Use of Modeling and Simulation (M&S) in Support of the Assessment of Information Technology (IT) and Network Centric Warfare (NCW) Systems and Concepts

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Abstract

The work described in this paper addresses recent advances in the application of modeling and simulation (M&S) techniques to the problem of quantifying the force-level warfighting value-added of Information Superiority (IS) and Network Centric Warfare (NCW) in the context of realistic scenarios including Operational War Plans (OPLANs). The IS/NCW M&S activities to be reported in this paper have taken place in support of operational experiments and wargames, as part of analyses in support of CINC-level commands, and as a part of analyses in support of certain specific acquisition programs having the requirement to demonstrate synergy with ongoing DoD/Service Information Technology/Network Centric Warfare (IT/NCW) improvement programs. Lessons-learned concerning the challenges associated with representing IT infrastructure improvements along with required NCW warfare process re-engineering (WPR) initiatives will be presented. It will be shown that an iterative cycle of WPR initiative formulation and evaluation is often a *required* part of an assessment of the force-level warfighting value-added of specific IT/NCW improvements. We have found that M&S tools hence provide an important adjunct to operational experimentation in the role of formulating and evaluating the WPR initiatives which will likely provide the most warfighting value-added for specific IT improvements relative to specific scenarios or war plans. Quantitative results, including discussion of specific sets of analyzed IT improvement(s), WPR initiative(s), and OPLANs, will be included in this paper.

1. Description of the Problem

The U.S. Department of Defense (DoD) and the individual Services are actively working across the board to exploit commercial Information Technology (IT) advances as the enabler of a shift from Platform-Centric to Network-Centric Warfare. As but one example, the U.S. Navy Program Executive Officer for Information Technology (PEO-IT) is leading the Navy/Marine Corps Intranet (NMCI) effort, formerly known as IT-21, which is designed to implement the IT strategies necessary to insure Information Superiority (IS) for Joint and Naval Forces in the Twenty-First century. Information Superiority (IS) is defined to be "*the capability to collect, process, and disseminate an*

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uninterrupted flow of information while exploiting or denying an adversary's ability to do the same[1]". Network Centric Warfare (NCW) can in turn be defined to be the IT improvements necessary to achieve IS plus a necessary set of Warfare Process Re-Engineering (WPR) initiatives required to fully exploit information superiority (IS). There is a growing collection of evidence, including that to be presented in this paper, that IS plus an associated set of WPR initiatives yields Network Centric Warfare Operations with increased combat power as manifested in terms of increased tempo of operations, increased responsiveness, lower risks, lower costs, and increased overall warfighting effectiveness.

The work to be described in this paper addresses recent advances in the application of modeling and simulation (M&S) techniques to the problem of quantifying the force-level warfighting value-added of IS and NCW in the context of realistic scenarios including Operational War Plans (OPLANs). The IS/NCW M&S activities to be reported in this paper have taken place in support of operational experiments and wargames, as part of analyses in support of CINC-level commands, and as a part of analyses in support of certain specific acquisition programs having the requirement to demonstrate synergy with ongoing DoD/Service IT/NCW improvement programs. Lessons-learned concerning the challenges associated with representing IT infrastructure improvements along with required NCW warfare process re-engineering (WPR) initiatives will be presented. It will be shown that an iterative cycle of WPR initiative formulation and evaluation is often a ***required*** part of an assessment of the force-level warfighting value-added of specific IT/NCW improvements. We have found that M&S tools hence provide an important adjunct to operational experimentation in the role of formulating and evaluating the WPR initiatives which will likely provide the most warfighting value-added for specific IT improvements relative to specific scenarios or war plans. Quantitative results, including discussion of specific sets of analyzed IT improvement(s), WPR initiative(s), and OPLANs, will be included in this paper.

The purpose of this paper is to describe recent advances in the application of modeling and simulation (M&S) techniques to the problem of quantifying the force-level warfighting value-added of Information Superiority (IS) and Network Centric Warfare (NCW) in the context of realistic scenarios including Operational War Plans (OPLANs). The results presented in this paper represent some of the very first successful attempts to quantify the potential value-added of the DoD-wide shift to Network Centric operations[2]. This work also represents some of the very first applications of M&S to help formulate and evaluate the Warfare Process Re-Engineering (WPR) initiatives that will be required to fully leverage IS and to hence realize the promise of Network Centricity.

