Use of Modeling and Simulation (M&S) in Support of Joint Command and Control Experimentation:

Naval Simulation System (NSS) Support to Fleet Battle Experiments

Colleen M. Gagnon[*]
William K. Stevens, Ph.D.
Metron, Incorporated
512 Via de la Valle, Suite 301
Solana Beach, CA 92075
Tel: 619-792-8904
Email: gagnon@ca.metsci.com / stevens@ca.metsci.com

Abstract

The US Department of Defense (DoD) has embraced the concept of Joint Experimentation to help identify future joint requirements and potential capabilities that may meet those requirements. Experimentation is viewed as a means to spur key DoD innovation, to help determine DoD priorities, and to transition potential 21st century technology and process improvements into the US military.

Despite the high level of visibility that first generation Joint and Service-specific experimentation programs have attracted, surprisingly little attention has been paid to how to best leverage scientific design of experiments and M&S practices to maximize the information that can be learned from such experiments. The application of scientific methods to DoD experimentation programs is, in the view of the authors, *required* in order to obtain the full benefit possible from operational experimentation.

This paper presents lessons learned from the application of the Naval Simulation System (NSS) and general design of experiment practices to US Navy Fleet Battle Experiments Alpha through Echo. NSS has been involved in many aspects of the Navy Experimentation process since its inception. These applications are described, and potential future applications of M&S to the Experiment process are recommended.

1. Introduction

In the past fifteen years, the US Department of Defense has come to recognize that the existing formal acquisition process has had difficulties keeping pace with improvements in technology. By the time a program is fielded, the state of the art – and indeed the requirement for the program – have often evolved past the original specifications for the system. To help identify future joint requirements and potential capabilities that may meet those requirements, the US Department of Defense (DoD) has embraced the concept of Joint Experimentation.

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Experimentation is viewed as a uniquely credible and robust means to achieve senior Military and Government consensus on required future military capabilities and the defense policies needed to realize them. This credibility stems from the fact that experimentation allows current operational forces to employ new technologies and new organizational command structures in an operational environment, along with complementary modeling and simulation (M&S) and a scientific approach, to quantify the value-added of specific new technologies and force structures in likely operational scenarios. Hence, Joint Experimentation is viewed as a means to spur key DoD innovation, to help determine DoD priorities, and to transition potential 21st century technology and process improvements into the US military.

Each of the three services (including the Marine Corps) has its own Experimentation program. The Fleet Battle Experiment (FBE) series was initiated when the Chief of Naval Operations (CNO) directed the Navy to engage in experiments to explore new weapons systems, technologies, and employment doctrines to carry the Navy into the 21st century. Commander, Third Fleet (C3F) initiated the first of these, FBE Alpha, in March of 1997 by combining a naval surface fire support (NSFS) power projection exercise with the Commandant of the Marine Corps Advanced Warfighting Experiment (AWE) Hunter Warrior. Together, these experiments demonstrated sea-based command and control of a special Marine Air-Ground Task Force (MAGTF) and examined the supporting Command, Control, Computers, and Intelligence (C4I) architecture required to effectively employ NSFS. Operationally, FBE Alpha examined the feasibility of an Arsenal Ship and introduced the "Ring of Fire" concept for large scale coordinated fire control services.

In FBEs Bravo and Charlie, conducted in September 1997 and May 1998, C3F and Commander, Second Fleet (C2F) respectively have continued the process of exploring new concepts and technologies by further investigating the Ring of Fire construct enhanced with Joint tactical air (TACAIR) precision strike support and future NSFS weapons. FBE Delta, conducted by Commander, Seventh Fleet (C7F) in October 1998, examined advanced C2 concepts and systems relevant to the counter-special operations forces (CSOF) and Joint Theater Air and Missile Defense (JTAMD) mission areas for the first time in a forward deployed operational theater. FBE Echo, recently conducted by C3F, examined JTAMD as well as force protection/port security issues against an asymmetric (terrorist) threat.

Despite the high level of visibility that first generation Joint and Service-specific experimentation programs have attracted, surprisingly little attention has been paid to how to best leverage scientific design of experiments and M&S practices to maximize the information that can be learned from such experiments. The application of scientific methods to DoD experimentation programs is, in the view of the authors, *required* in order to obtain the full benefit possible from operational experimentation.

This paper presents lessons learned from the application of the Naval Simulation System (NSS) and general design of experiment practices to US Navy Fleet Battle Experiments Alpha through Echo.

