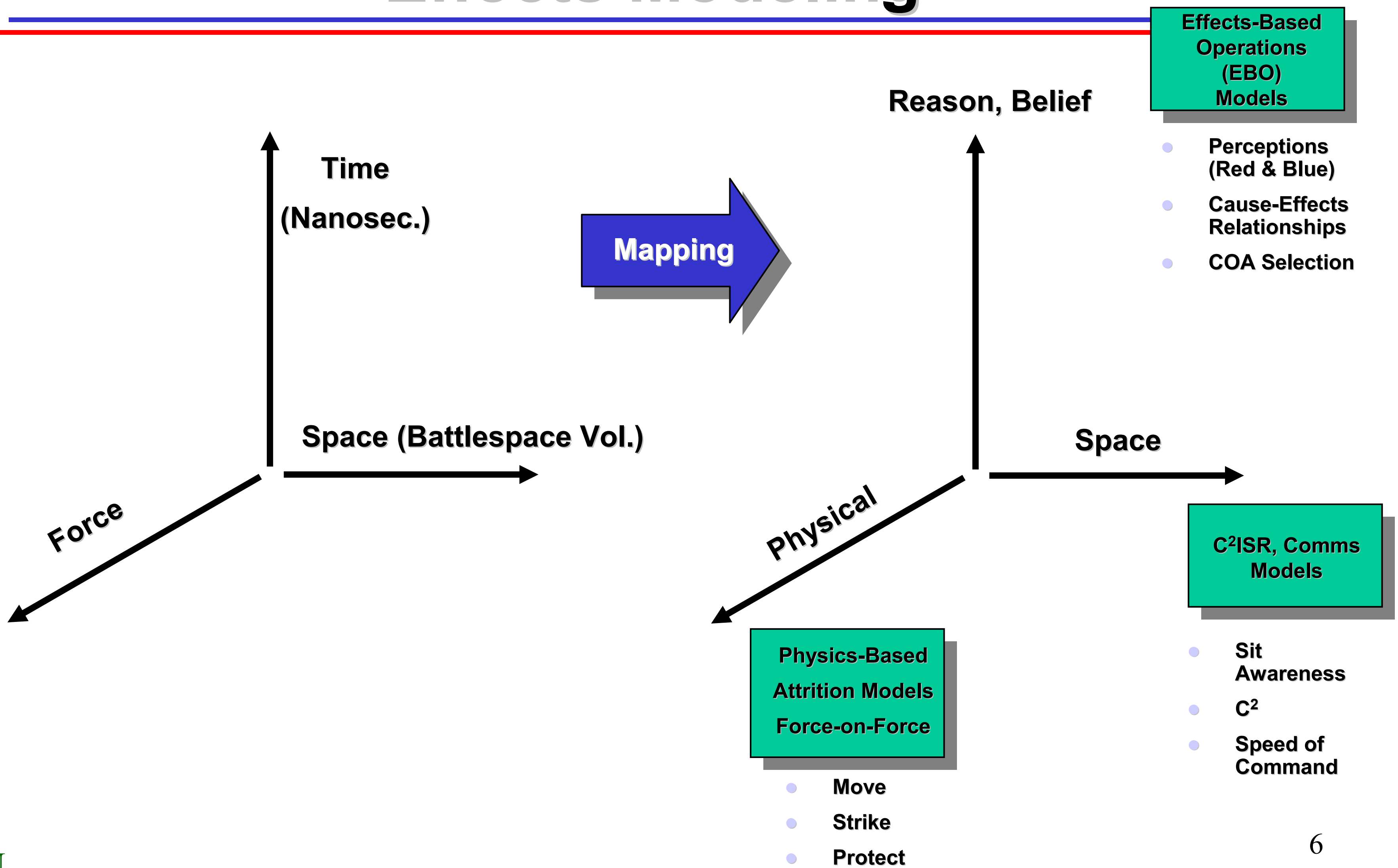
C^{2}ISR Sensor Networks

Stealth Platforms, Precision Weapons

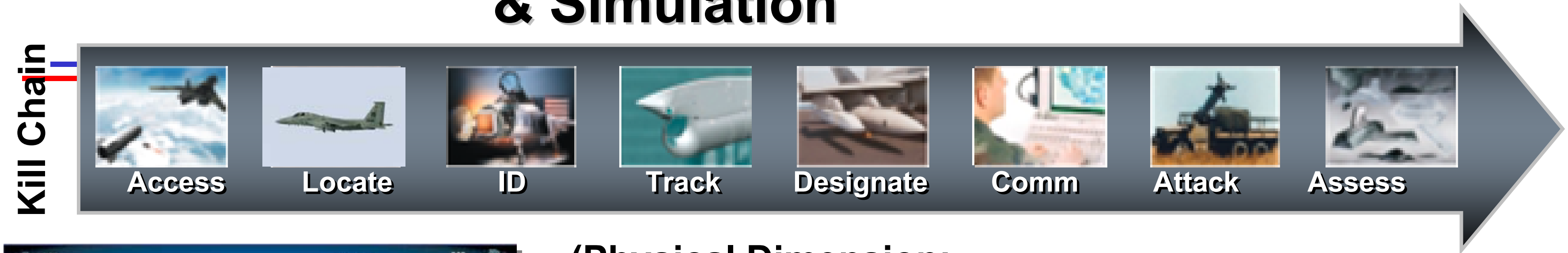
Sensor Grid

(1000s - 1,000,000s m.)

Integrate Physical & Cognitive Effects Modeling



EBO Modeling Linked to Attrition-Based Modeling & Simulation



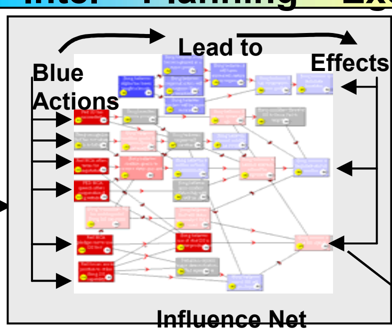
(Physical Dimension:
Force, Space, Time
Domain)

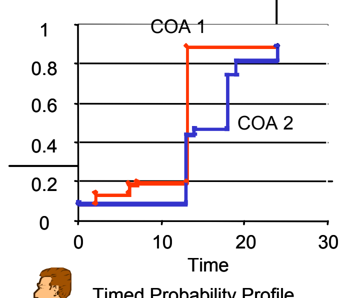
+

EBO NCW Operational System

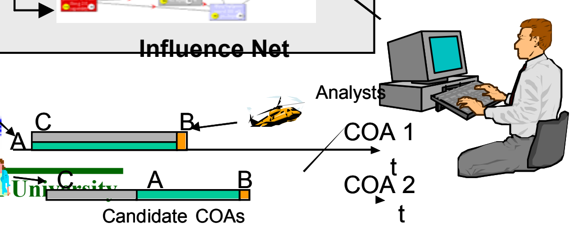
Intel + Planning + Execution Assessment

Campaign Plan





(Reason & Belief Domain)



Blue and Red COA Analysis

* *EBO are coordinated sets of actions – including diplomatic, economic, information operations, psychological operations, and lethal/non-lethal warfare—directed at* ***shaping the behavior*** *of friends, foes and neutrals in military operations*