2. **Modeling and Simulation (M&S) Approach**

2.1 ***Overview***

Multi-Warfare Modeling and Simulation (M&S) is employed by the Department of Defense (DoD) to support acquisition analyses, to provide operational decision support, to support operator training, and to support operational experimentation. In the area of acquisition analysis, next generation M&S tools are used to assess the impact of new command and control (C2) and information

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[1] DPG and Joint Publication 3-13.

[2] *"Network Centric Warfare: Developing and Leveraging Information Superiority",* Second Edition (Revised), Command and Control Research Program, May 1999, pp.196-200, by David S. Alberts, John J. Garstka, and Frederick P. Stein.

operations (IO) concepts and technologies on force level effectiveness. In the area of operations, next generation M&S tools are being fielded as a part of the Global Command and Control System (GCCS) to support course of action (COA) analysis. Next generation M&S tools are also being used in support of operational exercises and experiments and laboratory based wargames and distributed simulation federations.

The Naval Simulation System (NSS) is an object-oriented Monte Carlo modeling and simulation (M&S) tool under development by SPAWAR PMW-131 and Metron, Inc. for CNO N62. NSS is a multi-warfare mission area tool designed to support operational commanders in developing and analyzing operational courses of action at the group/force level. Its capacity to replicate C4ISR entities and organizations robustly makes it unique among M&S tools. In this capacity, prototypes have been employed in numerous FLEETEX and Fleet Battle Experiment (FBE) operational exercises and experiments, in the U.S. Navy Global Wargame, and in numerous High Level Architecture (HLA) distributed simulation federations. NSS has also proven to be a valuable warfare assessment tool, especially as demonstrated in fulfilling CINCPACFLT's task to produce a preliminary assessment of IT-21 value-added in a Korean Peninsula scenario.

The IS/NCW M&S activities to be reported in this paper have involved the application of the Naval Simulation System (NSS) in support of operational experiments and wargames, as part of analyses in support of CINC-level commands, and as a part of analyses in support of certain specific acquisition programs having the requirement to demonstrate synergy with ongoing DoD/Service IT/NCW improvement programs.

2.2 *Representation of IT Infra-structure Improvements*

The representation of command and control (C2) and command decision processes, through the use of modeling and simulation (M&S) techniques, has become a key element of Department of Defense (DoD) technology initiatives in the areas of analysis and acquisition, operations planning and execution, and training. It has become increasingly apparent that if DoD sponsored military simulations are to effectively represent the entire battlespace, it is imperative that they accurately simulate C2 and related command decision activities as well as the impact that deep sensors, communications, and information flows have on these processes. The closely related issues of accurately representing information warfare (IW) and command and control warfare (C2W) are also becoming increasingly prominent within the DoD analysis, operational, and training communities.

The following three paragraphs provide working definitions for C2, IW, and C2W with references.

> **Command and Control (C2)** is defined to be "the exercise of authority and direction by a properly designated commander over assigned forces in the accomplishment of the mission. Command and control functions are performed through an arrangement of personnel, equipment, communications, facilities, and procedures employed by a commander in planning, directing, coordinating, and controlling forces and operations in the accomplishment of the mission[3]".

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[3] JCS Publication 1-02.

Information Warfare (IW) is defined to be "any action to exploit, manipulate, or destroy an adversary's information and/or information systems while leveraging and defending friendly information and information systems to achieve information dominance[4]".

Command and Control Warfare (C2W) is defined to be "the military strategy that implements IW on the battlefield[5]".

Providing adequately realistic and robust modeling and simulation (M&S) representations of the Military commander's decision process is a very challenging problem domain which will be shown in this report to be at best only partially addressed in existing and planned Department of Defense (DoD) sponsored models and simulations. Representation of information based warfare, e.g. IW and C2W, is similarly difficult. This paper will focus largely on *constructive*[6] models and simulations used for analysis and acquisition, operational planning and execution, and training. We believe, however, that this work has significant applicability to *virtual*[7] and *live*[8] simulation domains as well, although this will not be discussed in any level of detail in this paper.

Although C2W and IW have been practiced to some degree in the past, it is only recently with the explosion of plans and concepts for the use of information in all aspects of warfare that these areas are becoming the subject of DoD M&S initiatives. Information in this context represents a union of many diverse data sets, to be used by the commander in many different ways (most of which remain to be determined), and as such it has proven difficult to represent C2W and IW in the current generation of computer models of warfare. As a result of this increased focus on C2W and IW, many new initiatives to incorporate details pertaining to C2W and IW in warfare simulations have begun, as evidenced in a 1996 DEPSECDEF memo[9] that lead to the initiation of the Joint Warfare Simulation (JWARS) project.

