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PLANNING AND ASSESSING EFFECTS BASED OPERATIONS (EBO)

Topic: Effects Based Operations

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PLANNING AND ASSESSING EFFECTS BASED OPERATIONS

Abstract

Effects Based Operations (EBO) analysis tools are important in assisting the analyst in determining whether or not a Course of Action (COA) will meet the stated Commander's intent and whether it is having negative, unintended consequences. Currently, assessment efforts are focused more on *combat* effects, than they are on overall *campaign* effects. In addition, current COA Analysis tools are limited in their ability to integrate effects across domains – from power to water, or gas to transportation for example.

In this paper, we describe an open architecture EBO assessment capability that may be used in either a planning role or as a real-time operations assessment tool to address the needs described above. Our research is based on SPARTA's modeling framework - the Net-Centric Effects-based operations MOdel (NEMO). NEMO treats the opponent's infrastructures as a system of networks representing the critical domains, such as electrical power, telecommunications, transportation, gas, water using 'Best-of-Breed' industry standard simulations. NEMO also uses Net-Centric enterprise service approaches (e.g., discovery, messaging, software agents, Geospatial Information System (GIS) Shape files and is built using the Commercial Joint Mapping Toolkit (CJMTK)) to capture and model the relationships between various parts of these networks that represent their real-world interdependencies.

1.0 Introduction

Adopting an effects-based approach to conducting military operations is central to the transformation underway in our armed forces. As an initial step to develop strong Network-Centric Warfare (NCW) credentials, SPARTA created the **N**et-Centric **E**ffects-Based-Operations (EBO) **MO**del (NEMO). NEMO provides a key capability needed for this transformation by allowing planners and analysts to observe potential cascading effects among or across several physical domains (e.g., gas, water, electric power, communication). NEMO demonstrates the ability to propagate these second and higher order effects across multiple physical infrastructure networks.

Today, EBO is a widely sought capability that is in the theoretical stages of concepts and warfighting desires. Numerous books, papers and procurements discuss the need for EBO and effects-based assessments, but there are no integrated tools in use by the community.

2.0 Organization of this Paper

This paper will develop a context for our effort by describing the concept of network interdependencies, cascading effects, and Operational Net Assessment (ONA). We then provide a discussion of the architecture and design approach used to develop NEMO, and how NEMO operates within a net-centric framework of core services. Finally, a brief scenario is presented to demonstrate the basic capabilities of NEMO, followed by a discussion of lessons learned from this effort, and next steps for future development.

3.0 Infrastructure Network Interdependencies and Cascading Effects

In today's world, different infrastructure networks (e.g., transportation, power, water, communications) are highly coupled. This coupling causes changes in one network's capabilities to be felt in other networks. These dependencies are not limited to the location of the original incident causing the change, and the resulting effects are often adverse and long-lasting. Localized changes in one network will often have regional and some times global effects on other domains.

Examples of these interdependencies are common. In 2003, a power generator failed and a transmission line tripped. These two events were geographically separated, and on equipment owned and operated by different electric power distribution agencies. Even so, their effects rapidly cascaded, and escalated, eventually resulting in a massive loss of power to a large part of the North Eastern US and parts of Canada.[1] This loss of power resulted in closures of businesses and financial markets throughout the area, and severely restricted the availability of public services such as telephone communications, mass

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[1] U.S.-Canada Power System Outage Task Force, *Final Report on the August 14th Blackout in the United States and Canada*, April 2004. https://reports.energy.gov/BlackoutFinal-Web.pdf

transit and health care. In an even more telling example from July 2001, a 60 car CSX train derailed and caught fire in a Baltimore Maryland tunnel. The resulting fire closed a main east-coast rail line for over six days, ruptured a water main, disrupted or halted commuter traffic in the area and melted fiber-optic cables providing a loss of internet connectivity in the North Eastern United States.[2]

Train crash brings net to a halt

July 20 2001

by Tony Hallett

A CSX train similar to that derailed in Baltimore

Derailment brings chaos to the East Coast...

A major train crash in a tunnel in Baltimore has brought the internet to a crawl for some users in the US.

The CSX goods train involved is reported to have derailed and cut important fibre optic lines. It was carrying a mixture of wood, hydrochloric acid and at least five hazardous chemicals. The resulting blaze has been fought by over 100 fire fighters for over a day.