CASE STUDY APPROACH

- Persian Gulf War *(Desert Storm*) well documented; much unclassified information published. Many of the situations encountered there are still significant today.
- We first used documentation* from Desert Storm to create a high level EBO model
  - Model behavior was "validated" using the Final Report
- We attempted to discover how the higher level model can foster the development and analysis of the lower level model and how, in turn, the lower level model results can impact the higher level model.
- By using a known situation it was possible to validate model results and to test the postulated interfaces between the models that were developed
- Specific results then are generalized

"*Conduct of the Persian Gulf War: Final Report to Congress*" [DoD, 1992]

FLOW DOWN OF PERSIAN GULF WAR OBJECTIVES

National Policy Objectives (5)(6)

↓

CINCCENT's Mission (1)(2)(3)(4)(5)

↓

CENTCOM's Theater Military Objectives (7)(8)(9)(10)(11)(12)

↓

- Air Campaign Objectives (13)(14)(15)(16)(17)
  - ↓ JFACC's Tactical Components (18)(19)(20)(21)(22)(23)(24)(25)(26)(27)(28)(29)
- Maritime Campaign Objectives (30)(31)(32)(33)(34)
  - ↓ NAVCENT's Tactical Components (35)(36)(37)(38)(39)(40)(41)
- Ground Campaign Objectives (44)(45)
  - ↓ Joint Force Tactical Components (42)(43)(46)(47)(48)

***(x) refer to event numbers in the report that were assigned the EB model**

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Desert Storm War Scenario

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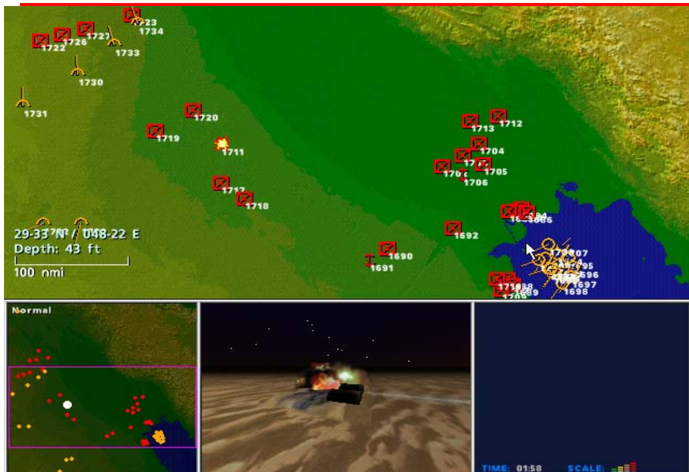
Fleet Command Naval Warfare Simulation…
3D Real-Time Modeling, Simulation & Visualization



Adapted by Raytheon for use on DARPA / NAVSEA Submarine Payloads & Sensors Program. Developed HLA-compatible interface to Raytheon Hi-Fi Missile Server. Can be run in Monte Carlo mode (turn off graphics).

✓Tested sensitivity to various Mission / System Concepts within context of Scenarios

✓Conducted Operational Utility Analysis to Quantify Military Value:

- »Notional Korea-China Scenario, (UNCLASS ver.)
- »Persian Gulf Scenario (UNLCASS ver.)

***Fleet Command* functionality:**

- **Set up Geo-scenario using Mission Editor GUI**
- **Modify Platform/Sensor/Weapon Parameters with Database GUI**
- **"Drag and Drop": Lay-down Red/Blue Forces (Lat/Long) on Geographic Map Window**
- **Simulation can be run in different ways:**
  - **Computer (Blue) vs Computer (Red)**
  - **Human (Blue) vs. Computer (Red)**
  - **Human (Blue) vs Human (Red)**

Features:

- Geographically accurate 3D environment
  - –Bathymetric Data (display depth with mouse)
  - –1000 meter resolution Terrain (Standard)
    - »Integrated DTED Level 1 (100 m resolution)
- Complete Jane's Order Of Battle for 16 countries; countries can be added
- Sim Objects include Submarines, UUVs, Surface Ships, Aircraft, UAVs, Missiles, Tanks, TELs, Land Vehicles, undersea mines and some ground installations; can customize sim objects
- Multiple views of unfolding scenario

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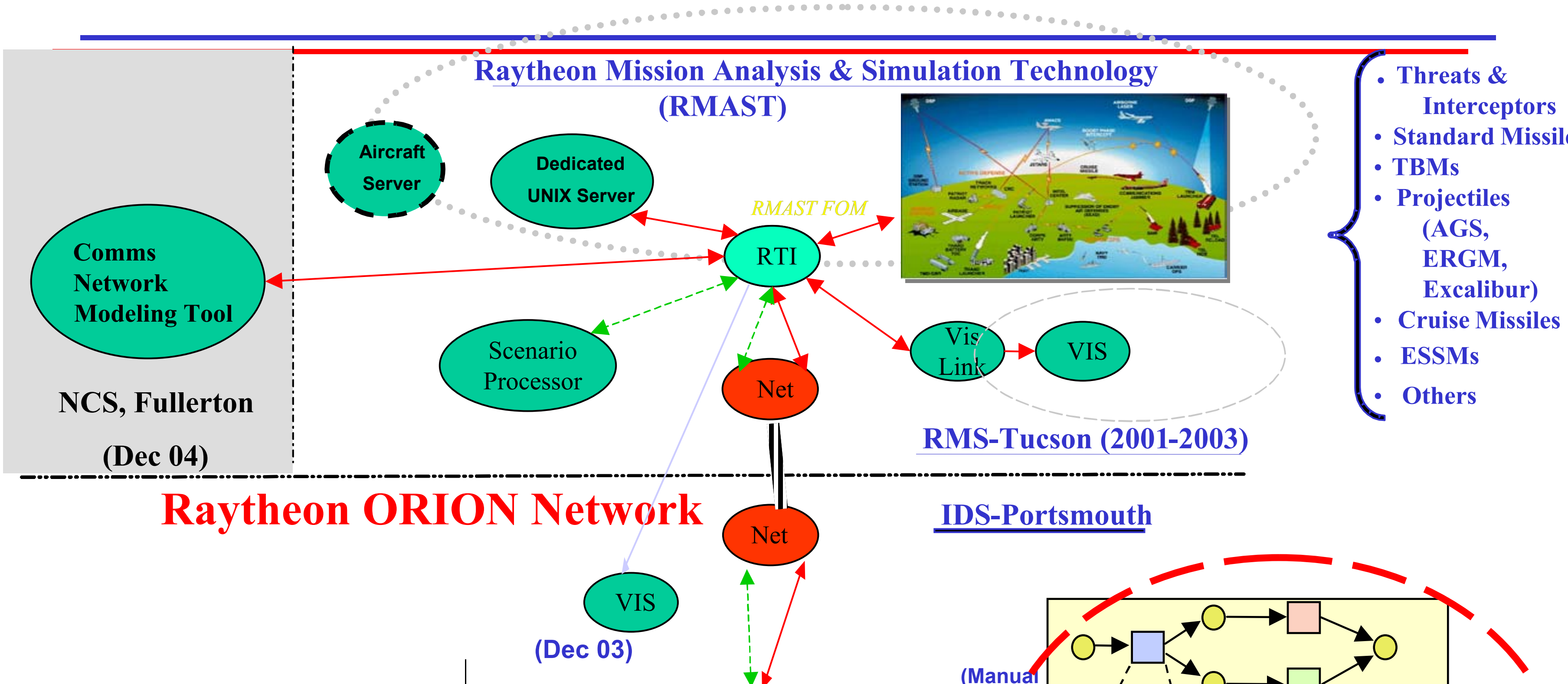
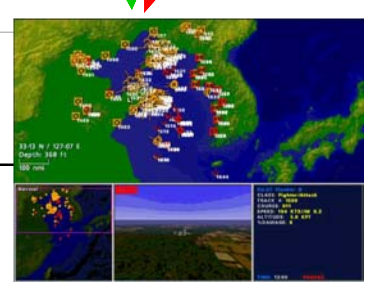
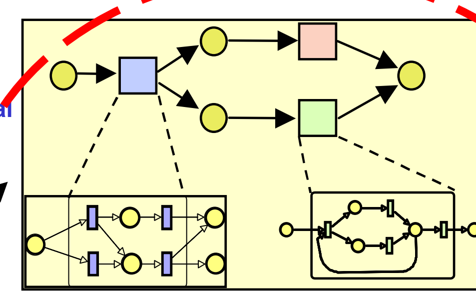
HLA Architecture Supports Distributed Scenario Generation, Req'mnts Analysis & Concept Development