2. The Naval Simulation System

NSS is an object oriented, Monte Carlo simulation first developed in the early 90s as an analytic tool for force employment and course of action analysis for Fleet use. It models entity-level interactions with a specific focus on C2, i.e. the collection of information by sensors, the dissemination of that information over communications networks, the fusion of that information into a tactical picture, and a commander's decision making based on his locally-held tactical picture. In addition, NSS represents detailed command structures to simulate decision making at various levels within a command architecture. Commanders' plans are represented as well as individual assets' reactions to stimuli within their perceived environment.

With its emphasis on C2, NSS was first tapped to support the FBE series in the role of scenario stimulator for C2 systems. NSS was modified to generate OTHT-Gold contact reports which were fed to C2 systems being evaluated in FBE-B. A single replication of the Monte Carlo NSS simulation was run in real-time mode and the tactical picture was simulated for human operators manning the C2 system.

NSS evolved further along the "scenario generation/stimulation" path in FBEs Charlie and Delta, where interfaces to the model were developed so assets simulated in NSS could be manipulated in real time in response to tasking from the human operators in the experiment. In FBE-D, this interactive mode of NSS was matured to the point where the NSS operator actually "played" simulated aircraft by making voice reports over real communications systems to live operators tasking them, simulating situation reports, battle damage assessments, and aircraft checking on station for tasking.

Although NSS has found a niche in the FBE process in scenario stimulation, it also has significant capability in an analysis role. This capability has been used to some extent in producing quicklook excursions, performing MOE calculation, and in post exercise analysis. However, most of this work has been performed on an ad-hoc basis, without formal tasking from the Maritime Battle Center (the agency tasked with running the experiment series) and the numbered Fleet Commands hosting the experiment.

In the following section, we will discuss the specific applications of NSS to various roles in the Fleet Battle Experiment process. We divide these applications into three phases of support: pre-experiment, experiment execution, and post-experiment[1] and cite specific examples of using NSS in these roles in the five FBEs conducted to date. References [Stevens and Johnson, 1997], [Gagnon and Stevens, 1998(1)], [Gagnon and Stevens, 1998(2)] document this work.

3. NSS Experience in the FBE Process to Date

NSS has had the unique experience of filling various roles continuously in the Fleet Battle Experiment series, from its inception. We cite here a few standout functions that NSS has performed in the pre-experiment phase, the experiment itself, and in post-experiment analysis as illustrative examples of the role that M&S can fill in operational experimentation.

[1] This closely aligns with the concept of "model-test-model" being considered for future FBEs and for use in the Joint Experimentation program.

3.1 *Pre-Experiment*

Prior to the actual execution of an experiment, several things have to happen. The technologies that will be tested must be identified and the concepts for their employment must be thought out. A scenario must be agreed upon which is both of interest to the Fleet Command hosting the experiment and which will be a good context for the proposed tests. Scenario details such as Blue and Red orders of battle, time frame within the scenario, number and duration of experiment runs to be made, and data collection and proposed MOEs for analysis must be determined.

NSS has been employed as a scenario development and preview tool in both FBE Charlie and Echo, using a different approach in each experiment. In FBE Charlie, where Joint Fires were used to delay an enemy advance on a beach head being secured in an amphibious assault, scenario design was initially performed on a large chart where enemy columns' tracks were drawn along roads and across bridges, coordinated with movement of tactical SAMs and synchronized with Blue transportation of troops and equipment across the beach. Once the data was satisfactorily drawn out on paper, it was entered into NSS and then played back in a single replication for checking. Errors were corrected, tracks were adjusted, and timing of sorties and movement of forces were modified to ensure that events happened in the desired order. The playback capability of NSS proved to be an extremely useful tool for review of the scenario and to help tailor the threat presentation for the desired effect for the experiment. Figure 1 below shows a screen snapshot of one of the three scenarios NSS represented in FBE Charlie.