Late yesterday in the US, major East Coast-based ISPs Genuity and PSINet were experiencing peering problems with most other backbones. Peering locations in the eastern cities of New York, Philadelphia and Washington DC have been affected.

According to statistics from internet performance company Keynote Systems, there has been a dramatic slowdown for some websites starting at 03:00(EST) Wednesday.

In such circumstances, internet traffic is rerouted through other cities, and there have been reports of performance problems as far away as Atlanta, Los Angeles and Seattle.

silicon.com

These cascading effects are not limited to physical infrastructure. Changes in physical infrastructure also impact the 'softer' social, political, economic and even military network infrastructures. Telecommunications services, especially Internet, cellular/satellite phones, etc, have made it possible to distribute news and information on a global scale in almost real time. The availability of this information can shape the opinions and will of vast numbers of people, and is a fundamental requirement of today's Net-Centric force.

These interdependencies lead to vulnerabilities that may be exploited to achieve a desired effect across all levels of operations. As a tactical application, for example, these interdependencies could be leveraged to identify alternatives for disrupting radar

[2] http://www.cbsnews.com/stories/2001/07/18/national/main302195.shtml

surveillance of a specific region. As a strategic application, examining the resulting effects of various courses of action against these vulnerabilities can determine which has the most potential for achieving a commander's strategic intent. The challenge, however, is the complexity of the nodal analysis task that must be done to assess operations that leverage these vulnerabilities. First order effects are relatively straight forward as long as the analysis can be restricted to the local area, but become extremely difficult and require a significant amount of domain expertise when this proximity restriction is lifted, as is the norm in real systems. Second and higher order effects are nearly impossible to estimate using manual techniques. This paper discusses an automated approach to viewing these higher order effects while leveraging existing, commercially available software models to the maximum extent possible.

Operational Net Assessment

In the military, the process of EBO is currently either ignored, or worked separately in each domain as human analysts try to identify and bring the interrelationships together to estimate resulting behavior. There is no tool which works across domains to understand the implications of an outage in one 'layer' of infrastructure (e.g. power or water) on another (e.g. communications, transportation). Further, the social/political network issue is studied by psychologists and analysts without the aid of an EBO model. JFCOM has a methodology called Operational Net Assessment (ONA) that they use to identify vulnerabilities (www.jfcom.mil/about/fact_ona.htm). "Operational net assessment (ONA) is the integration of people, processes, and tools that use multiple information sources and collaborative analysis to enhance command decision-making. This continuous, dynamic process produces a coherent, relevant, and shared knowledge environment". We will use this process to frame our understanding of a potential adversary's political, military, economic, social, information, and infrastructure (PMESII) systems through link analysis, network analysis and structured augmentation. The ONA process accomplishes several goals, including revealing critical nodes and vulnerabilities that may be used in EBO, but there are currently no tools that provide a means for integrating changes across the PMESII networks.

4.0 Net-Centric Effects Based Operations (EBO) Model (NEMO)

An application for modeling inter-network relationships

Understanding how a particular element of one network relies on the elements of one or more other networks provides the basis for analyzing cascading effects. Understanding and quantifying the nature of these relationships is the key to performing effects based analysis.

The NEMO architecture (discussed in detail in a later section), provides analysts with the means for defining relationships between network domains using a single user interface. Creating these relationships is key to successfully analyzing Effects Based Operations across infrastructure layers. These interdependencies may be quantified in any number of ways, such as an on/off relationship which simply turns the dependent component off when the other component fails. Another possible relationship could include a time delay, where the dependent component in one infrastructure layer fails a specified period of time after the other component fails. Additional alternatives can include relating many independent components to a single dependent component, or many dependent components relying on the same one. Relationships are not limited to components in close physical proximity, and may also include functional or logical components; regardless of the type of relationship, the NEMO architecture provides a straight-forward means for integrating new ones as they are identified and developed.

Users define different relationships at multiple places across the infrastructure networks to build up a model representing the individual networks and the dependencies between them. NEMO relies on domain specific legacy simulations to evaluate changes to any given network, thus, any dependencies within any given domain are dealt with internally by the infrastructure models themselves. NEMO uses these relationships to allow changes in one network to cause changes in another network. These changes may, in turn, generate changes in yet other networks. The end result is a means for observing the second and higher order effects of a single, localized change in an infrastructure network's operating capability.

Using NEMO to support Effects Based Planning and Analysis

NEMO provides analysts and planners an automated tool for effects based operations planning, offering two critical capabilities: consequence management and course of action analysis.