Functions \ Federates	Fleet Command	Scenario Processor	RMAST: Missile	Comms Model
Create Scenario	x			
Send Scenario	x			
Receive Scenario		x	x	
Convert Scenario		x		x
Execute Scenario			x	x
Send Results			x	



Real- Time Naval Warfare Sim



Effects-Based Models*

*George Mason Univ Tools installed at IDS/Portsmouth

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COURSES OF ACTION FOR EBO

- An effects-based way of thinking has been evolving for some time. Objectives can be obtained by achieving effects. Effects can be achieved by actions that comprise COAs
- Needed is an approach that captures the rationale for COAs that explain how actions can achieve effects
- Different levels of detail impact the type of analysis that can be done
  - Detailed Engineering and physics knowledge can allow engineering models to show the behavior of systems to actions
    - How to disrupt electric power, POL, an IADS are examples
    - If we have the knowledge and the models they can give very precise results
  - Qualitative knowledge about system or the reasoning belief and decision make aspects require a more abstract approach
    - Probabilistic modeling techniques may be helpful

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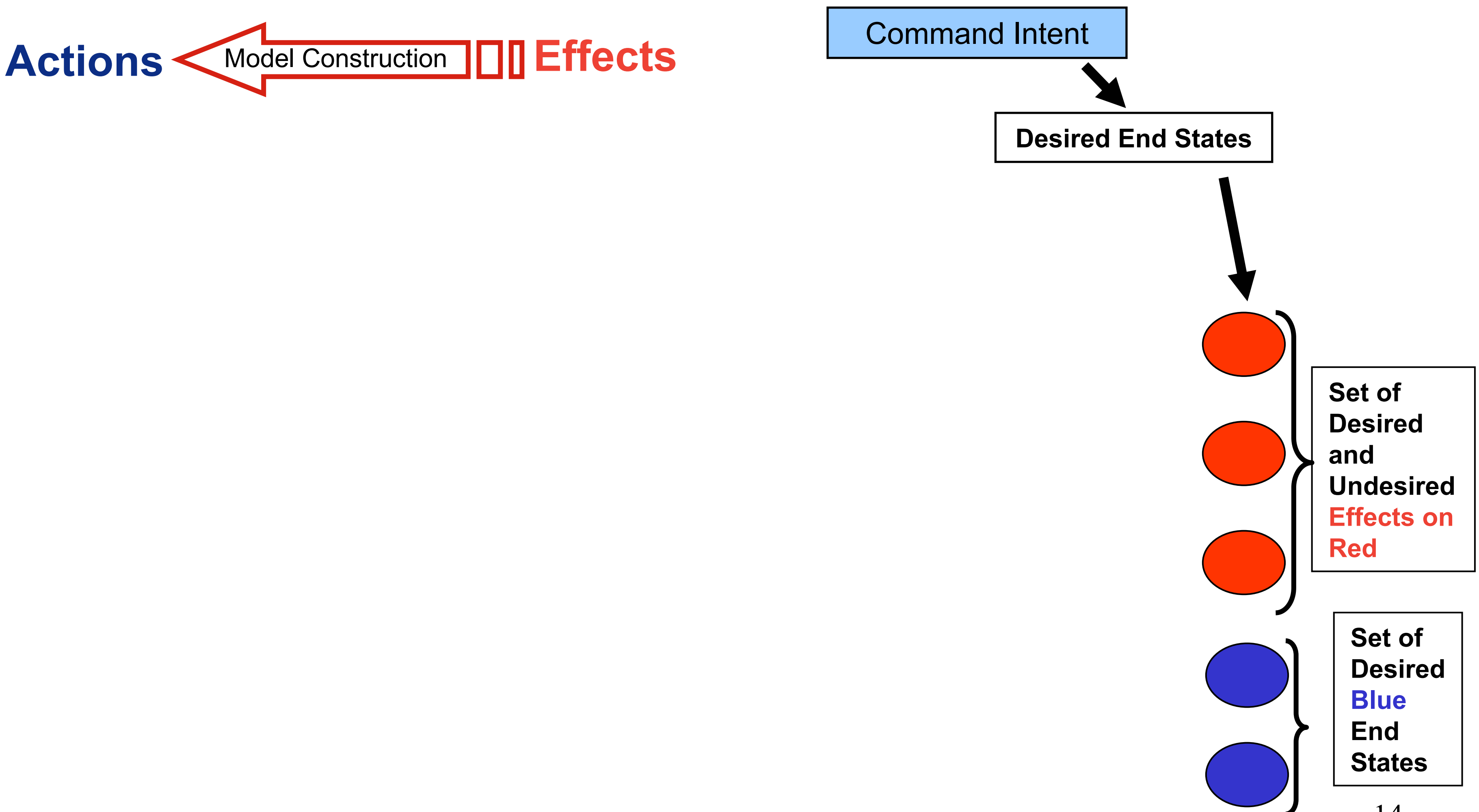
Effects Based Modeling for COA Development