2.2.1 ***Representation Requirement***

Many approaches for simulating human decision-making processes have been attempted. All have various associated strengths as well as weaknesses. In a recent RAND Corporation report[10], it was noted that: *"Decision-making and C4I issues dominate much of campaign analysis. At the campaign level, the problem to be addressed is often not how much force there is, but how it is used. Despite the importance of this problem, it remains the least understood and most inadequately modeled part of most campaign-level simulations."* The experience of the authors of this report confirms this view; there are elements of the command decision process which are clearly beyond the current M&S state-of-the-art as realized in the current suite of DoD models and simulations. We have also found, however, that there are elements of the command decision process which *can* be adequately addressed. From a M&S simulation technology standpoint, we believe that there are six key areas

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4 Nicholas Sabalos, Jr. (ed.), *Copernicus...Forward*, Surface Warfare, July/August 1995.

5 *Command and Control Warfare (C2W)*, CJCS Memorandum of Performance (MOP) 30, Revision 1, 8 March 1993.

6 *Constructive* simulation involves simulated people operating simulated systems, e.g. combat models, costing models, performance models [DoD M&S].

7 *Virtual* simulation involves real people operating simulated systems, e.g. SIMNET, BFTT, CCTT [DoD M&S].

8 *Live* simulation involves real people operating real systems, e.g. conducting training and testing on instrumented ranges [DoD M&S].

9 DEPSECDEF John Deutsch, *Joint Theater Models*, Memorandum dated 8 February 1995.

10 Richard Hillestad, Bart Bennett, and Louis Moore. *Modeling for Campaign Analysis: Lessons for the Next Generation of Models*. RAND Corporation, 1996.

which must be addressed in order to provide sufficiently realistic and robust (M&S) representations for (portions of) the Military commander's decision process. These six key M&S technology areas are as follows:

1. Collection: Representation of the collection of all-source surveillance and intelligence data including information content and information uncertainty. This includes modeling the dependencies on threat type and state, collection system type and state, and environment.

2. Dissemination: Representation of the means by which all-source surveillance and intelligence data is communicated to processing, evaluation, command, and execution nodes.

3. Fusion: Representation of the means by which all-source surveillance and intelligence data is processed into information suited to the Military commander. This includes various forms of derived data extraction, correlation, and state estimation (fusion).

4. Situation Assessment: Representation of the means by which situation assessments are obtained and provided to the Military commander, e.g. assessment of threat intent.

5. Decision Process: Representation of the decision process itself, e.g. the procedures employed by a commander in planning, directing, coordinating, and controlling forces and operations in the accomplishment of the mission.

6. Metrics: Providing the means to measure the ability of the surveillance/intelligence architecture to collect key tactical data, the ability of the communications architecture to deliver key surveillance/intelligence products, the marginal utility of specific surveillance/intelligence products to decision making, and other related quantities.

It is important to capture these elements in order to adequately represent the command decision-making process. It is equally critical to represent these steps in an integrated, versus a piecemeal, fashion. Interruptions or delays in the process at some point should translate into a lack of information at the next step. Errors should propagate through the collection and fusion steps and should influence decisions made based on the resulting erroneous tactical picture. This *traceability* through the entire process is key to understanding the impact of changes in the C2 architecture have on overall force effectiveness. Integration of the key steps of the decision-making process will ensure that the simulation is sensitive to potentially important changes in the C2 architecture, allowing realistic C2 analyses to be conducted.

Note also that these elements of C2 are pervasive activities which span Service-specific as well as mission-area-specific boundaries. They should be present in C2 models and simulations whether they represent Air Force space collection operations, Army battlefield reconnaissance, Navy undersea warfare surveillance, or other Service-specific and Joint applications.

It is also important to note that although this list of C2 elements should be addressed for the realistic representation of C2 processes, it is not always necessary to include every element on the list for every application. Models should contain (or invoke) only as much detail as is required for the analysis being conducted. Over-representation of a problem simply results in increased data collection requirements and unnecessarily long run times. For example, if an analyst seeks to understand the delays inherent in a given C2 architecture and is not concerned with the collection of information over the battlefield, then the representation of the sensors (and their detection processes, scheduling, and positioning) need not be addressed in great detail; in fact, one alternative might be to represent the information "entering" the C2 architecture parametrically to test the response time of the architecture to varying sensor configurations. A simplification of the modeling such as this would reduce the amount of sensor data to be collected and could also result in vastly reduced model run times.