Consequence management, in this context, deals with identifying and accounting for the unintended effects of an operation (adverse or otherwise). Simply put, NEMO allows the analyst to ask, "if I do something to X, what is the effect on Y". A tactical example of this problem is determining the additional effects of a strike against a bridge beyond the obvious disruptions in the opponent's lines of communications (LOC). Using NEMO's capabilities, analysts can determine the broader effects of not only the disruption in LOC, but also account for disruptions in other domains such as power or water, if the targeted bridge were used to support spans of these networks as well. It could show, perhaps, that destroying the bridge would disrupt power to a command and control center we had penetrated and which was providing real-time data on enemy force movements. While this knowledge may not change the decision to conduct the strike in the first place, it may, depending on the objective, alter the weapon selection, or provide at least information to the commander's contingency plans for reconstitution once the initial campaign has ended.

Consequence management applies not only to campaign planning, but to homeland defense as well. This approach may be used to provide a means for conducting vulnerability analysis of our own infrastructure and to assist in identifying critical nodes that present the highest impact for a terrorist threat. Once identified, based on the assessed risk of an attack, appropriate defensive measures may be put in place.

Where consequence management deals with examining what else could happen if I do things a certain way, course of action analysis deals with examining the various ways of accomplishing a task to determine which one best achieves the desired goal. Simply stated, the analyst is asking, "What is the best way for us to cause a desired outcome?" There are several significant challenges implicit in this question. These include (but aren't limited to) defining and quantifying what goes into the term 'best', identifying the different means of accomplishing the desired outcome, and establishing metrics to determine how closely a given approach achieves the goal. Of these, NEMO's present implementation can address the third of these challenges. However, the architecture is in place that allows NEMO, with additional extensions to address the first two challenges as well (these are discussed in later sections).

By providing a framework to model an opponent's PMESII networks as well as their interdependencies, NEMO provides a means for an analyst to consider the target (regardless of the type) as a component of the network. This holds true for hard networks, such as physical infrastructures, as well as soft networks, such as political or economic infrastructure. By observing the behavior of the targeted component, analysts can measure the impact of alternative means of attack. Analysts have the flexibility to attempt different means of attack (IO, Non-Lethal, Kinetic, etc.) and at various points in the infrastructure network. Analysts may alter the timing, sequencing and combinations of different attack modes, and observe the outcome of the attack in the targeted node. NEMO provides the mechanism for allowing changes in one network to impact other networks through its dependency relationships.

Why did we do NEMO

SPARTA developed NEMO as an internal investment to support two goals. The immediate goal was to provide a research tool for modeling and understanding effects based operations. Our second and larger goal was to move from an academic to practical understanding of what it takes to develop and deploy applications based on Network Centric Warfare approaches.

What kinds of things can we do with NEMO now?

Presently NEMO is capable of performing interdependency and effects based analysis to determine the cascading results of a user defined initiating event. We have successfully integrated four infrastructure models into the NEMO architecture: Lines Of Communications, Electrical Power, Gas Pipelines, and Water Pipelines. The models used to evaluate these networks are industry best-of-breed simulation tools for their domains. CitiLabs' Voyager[3] simulation provides road and rail network analysis, while Advantica (formerly Stoner Engineering) provides the Solver[4] tools for electrical power networks as well as the water and gas pipelines. While the prototype uses these tools to demonstrate the initial capability, the next section discusses NEMO's independence from the specific modeling suites used to evaluate networks.

An additional tool available to assist analysts in identifying potential relationships is the geospatial relationship agent. This software agent 'browses' the geospatial database and identifies nodal intersections between layers. These intersections are places where components of different infrastructure layers are within some user specified distance of each other. These commonalities are used to make up a new layer that analysts may use to highlight locations where potential relationships exist. By allowing the user to specify a 'range' of geographic overlap, NEMO is able to easily deal with lack of uniformity in geographic registration between infrastructure layers, as well as deal with 'area effects' from potential courses of action (e.g. analyze the impact of a 20 ft crater).

5.0 NEMO in the context of NCW

As discussed earlier, a fundamental approach used to develop NEMO was to use Network Centric approaches. This meant relying on core enterprise services such as messaging and storage, for various components of the application. The general NEMO architecture is discussed below.