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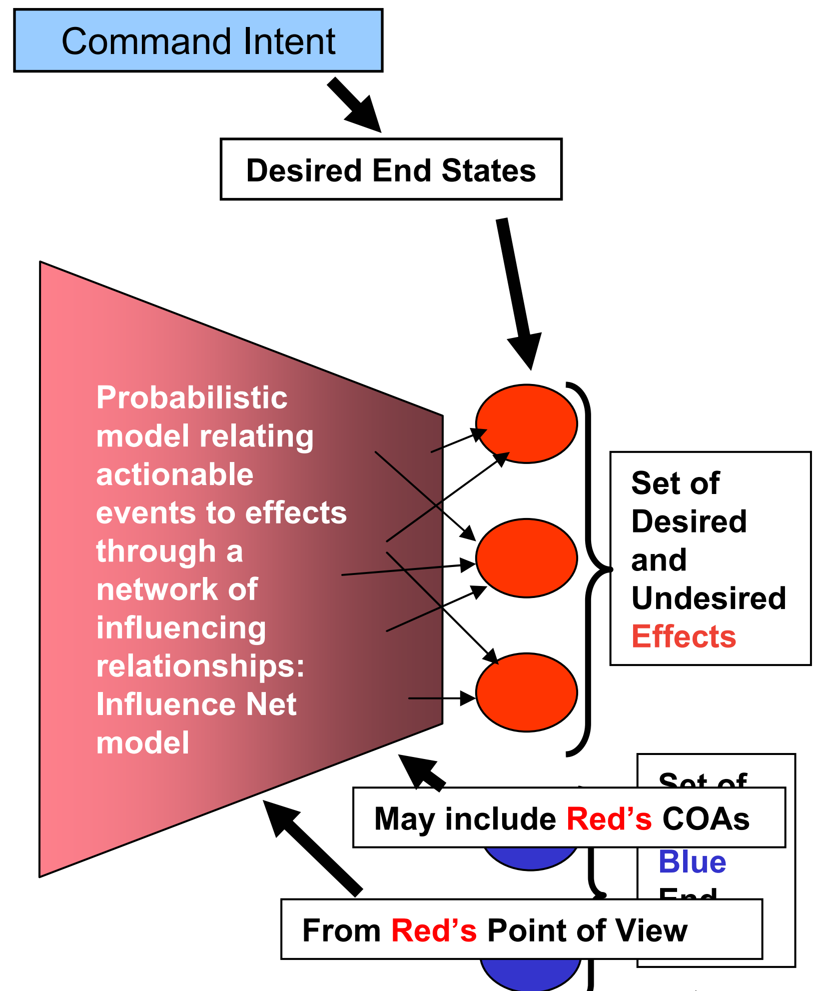
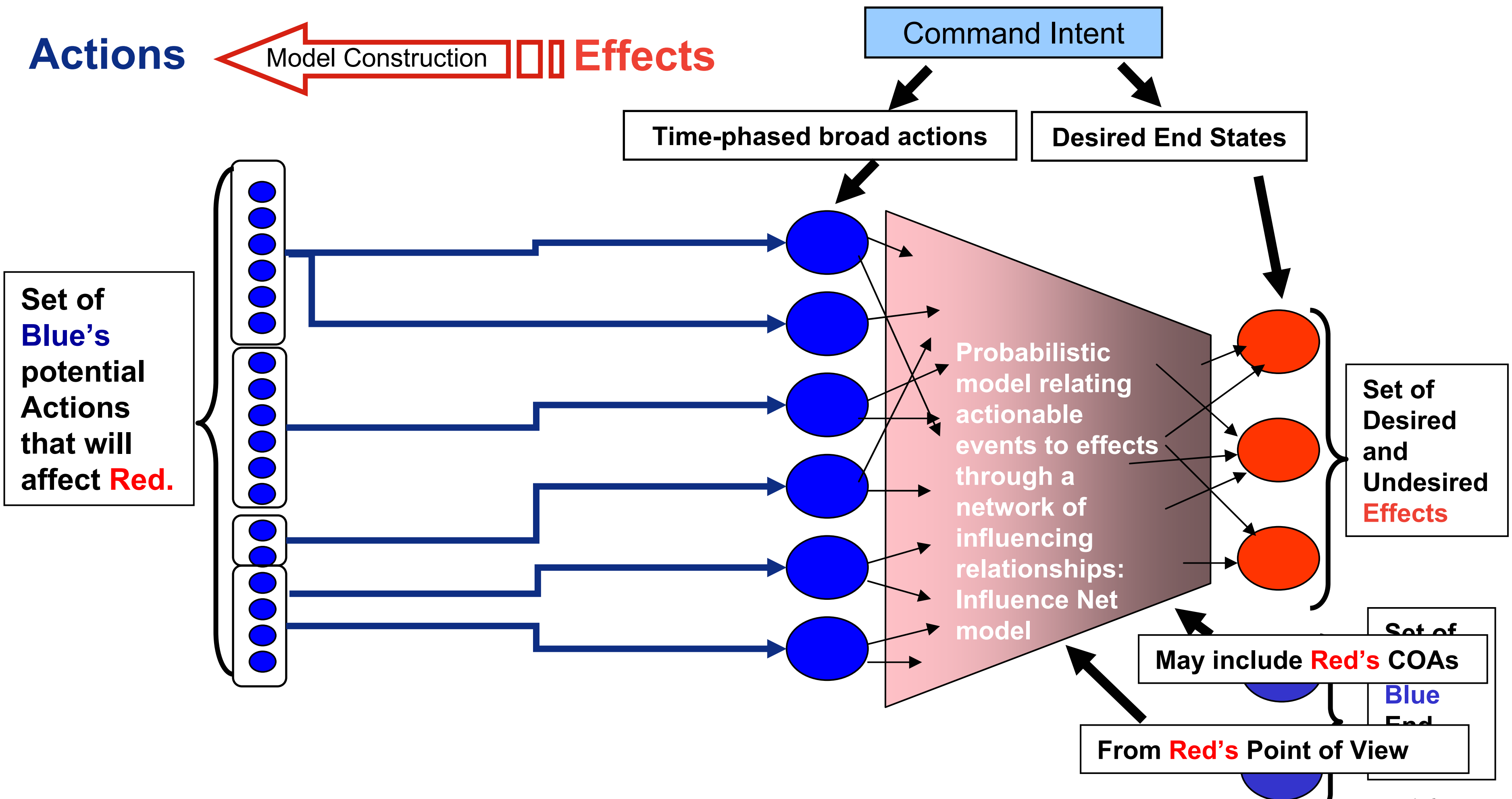
Effects Based Modeling for COA Development