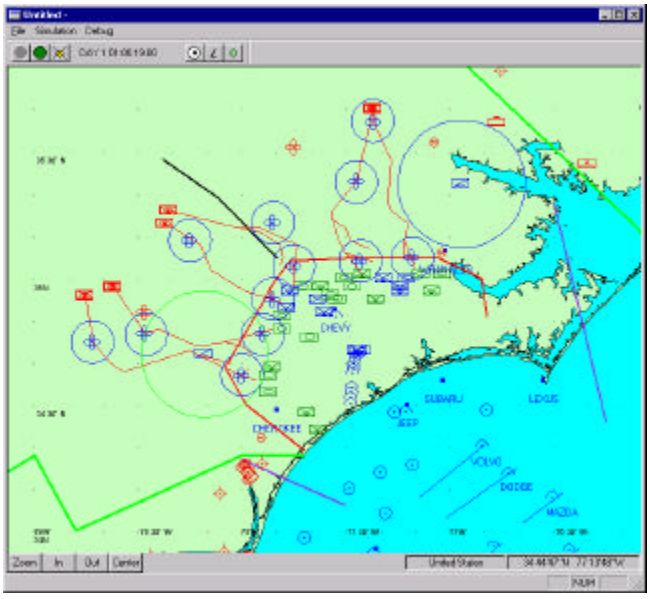

Figure 1. NSS Scenario Representation for FBE Charlie

In FBE Echo, NSS was also employed prior to the actual experiment to explore potential tactics for a new mission area for which tactics really did not exist. Among other subjects, FBE-E explored a port security scenario, where several Blue ships were anchored in a port and defended by patrol boats against small-scale attacks by a non-standard ("asymmetric") threat such as

swimmers laying mines or terrorists on jet skis making high speed attacks. This scenario was entered into NSS and run with several different threat presentations to explore where the proposed defenses broke down. The idea was to understand the problem in the model to a point where (1) a challenging and realistic threat presentation could be devised, and (2) a valid defense strategy could be suggested for testing in the actual experiment.

FBE Echo was the first time that M&S was used to explore tactics and threats in this manner prior to the actual experiment. A good deal more could have been done with the scenario in NSS if time had permitted. Different sensors, command and control arrangements, and even postulated weapons could have been substituted and run within the simulation. Unfortunately, there was not enough time to perform these runs prior to the actual experiment. In addition, the insights gathered from the model were not successfully fed into the experiment planning process due to insufficient lead time and the absence of an official mechanism for this transfer of information. However, we anticipate that this approach will be used in subsequent experiments, starting with Foxtrot in the Fall of 1999. In fact, the Naval Postgraduate School, which is performing the official data collection and analysis for the FBE series starting with Echo, has already stated a desire to use M&S prior to the experiment to mature tactics and scenarios "in the laboratory".

3.2 *Experiment Execution*

Fleet Battle Experiments are typically held concurrent with real-world exercises to leverage the assembly of live forces. Often this means that the FBE must compromise its goals because it cannot interfere with the live "host" exercise. One way for the FBEs to maximize the opportunity is to simulate forces that are not available from the host exercise. This has been the main focus of M&S in the FBEs to date. In addition to "filling in the gaps" of the live host exercise, M&S also provides a mechanism for data collection, real-time (quicklook) analysis, and training of operators of new systems under evaluation. NSS has been used in FBEs in each of these roles. We will now discuss these uses with examples from different experiments.

In Experiments Bravo, Charlie, and Delta, NSS teamed with the Land Attack Warfare System (LAWS), a C2 system that allows for efficient management of joint fires from the sea, to examine the Ring of Fire concept for joint fires, and to examine the use of precision weapons against time-critical targets in JTAMD. NSS simulated the majority of the scenario in each experiment, typically representing the following assets and capabilities:

- Blue ships, subs, forces ashore, and aircraft;
- Red order of battle, including surface, air, and ground assets;
- White ships and aircraft in the area;
- Green (coalition) ships, aircraft, and forces ashore;

Blue sensors simulated in NSS (including JSTARS, UAVs, satellites, Forward Air Controllers, P-3s, and AWACS) sent contact reports over designated communications paths to nodes were the information was fused into a tactical picture. A simulated command node declared targets from this picture "actionable" for attack based on specific criteria. These actionable targets were then

transmitted to the LAWS using standard OTH-Gold reporting formats for display to the operators and decision makers. Figure 2 shows the FBE Bravo C4ISR architecture for the Ring of Fire concept. NSS simulated everything to the left of the dotted line between the Intel and Fires Cells. The arrangement for FBE Charlie was very similar.