The NEMO architecture is shown in Figure 1. The main client application provides Graphical User Interface (GUI) tools for loading networks from the database, defining relationships between network components, creating and managing scenarios, and selecting models for use during the scenario. The map component of the GUI is based on ESRI MapObjects™ technologies, and is compliant with the Commercial Joint Mapping Tool Kit (CJMT/K). This allows NEMO to store, load, display and share network files in the ESRI shape (e.g., .shp) file format.

[3] http://www.citilabs.com/base/index.html

[4] http://www.advantica.biz/stoner_software/solver/default.htm

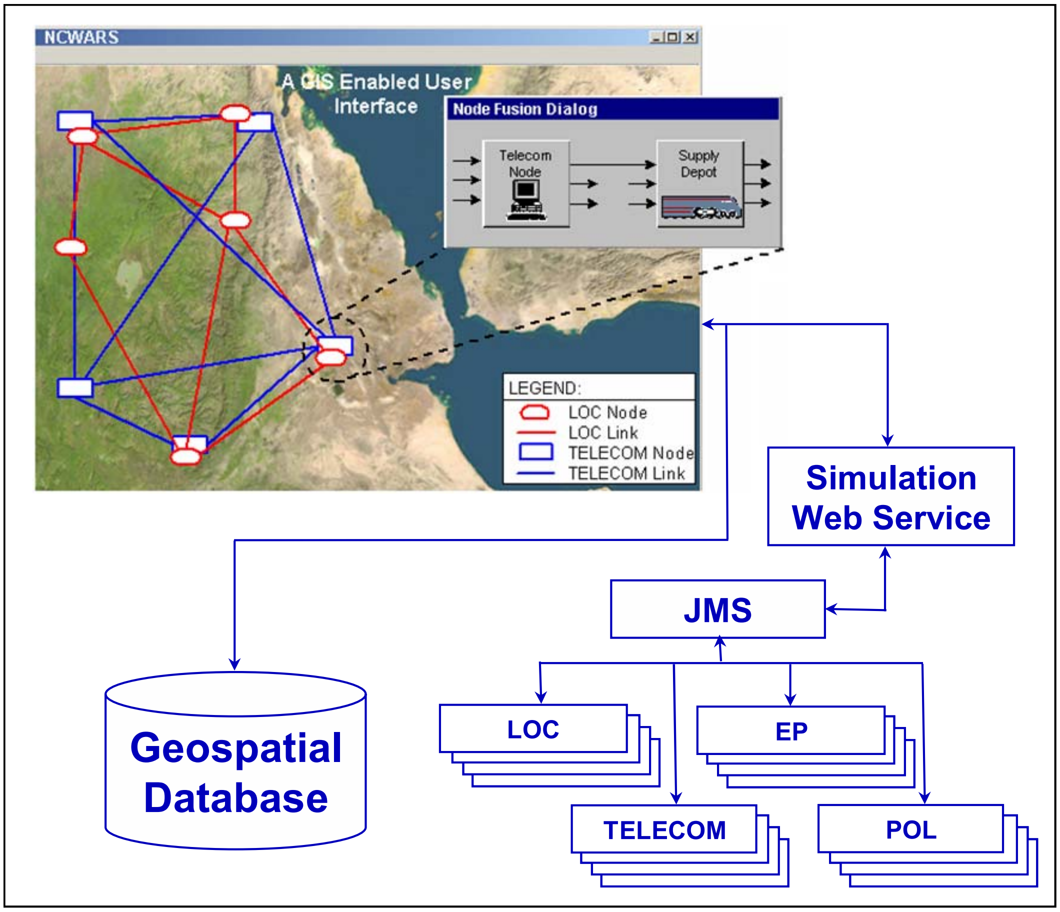

Figure 1. NEMO Architecture

The GUI is backed by a service oriented architecture (SOA) consisting of two web services; one for accesses to a geo-spatial database for storage and retrieval of network databases, and another to coordinate interaction with the various infrastructure models used to provide network status feedback. The geo-spatial database web service, Earth Resource Terrain Hierarchical Archive (ERTHA), contains nearly 200GB of network definitions that may be accessed via the NEMO GUI and used to support Effects Based Analysis. ERTHA is a GIS database, based on ESRI[5] products, of infrastructure data items (e.g., power lines, road networks) that was developed as an unclassified source. Abstracting access to data through a web service decouples NEMO from a specific database and specific vendors, making it possible to integrate other data sources in the future.