Actions ⟵ Model Construction ⟸ **Effects**



Effects Based Modeling for COA Development



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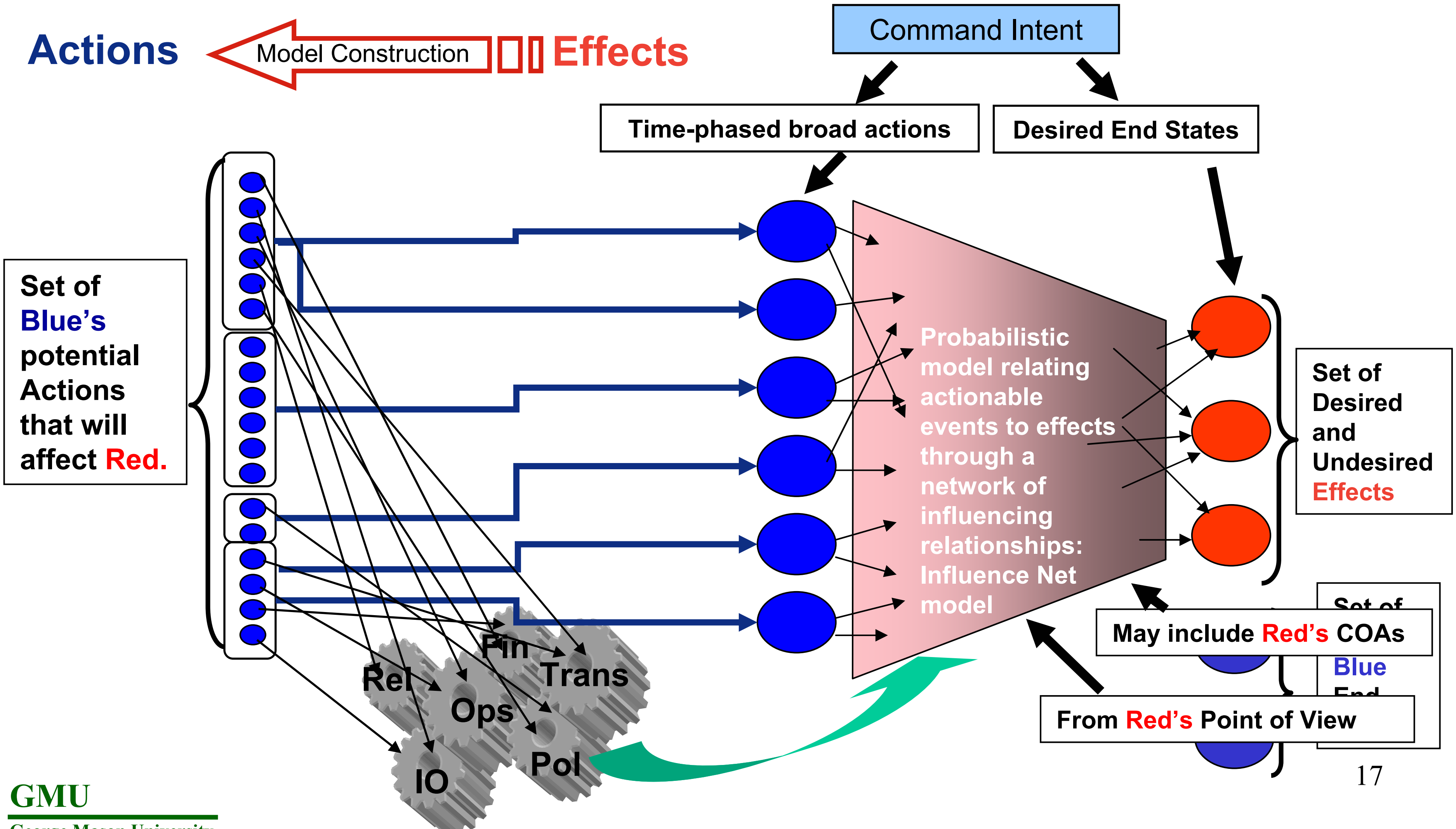
Integrated Defense Systems

Effects Based Modeling for COA Development



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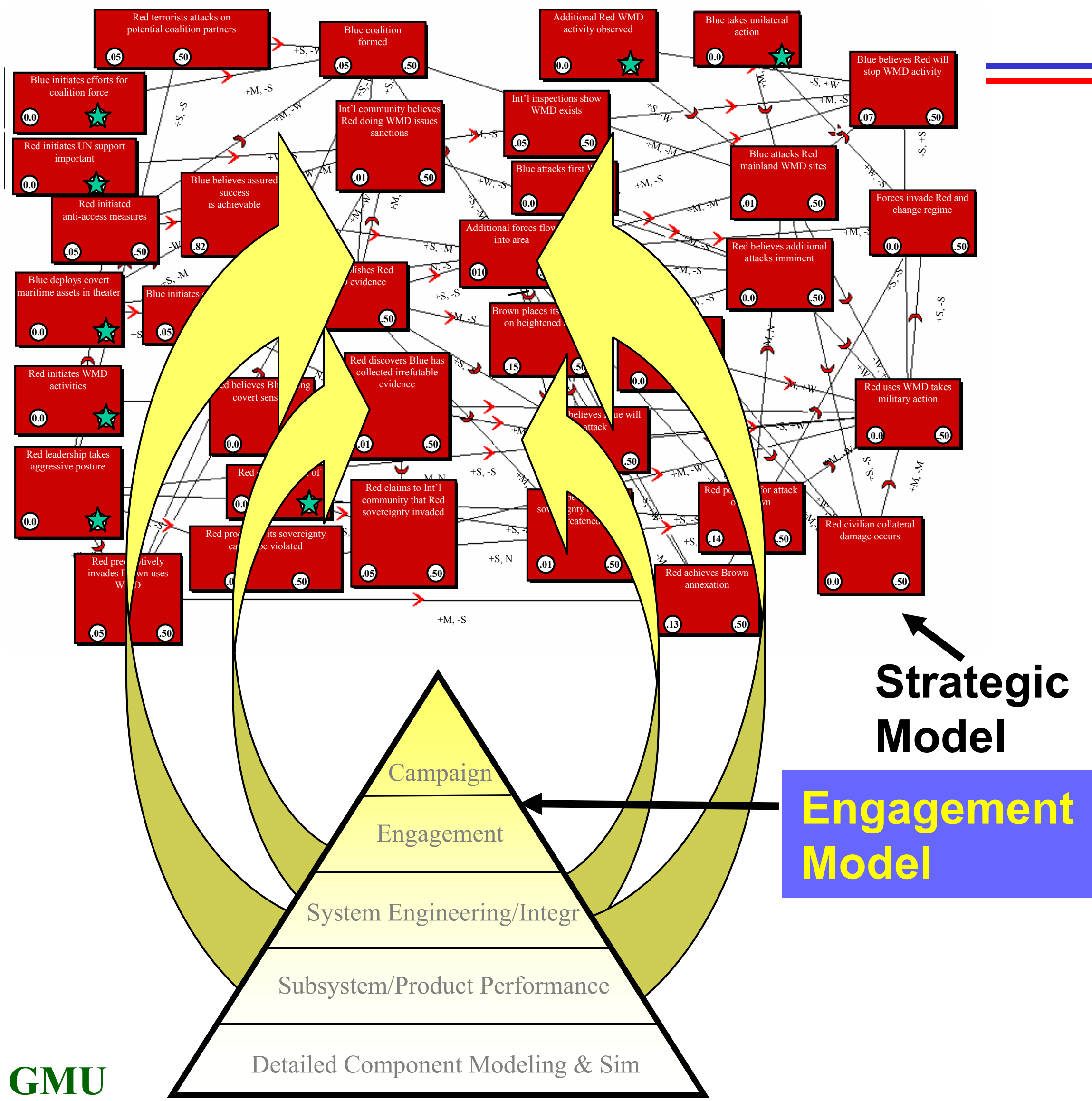
AN INTEGRATE MODELING APPROACH



Objective: Codify belief structure of Adversary to establish cause and effect relations and impact of actions