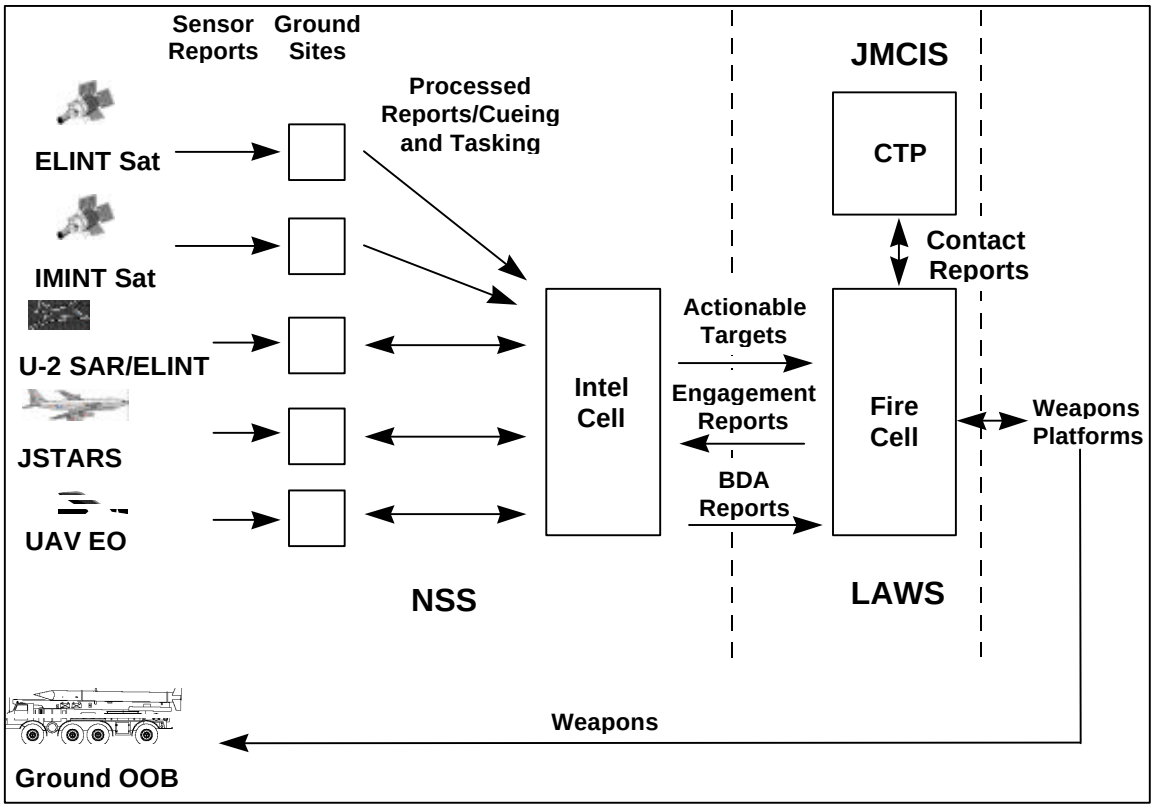

Figure 2. FBE Bravo C4ISR Architecture for Ring of Fire

In FBEs Charlie and Delta, LAWS operators tasked (simulated) airborne Combat Air Support (CAS) missions to attack (simulated) actionable targets on the battlefield. When the tasking assignment was received, NSS "flew" the CAS sorties to the targets, simulated the engagement, simulated Battle Damage Assessments (BDA) by sensors, and sent the BDA reports to LAWS using standard message formats and language. NSS also reported BDA on targets engaged by cruise missiles and guns, weapons represented by another simulation playing in the experiment.[2]

In FBEs Bravo and Charlie, NSS essentially executed a scripted scenario. Only CAS sorties and some target motion (in Charlie) were dynamically managed from the simulation. In FBE Delta, NSS' execution interface was greatly expanded to allow the NSS operator to respond to a wide variety of requests from the live LAWS operators managing a maritime offense against North

[2] The Johns Hopkins Applied Physics Lab's APLSIM was a high-fidelity simulation capable of representing TLAM, tactical TLAM, gun rounds, and other flyout weapons. Detailed weapons trajectory and flyout parameters were desired so airspace deconfliction could be examined in the Experiment. NSS and APLSIM were linked so that weapon impact events in APLSIM could be evaluated in NSS.

Korean seaborne insertion of special operations forces. Functions NSS simulated dynamically in FBE Delta included:

- Launch of alert aircraft specified by type, launch base, and callsign.
- Vectoring of attack assets against targets; attacks could be focused on higher priority targets if directed by LAWS operators.
- Redirecting of sensors.
- Redirecting of ships for attack or threat avoidance.