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[5] http://www.esri.com/

Infrastructure models are accessed via a model and simulation web service that controls access to simulation services for all users requesting support. Integrating models into this web service architecture is accomplished via a Model Interface Client (MIC) that acts as a translator between the models application programming interface (API), and the eXtensible Markup Language (XML) schema used by NEMO. These MICs coordinate status with the web service through Java Message Service (JMS) message queues. By deploying the supporting simulations in a SOA allows multiple users access to these (often expensive) resources without having to purchase multiple licenses of each.

A key feature of this approach is that the domain models are Plug-and-Play. NEMO operates independent of any of the domain specific models that may be used to evaluate infrastructure networks. It is thus not coupled to any specific vendor's domain model for successful network analysis. All that is required for any network model to be used in this construct is to develop an application specific MIC to coordinate its actions via JMS with the NEMO M&S Web service.

6.0 Sample Application/Analysis

As a demonstration of NEMO's current capabilities, we will provide a notional example of how the cascading effects of strikes against a power network can be observed in an LOC network. Figure 2 shows the NEMO map, zoomed in to a region with electrical power (red lines) and LOC networks (black lines) available. We want to examine the impact on travel time between two points (**A** & **B**) after a strike against an electrical power target is made.

The current shortest path, reported by the LOC model is yellow. A nodal analysis reveals an electric draw bridge at point **C**, which reacts to power outages by automatically moving to the up position on emergency power to maintain navigational right-of-way on the river it spans, and remaining there until power returns. This dependency is reflected in NEMO using an on/off relationship, specifying the road link at **C** is operational as long as power is available at **C**. Our proposed strike occurs at **D**. Figure 3 shows the power outages resulting from the strike, as well as the new shortest path between the points of interest.

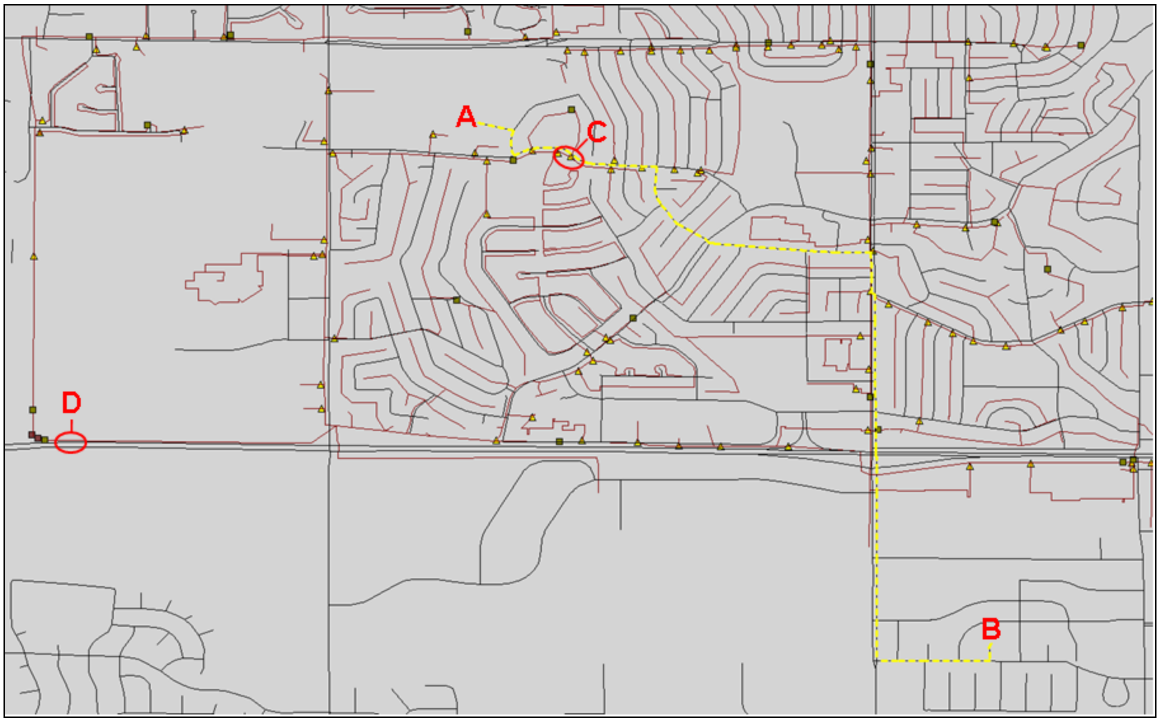

Figure 2. NEMO Analysis Of Electrical Outage Impact on Travel time

This simplified example demonstrates how NEMO can provide non-intuitive insights into the cascading effects of operations across infrastructures. There is no limit to the number of relationships that may be established. Additional relationship mechanisms, beyond on/off relationships may be easily integrated as well, as described in section 8.