Identify
- Intent/outcome
- Beliefs
- Initial events
- Actions

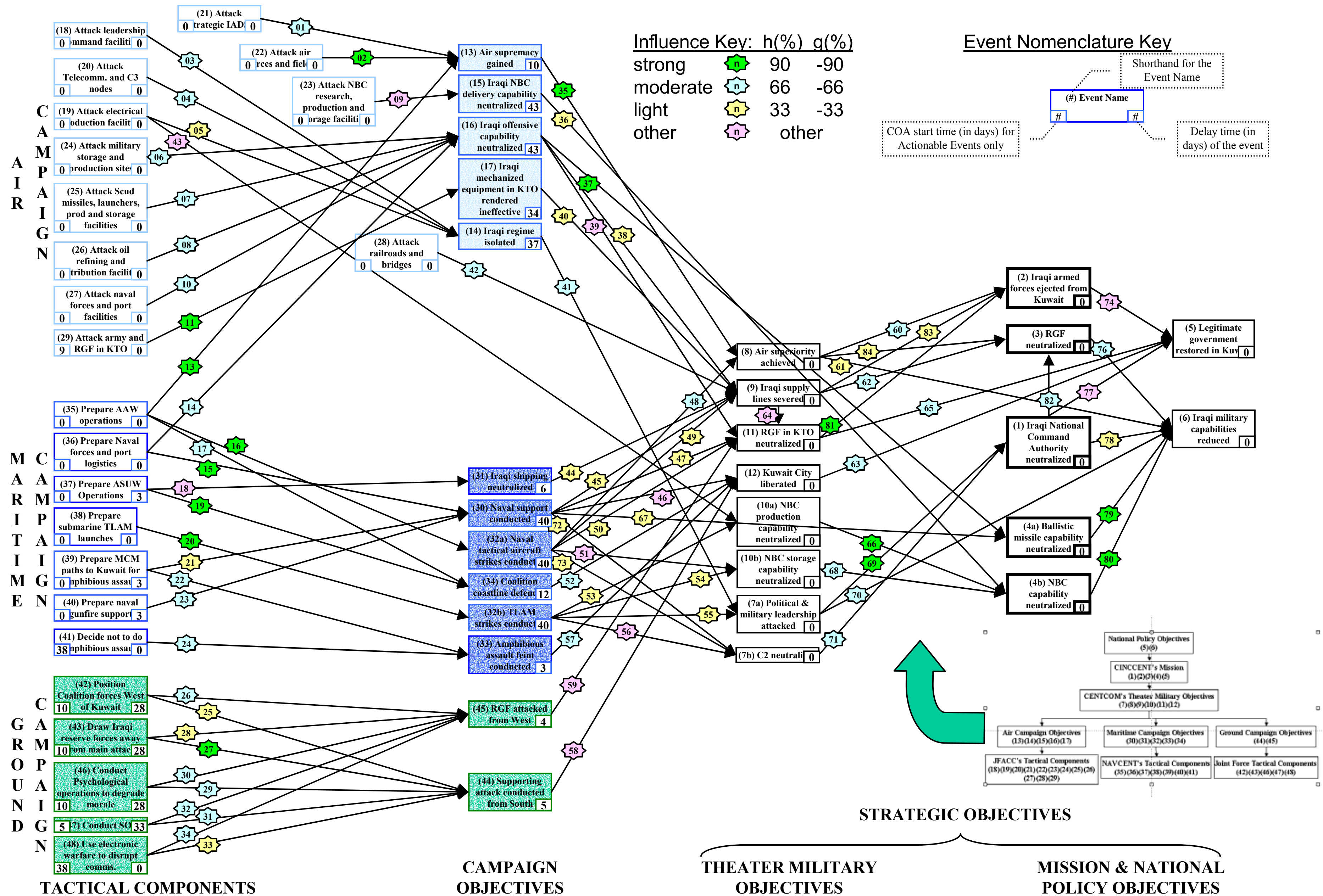
Establish
- Cause and effect relationships
- Probability estimates
- Times (when, how long)

Link with Engagement Models
- Quantity appropriate action for increased fidelity

HYPOTHESES

- Use of more detailed modeling improves the derivation of the elements of the higher-level EBO model
  - High fidelity simulations can provide more accurate values for the conditional probability values and the time delay information that the higher-level models use as input.
- High fidelity simulations can be useful in providing a more detailed look at actionable events that are created in the high level EBO model

Gulf War Model Rev 16b



HIGH LEVEL MODEL VALIDATION

- Concentrated on the overall behavior given the choice of values for the influence strength parameters, since the structure and timing more were directly derived from the Final Report to Congress.
- Examined *static* behavior by examining how changes in input actionable events result in reasonable changes throughout the net as well as changes at the overall effect nodes (Mission and National Policy Objectives).
- Compared *dynamic* behavior with timelines in Final Report.

Actionable Event Group			Probability of Effect						
Air	Maritime	Ground	(5) Legitimate government restored in Kuwait	(6) Iraqi military capabilities reduced	(2) Iraqi armed forces ejected from Kuwait	(3) RGF neutralized	(1) Iraqi National Command Authority neutralized	(4a) Ballistic missile capability neutralized	(4b) NBC capability neutralized
no	no	no	0.01	0.02	0.01	0.01	0.15	0.04	0.12
no	no	yes	0.04	0.02	0.05	0.01	0.15	0.04	0.12
no	yes	no	0.05	0.11	0.05	0.29	0.35	0.09	0.28
yes	no	no	0.04	0.78	0.20	0.71	0.64	0.91	0.34
no	yes	yes	0.35	0.11	0.30	0.29	0.35	0.09	0.28
yes	no	yes	0.52	0.78	0.86	0.71	0.64	0.91	0.34
yes	yes	no	0.33	0.95	0.55	0.90	0.84	0.96	0.65
yes	yes	yes	0.94	0.95	0.98	0.90	0.84	0.96	0.65

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DYNAMIC BEHAVIOR - INITIAL HI LEVEL MODEL