The realism of the NSS scenario simulation in FBE Delta was significantly enhanced by the addition of voice reports accompanying the contact reports sent to LAWS. A voice circuit between the NSS and LAWS operators allowed the following reports to be made:

- Situation Reports (SITREPS) made by the P-3 acting as airborne controller and area sensor. These included a surface picture summary, attack assets under the P-3's control, engagement status of these assets, fuel and weapons status, and any unassigned contacts.
- Alert aircraft check-in and check-out of the engagement airspace.
- Battle damage reports.

The details of the NSS simulation and the accompanying voice reports enhanced the realism of the presentation to the LAWS operators. This allowed the task loading of the decisionmakers using the LAWS system to be evaluated realistically.

When NSS is used to drive a scenario, it is in a unique position to automatically collect data that can be turned around for a quicklook analysis after the scenario run is complete. In FBE Bravo, data collected by NSS was used to generate MOEs that were used by the Maritime Battle Center to monitor progress and to determine if experiment objectives were being met. NSS automatic data collection and MOE generation provided details on:

- Target status (targets damaged as a function of time by target type, and the distribution of times required to detect, localize, damage, and destroy targets);
- Ring of Fire Asset utilization (asset assignment versus time compared to the number of targets within range); and
- Ring of Fire C2 node efficiency (the number of actionable targets held by LAWS compared to the number of assets allocated by LAWS, over the course of a run).

Data collection for final report generation is also supported. For example, in FBE Charlie, NSS provided data in electronic format to the Center for Naval Analyses, the agency tasked with formal data collection and analysis in that experiment.

Another very important function filled by NSS in the FBE series has been C2 system operator training. As directed by the CNO charter, the FBEs have examined new C2 technologies and

innovative C2 concepts, which are typically unfamiliar to the operators participating in the experiment. Training and familiarization with the equipment and procedures has been necessary to ensure smoothness of operation in the actual experiment. In FBE Charlie, separate training scenarios were developed to provide a simple threat presentation for operators using LAWS for the first time. In FBE Delta, a full week of training sessions was conducted with NSS scenarios, involving LAWS operator teams with various experience levels, to prepare for the three days of actual experiment runs. Without these training sessions, data collected during the actual experiment would be tainted by operator learning curves.

Another unique use of M&S during an experiment run is to examine excursions to the experiment scenario in near-real-time. This is often impossible because of the short turnaround time and the requirement to enter data into the simulation for the excursion. However, in two separate occasions, NSS analysts were able to use the simulation to generate data on possible scenario excursions within a 24-hour period during the experiment, providing insight into the data being collected. In FBE Alpha, NSS was run to examine alternative Arsenal Ship weapon loadouts and how these loadouts would change the preparation of the battlefield in support of tactical air strikes. These results were briefed to C3F the next day. In FBE Delta, data collected in NSS on the LAWS operators' times to make decisions for allocations of assets was fed back into the simulation. Monte Carlo runs were then made with excursions on both attack assets available and weapons effectiveness to see what impact these parameters would have on the rate at which targets could be prosecuted. Figure 3 shows the results of these runs, which were provided to the Maritime Battle Center and were subsequently cited in post-experiment briefings and reports. The data with diamonds and squares marking the lines are "live" experiment data collected by NSS during scenario runs. The data without diamonds and squares were generated by Monte Carlo runs of NSS with the excursions noted in the key. NSS's simulated LAWS operators' performance was tuned to the Team B performance shown in the plot.