7.0 Lessons Learned

During the course of our development efforts we uncovered two critical issues that we will need to address when our approach to effects based planning and analysis enters regular use. These issues are model fidelity and availability of data.

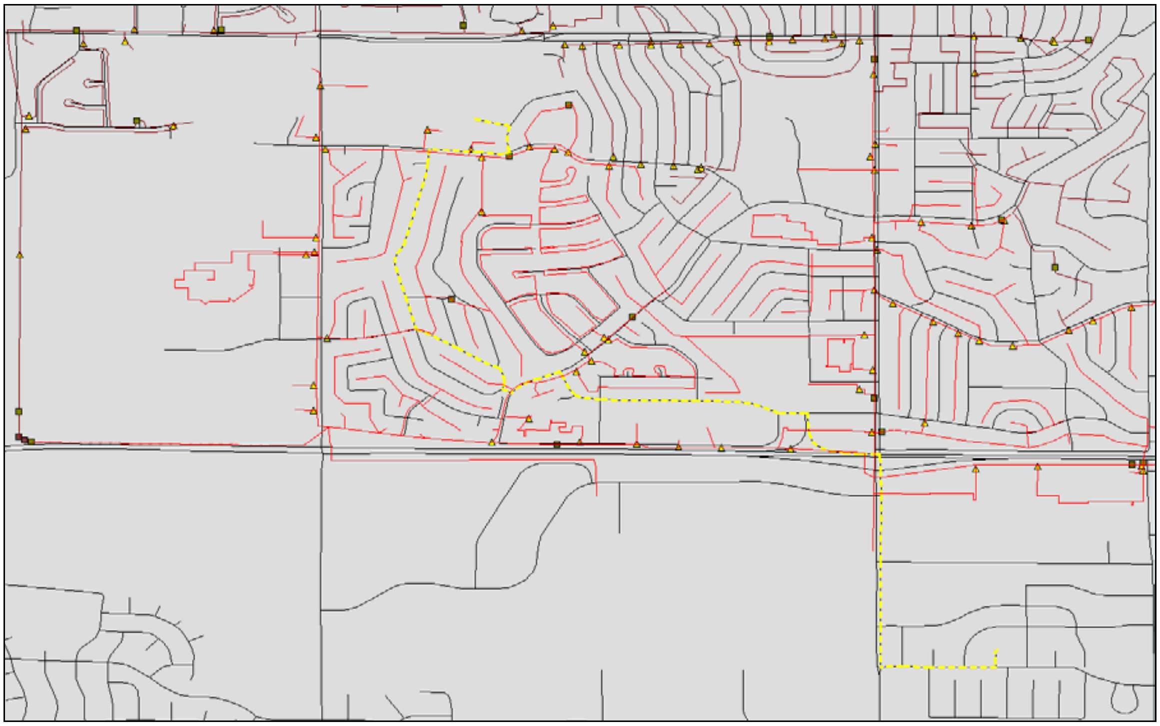

Figure 3. Resulting Time Delays in New Route (Due to Power Outage)

The models we used to support the prototype, while best of breed, are highly detailed, physical engineering models. They assume the user has a significant amount of domain experience and knowledge to make them work correctly. Using these tools in an operational way would require access to domain experts in some manner to ensure the assumptions made were correct, and to provide some validation of the model's outputs.
While the solution could be worked, it's less than desirable in today's age where our military is being steadily asked to do more with less. An alternative is to identify and integrate behavioral models -- tools that abstract away the physical underpinnings of the systems being involved, and focus on their behavioral aspects.

Secondly, we faced the issue of data availability. Generally, network topology information for nearly any domain in any area can be obtained. However, this level of detail is not sufficient to support highly detailed models used in the prototype. Nor is it clear to us that the high level of detail used is required. Sensitivity studies must be performed to determine whether, for example, knowing if the material a given waterline was made of will have any impact on the desired analysis. For any model used, these sensitivity studies must also address model accuracy. Does the model's behavior under simulated stimulus provide predictions that are similar to what is observed if the actual network is stimulated in the same way? These 'what-if' exercises will give the analyst and the commander a measure of the 'quality' of NEMO's predicted results.