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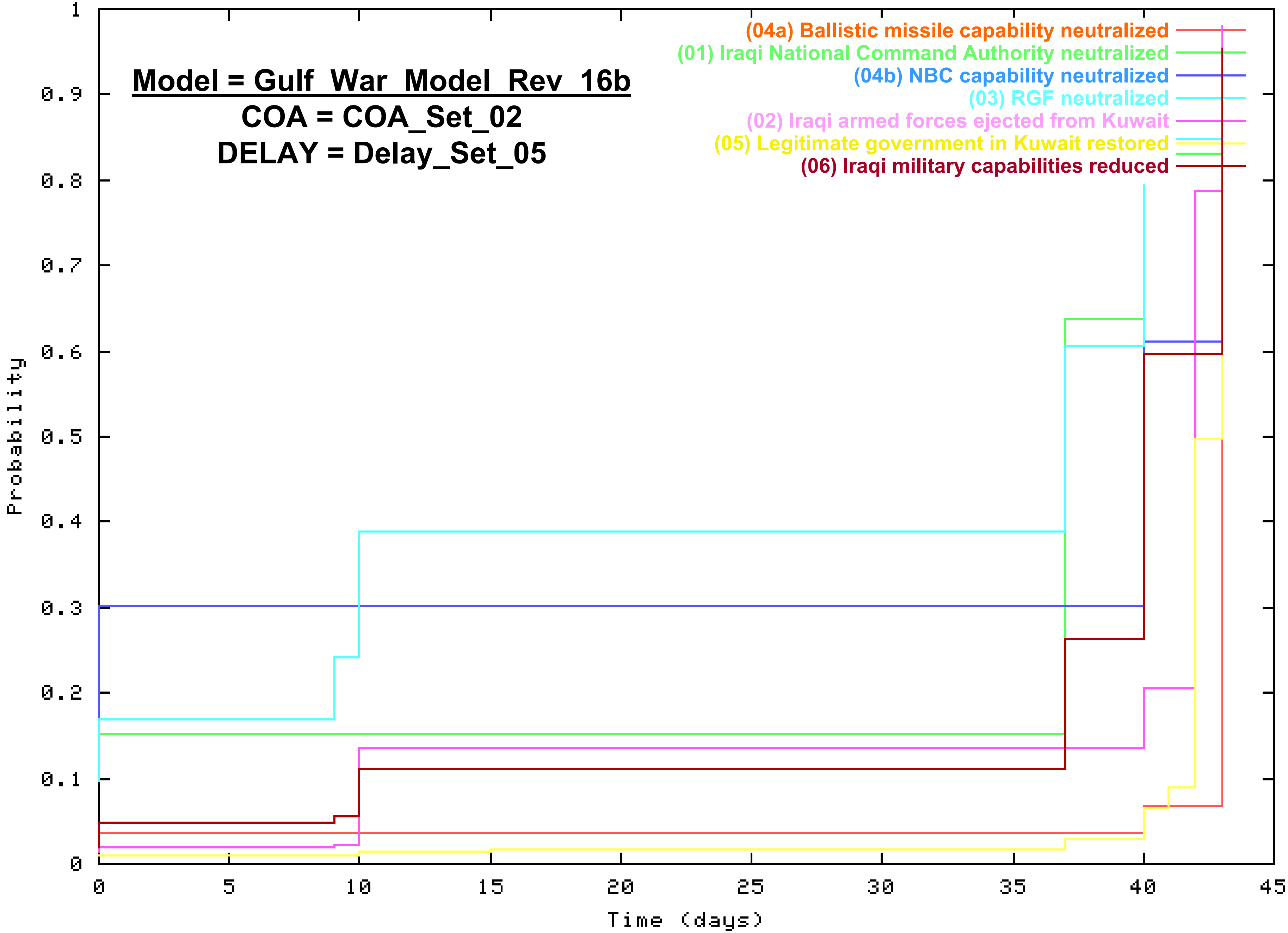
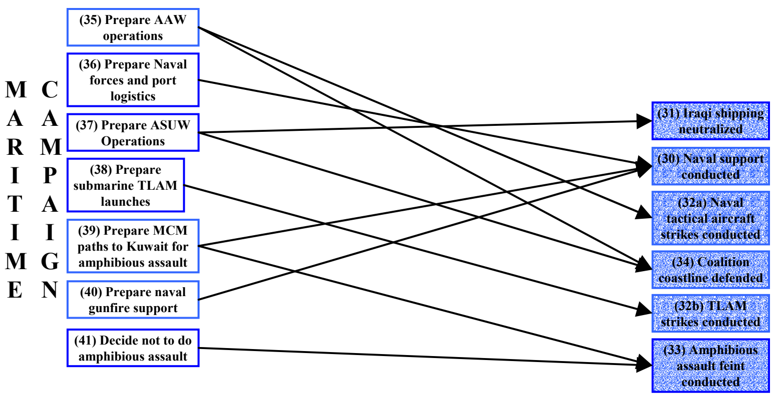
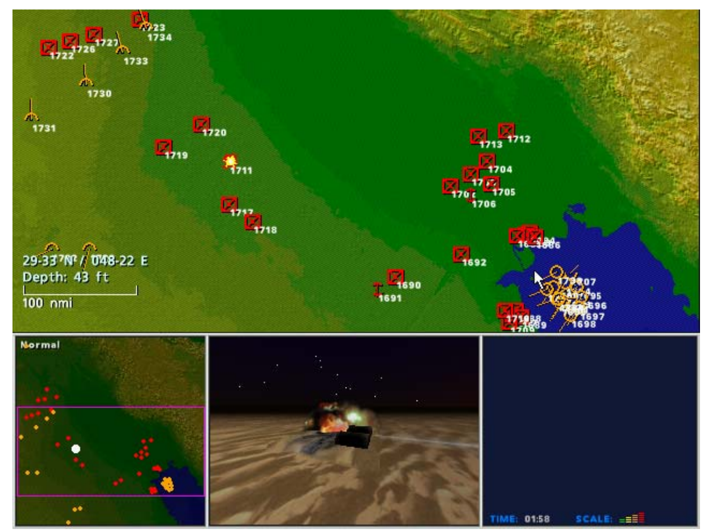
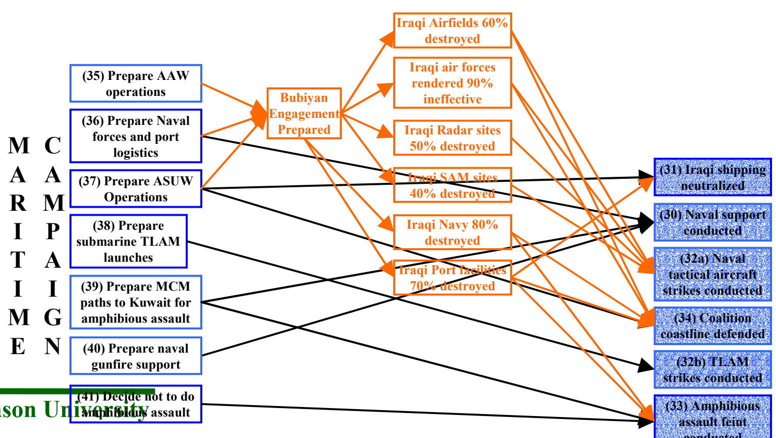


INTEGRATING ATTRITION MODEL

- Identified specific tactical engagements within the campaigns (from the Final Report to Congress) for modeling with physics-based simulations
- Used a modified version of *Jane's® Fleet Command*™ [modified by Raytheon]







INTEGRATING ATTRITION MODEL

- **The attrition-based model provides quantitative measures of effectiveness (% killed) of the engagement participants versus time.**
  - **Thus, the effect(s) of the attrition model are events that reflect achievement in progress for the neutralization of adversarial participants.**
- **Such events became the vehicle for interfacing information from the lower level to the Hi Level EB model**
- **Several engagements were run in the attrition-based model and used to enhance the Hi Level EB Model**
  - **Additional structure added**
  - **Time delays refined**
- **The enhancements to the Hi Level model did not effect its basic behavior, but provided a more detailed description of intermediate events that could be examined**