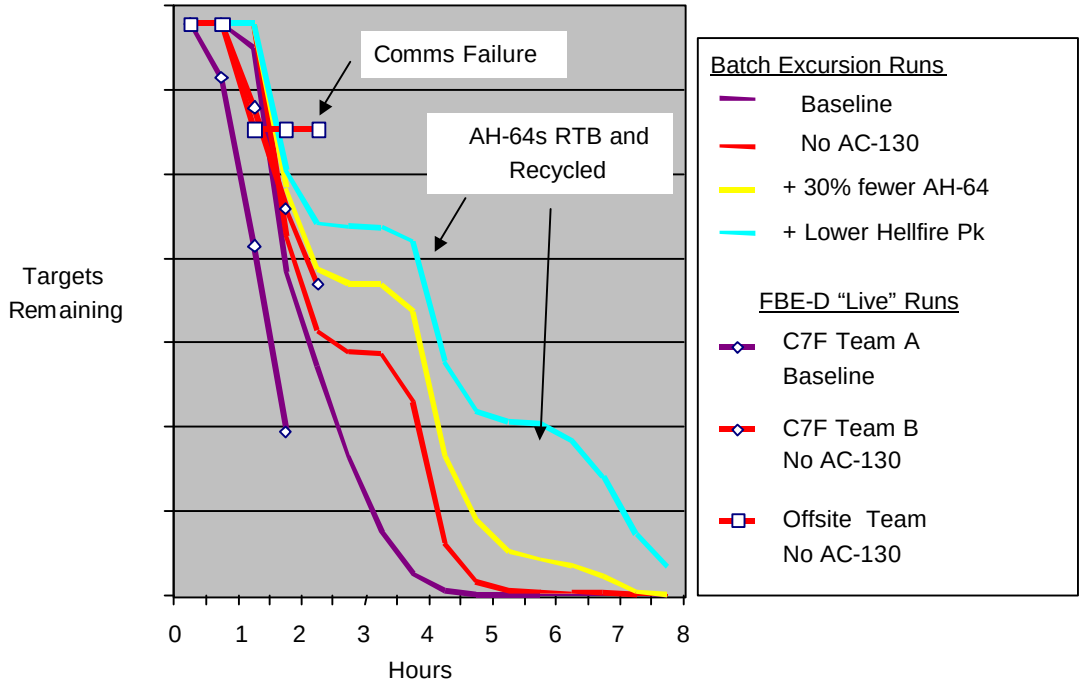

Figure 3. FBE Delta Excursion Analysis Performed During Experiment Execution

3.3 *Post-Experiment*

As a source of data, NSS has been involved in post-experiment analysis, most notably in FBE Bravo and Charlie [Bravo, Charlie final reports]. However, no new runs of the model were made to support these efforts. In FBE Echo, for the first time, the NSS scenario developed pre-experiment is being used to examine excursions post-experiment using data collected during the experiment. Although this effort is ongoing at the time of this writing, several observations can be made on this effort and its utility to the FBE process.

Data collected during FBE Echo on the performance of new sensors tested (target detection as a function of range) will be used in NSS instead of estimates of sensor performance previously used. Patrol boat defense tactics actually employed in the experiment will also be coded into the simulation as closely as possible to replicate the experiment play. Tracks of patrol boats and the jet ski threats were recorded using global positioning system (GPS) units during experiment runs. A parser routine has been built to read this data into NSS scenario files so actual tracks can also be used in simulation runs.

One way NSS has immediately shown value in post-experiment analysis is in simply replaying the GPS-recorded tracks. By simulating the proper assets on the tracks and running the model in a single replication, the movement of assets as recorded by the GPS units can be viewed. This presentation, combined with observer notes and other automated data collection, is essentially a complete historical record of the FBE Echo port security events. As the saying goes, "A picture is worth a thousand words".

Using the actual FBE tracks and sensor performance data, the FBE events can be simulated in NSS beyond a simple playback. By allowing the model to simulate communications, data fusion, and the centralized commander's tactical picture, the experiment play can be replicated and expanded upon with details of the commander's perception of the threat. With the simulation set up in this way, excursion analysis can be performed by simply altering aspects of the scenario. With the FBE Echo analysis, tentative plans are to run different weapons systems, try different patrol boat patrol regions, vary threat presentations, and perhaps explore alternative command arrangements. In this way, the limited set of data collected in the actual experiment can be leveraged into a wide variety of lessons learned through the application of M&S. In theory, these lessons learned can be re-tested in follow-on experiments.

4. **Recommendations: What M&S Can Still Contribute to the Experiment Process**

Although M&S has played a significant role in each stage of every experiment to date, there remain some important areas where it has yet to improve the overall process. The authors are hopeful that as the Fleet Battle Experiment series matures, M&S will be applied to bring more scientific rigor to the entire process.

Each FBE has been a relatively isolated event loosely connected to previous experiments by the common theme of battle management using future C2 systems such as LAWS. FBE Alpha through Delta increasingly widened the scope of the problem, from naval surface fire support through combined fire support in a forward-deployed theater. Although the themes have been

related, there has been no effort to baseline capabilities and experiment off that baseline with new weapons, sensors, or command techniques. This is the essence of "experimentation".