8.0 Next Steps

NEMO provides a basic capability for performing effects based planning and analysis of operations against an opponent's physical infrastructure network. Future areas of research and development include integration of social/political networks, optimization, leveraging multi-agent capabilities, and expanding the suite of relationships that may be used. Each of these areas is discussed below.

Political/Social Network Modeling

The critical aspect of NCW that has yet to be addressed is the interaction of social/political networks with other network domains. As stated by Smith, in the seminal text on EBO, **"Effects-based operations are coordinated sets of actions directed at shaping the behavior of friends, foes, and neutrals in peace, crisis, and war."**[6] SPARTA currently is working to integrate a social/political behavior network to interface with NEMO. This software application will include definitions of players, potential strategies (or behaviors) and utility functions for selecting the desired strategy. The utility function may differ based on the type of player, and will include status of the appropriate infrastructure networks from NEMO as inputs. This resultant capability will provide the "missing piece" – a means of modeling how cascading effects impact the human dimension, and show how various actions (e.g., destroying the water supply) shape the behavior of friends or adversaries. Suppose the social/political network model were available in the example given earlier and we used it to represent a C2 network with cells at various locations. If one of those cells had been placed inside the region of the

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[6] Smith, Edward, "Effects Based Operations, Applying Network Centric Warfare in Peace, Crisis and War", CCRP, Nov 2002. www.dodccrp.org

power outage, and the appropriate relationship set, it would have been adversely affected by the power outage as well, with a resulting impact on the entire C2 network.

Optimization (finding an 'ideal' solution)

Finding the ideal way to achieve some strategic goal is most likely an impossible task. However, NEMO can provide significant steps in that direction. This would involve developing a means to identify the goal, as well as methods for measuring how 'good' a proposed approach to achieving the goal is. Once these are established, a number of optimization algorithms exist that may be integrated into NEMO to find a solution that best fits the parameters. The most straightforward of these are evolutionary algorithms that take a number of possible approaches to a solution and evolve them over time using numeric approximations of principals taken from genetics to assure subsequent solutions are better than their predecessors.

Agents – Automate some relationship behaviors.

As stated earlier, the key component that allows NEMO to work is the definition of relationships between components of different network layers. These are presently modeled as static entities. In actuality, these relationships are generally dynamic in nature, reflecting our tendency to adapt in the presence of adversity. As we lose resources, we will usually make some effort to attempt repairs, look for alternative sources, or adjust priorities to re-allocate what's left.

NEMO is an agent-based application. Presently, there is a single agent defined that exhibits a static, non-adaptive behavior. Additional agents could be defined that exhibit the behaviors listed above. For example, an agent could search and compete for an alternative source of fuel if its primary source is disrupted or destroyed. This added capability would result in a multi-agent system, much like SWARM[7] or FLAMES[8]. Done correctly, NEMO may then be used to study 'emergent' behavior -- showing how an opponent's behavior may evolve from their current state.

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[7] SWARM Development Group, http://www.swarm.org

[8] Flexible Analysis Modeling and Exercise System, Ternion Corporation, http://www.ternion.com

Broader selection of relationship definitions

The prototype application allows the user to specify a simple on/off relationship between components of two networks. A number of additional relationship types are useful in specifying the nature of how network components interact. For example, many locations may be dependent on the same source of fuel. Conversely, a component may be dependent on the availability of several different resources to operate efficiently, and degrades over time if any or all of these resources are interrupted. Expanding the set of relationship definitions will allow an analyst to more accurately model the interdependencies between infrastructure networks, and provide a richer set of alternative approaches an adaptive agent can use.

9.0 Summary

NEMO is a prototype effects based planning and analysis application for modeling the cascading effects of events across multiple infrastructure networks. It is a Net-Centric compliant application, relying on an SOA approach to access infrastructure models, data repositories, and CJMT/K mapping tools. NEMO is currently capable of modeling interactions across electrical power, water, gas, and road networks using an on/off interaction behavior between the components of the different networks, and provides a solid foundation for advancement. Efforts are currently underway to integrate social/political networks into the EBO process. Future development needs to enhance it's capabilities for integrating additional relationship definitions, multi-agent capabilities, and optimization. NEMO provides a first of its kind capability for observing second and higher order effects of operations against an opponents infrastructure networks.