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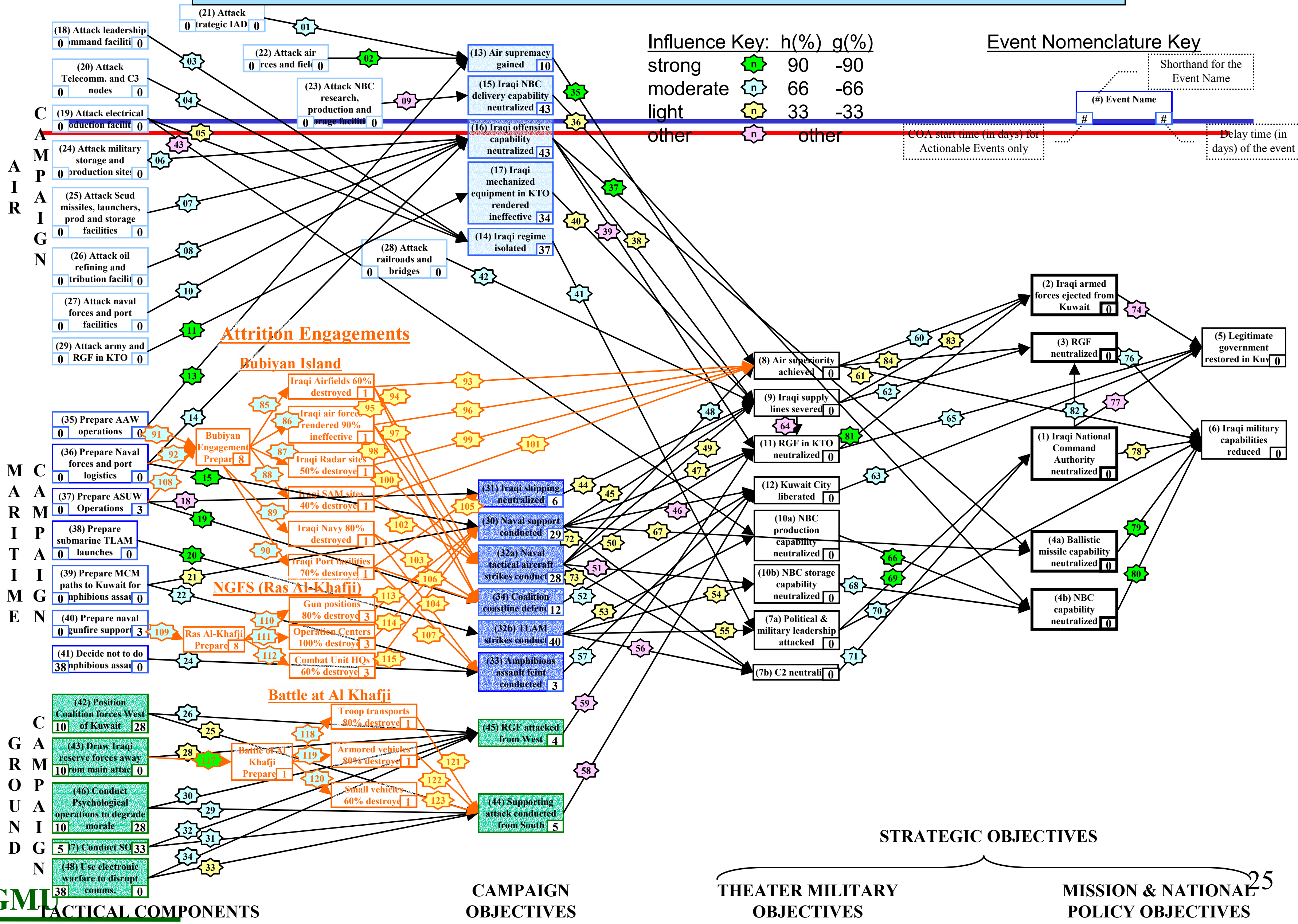
ENHANCED HI LEVEL MODEL



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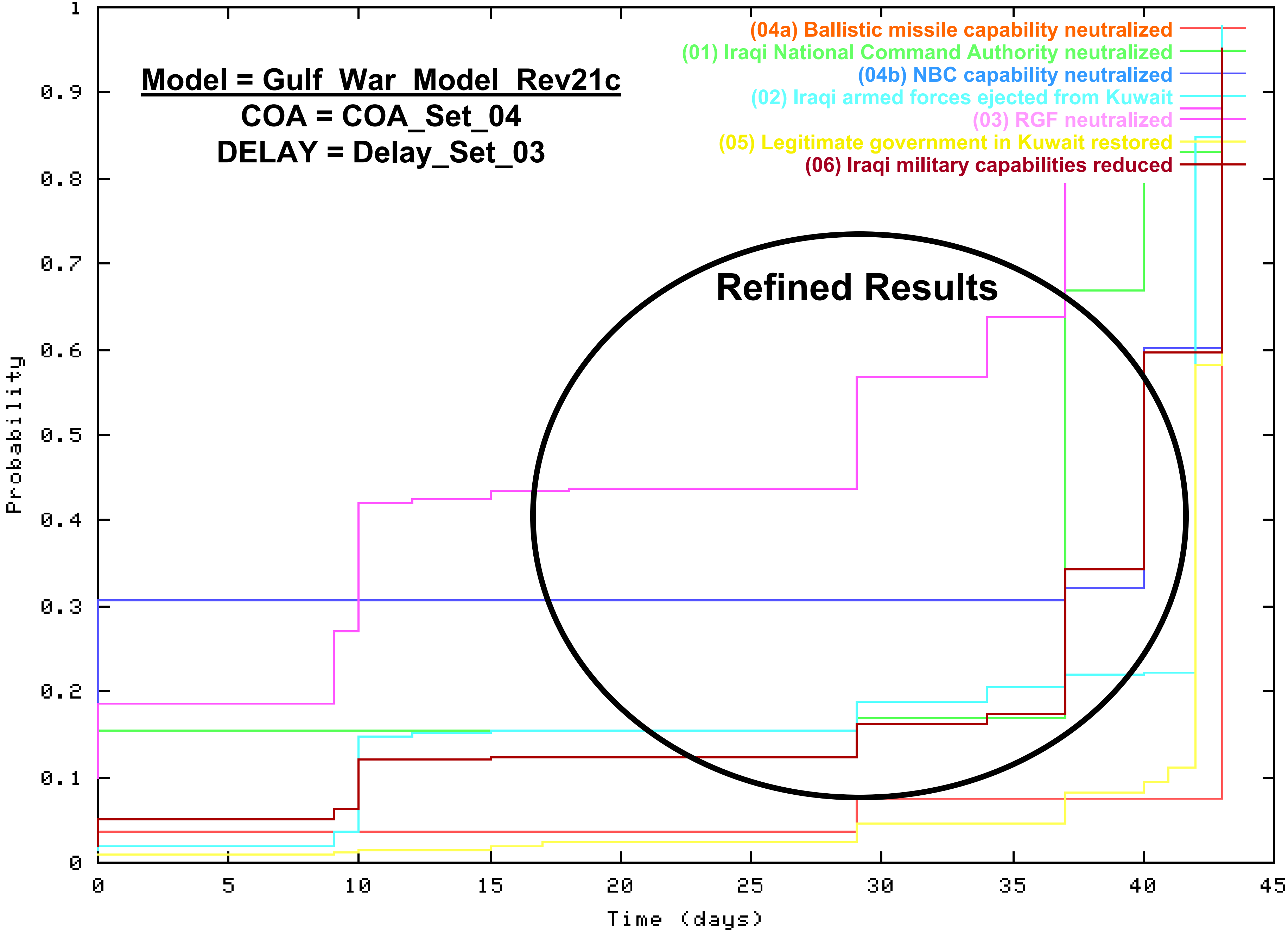

CONCLUSIONS

- Using a case study approach we explored a process for relating a high-level effects-based model with detailed attrition-based models
  - Attrition models can provide a more detailed look at actionable events that are created in the high-level EBO model and can help planners refine the courses of action selected from analysis of the EBO model
  - Attrition models can help refine the structure and the conditional probability and time parameters EB model (increases the confidence in the EB model)
- Creating the interfaces was labor intensive; no "automated" technique for linking the two types of models was discovered
- Some preliminary "rules of thumb" were postulated for creating new structure in the EB model as a result of the analysis of the attrition model
- More research should yield a more efficient approach to establishing the ties between hi level effects based models and the higher fidelity attrition models