The concept of an Experimental Campaign, which is receiving serious consideration for Joint Experimentation, bears some discussion here. The Campaign links a series of experiments together, with each subsequent one building on what was learned from previous ones. Topics for future experiments are derived from lessons learned in past experiments, which serve as a baseline for the "new" ideas. This rational process closely mimics the scientific premise of establishing a known and understood benchmark and then measuring deviations from that benchmark to identify the best return of investment with respect to established operational requirements and scenarios of interest.

M&S can be also be used to "screen" likely topics for future experimentation. Analytic (Monte Carlo) model runs considering new proposed operational concepts can be made using a familiar baseline scenario. Results would provide a measure of the likely improvements obtained using the proposed advanced concept. Given that significant improvements are possible, one could then identify existing prototype C2 systems consistent with the new operational concept. These systems could then be investigated further through wargaming or similar techniques. The most promising systems would then be nominated for subsequent operational experimentation.

For example, referring back to the FBE Delta counter-special operations forces (SOF) scenario, suppose that M&S analytic runs indicated that significant speed of command improvements could be made if the centralized maritime commander responsible for prosecuting the SOF forces could be decentralized into multiple command functions.[3] The next step would be to identify potential C2 systems that would enable distributed command and control in that mission area. These systems could be linked together in the laboratory with M&S systems capable of providing scenario stimulation and of simulating resulting tasking orders to Blue assets. Metrics evaluating likely warfighting performance improvements with respect to baseline performance could be calculated, and the most promising C2 systems could be identified for future "live" experimentation.

Post-experiment, M&S could be used to stress-test concepts for larger-scale scenarios. The result would be to show there is reason to believe that the new concepts could meet identified operational requirements.

Employing a consistent M&S framework throughout the experiment process – from pre-experiment modeling, through at-sea experimentation, to subsequent post-experiment analysis – allows for consistency in evaluation both within the single experiment and throughout the Experimental Campaign. The Defense Modeling and Simulation Office (DMSO) has developed the High Level Architecture (HLA) standards, practices, and federation software for just such a purpose. Multiple C4ISR simulations, C2 systems, display systems, and post-analysis systems could interact using a standard, documented interface, which would enhance analysis, wargame, and experiment credibility and repeatability. A HLA M&S framework should receive serious consideration for future experimentation efforts.

[3] Indeed, the NSS IT-21 Warfighting Assessment study conducted for CINCPACFLT in November 1998 determined that distributed command would result in major timeline improvements in the counter-SOF mission for that theater [Atamian, 1999].

5. **Summary**

Modeling and simulation has played an important role in the Navy's Fleet Battle Experiment program since its inception. M&S has been active in pre-experiment analysis, has been instrumental in experiment execution, and has contributed to post-experiment analysis and interpretation of results.

The authors believe that M&S should play an even greater role by providing a comprehensive environment for Joint and Navy experimentation. This environment can support advanced C2 concept generation, assessment, wargaming, and operational experimentation, including seamless transition from one activity to the next, by providing a consistent framework. The software required to realize this vision already exists to a large extent. The DMSO HLA construct for simulation and C2 system interoperability has been demonstrated to provide an effective interface for linking systems in a manner which well suits the experimentation process. The Naval Simulation System, which has already established itself in the FBE process as a key tool for experimentation, is one of many HLA-compliant simulations that could be integrated to support experimentation. Developing a software framework and an experimental concept for cradle-to-grave concept testing will result in a more robust test process and add credibility to any experimental program.

6. **References**

[Atamian, 1999] Michael Atamian. *Naval Simulation System (NSS): An Assessment of IT-21 Warfighting Value-Added*. Metron, Incorporated, 1999.

[Gagnon and Stevens, 1998(1)] Colleen M. Gagnon and William K. Stevens. *NSS Support of Fleet Battle Experiment-Charlie / Phase II*. Metron, Incorporated, 1998.

[Gagnon and Stevens, 1998(2)] Colleen M. Gagnon and William K. Stevens. *NSS Support of Fleet Battle Experiment Delta / 27 – 30 October 1998.* Metron, Incorporated, 1998.

[Stevens and Johnson, 1997] William K. Stevens and David S. Johnson. *NSS Support of Fleet Battle Experiment-Bravo / Ring of Fire Phase*. Metron, Incorporated, 1997.