2.2.2 *Representation Approach*

The experience of the Naval Simulation System (NSS) design and development team suggests that the quantitative representation and evaluation of C2 and C2 systems in realistic scenarios via simulation is very involved and at a minimum must address: (1) command structures and relationships; (2) representation of operational plans; (3) simulation of plan execution including dynamic/responsive asset allocations; (4) tactical picture generation; (5) dissemination of surveillance and intelligence products; and (6) simulation of surveillance and intelligence product collection and generation. The NSS design and implementation for addressing each of these very complex C2, IW, and C2W processes and systems has been reported on extensively in numerous previous conferences[11, 12].

2.3 *Representation of NCW and Associated WPR Initiatives*

As is discussed above in Sections 1 and 2.2, the representation of Network Centric Warfare (NCW) involves both the representation of information technology (IT) infrastructure improvements as well as the warfare process re-engineering (WPR) steps required to achieve NCW implementations for each major warfare mission area. Representation of needed IT improvements is largely independent of warfare mission area and hence can typically be handled as described in Section 2.2. Representation of the WPR initiatives required to leverage IT improvements for each warfare mission area is more specialized, however. As was discussed above, IT improvements will only yield warfighting value-added for decision makers whose decision processes are specifically designed to take advantage of an improved information position. Generally speaking, WPR initiatives are required for each warfare mission area in order to realize the promise of NCW.

The Navy/Marine Corps Intranet (NMCI) effort is leveraging ongoing commercial information technology (IT) breakthroughs permitting video, voice, and data communications over common high-speed networks employing common formats and supporting user "bandwidth on demand". These NMCI improvements and other similar Department of Defense (DoD) and Industry IT infrastructure improvement programs offer the prospect of a virtual network of afloat and ashore command and control (C2) and execution nodes, supported by high bandwidth communications and full all-source info exchange. Network Centric Warfare "speed of command" improvements will be

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[11] *Representation of C2 and IW in Military Simulations.* (W.K. Stevens, W.L. Decker, and C.M. Gagnon) Proceedings of the Second International Symposium on Command and Control Research and Technology, Market Bosworth, Warwickshire, UK, 22-26 September 1996.

[12] *Representation of Command and Control (C2) in the Naval Simulation System (NSS).* (W.K. Stevens, W.L. Decker, and C.M. Gagnon) Proceedings of the NATO Studies, Analysis and Simulation Panel (SAS) 1999 Symposium on Modeling and Analysis of Command and Control, Paris, France, 12-14 January 1999.

derived from these virtual networks coupled with new network-centric, distributed, PC- or workstation-based, C2 problem-solving applications that are designed to specifically take advantage of the network.

2.3.1 *Need for WPR Initiatives*

Information Technology (IT) infrastructure improvement programs in and of themselves are often not sufficient to result in warfighting value-added. What is often required are new command processes supported by new command and control (C2) applications designed specifically to take advantage of the Information Superiority (IS) that might result from IT improvement programs. *A commander who commands without regard to his information state will not benefit from an improved information situation.* Hence IT improvement programs will only result in significant warfighting value-added if there are associated C2 warfare process improvement programs designed specifically to leverage resultant IT/IS improvements.

The following notes briefly summarize lessons-learned to date concerning Network-Centric C2 application requirements. It is hypothesized here that individual commander/execution nodes should be allowed to exercise maximum autonomy and flexibility consistent with the force commander's guidance. The union of individual commander's actions must yield coherent, consistent, and effective global command and control. The above relies on existence of a common operational/tactical picture. The goal of network-centric C2 is to leverage the power of the network to enable speed of command improvements. What distinguishes a network-centric architecture from a platform-centric architecture is not just connectivity, but the attempt to push C2 functionality down to the lowest possible command level without having the C2 architecture degenerate into "every man for himself".

Network Centric Warfare relies on the existence of a single integrated operational/tactical picture which is managed via tactical picture management functions distributed throughout the C2 network. On-scene operational players should be able to support the management of the local picture for the force. Such distributed, network centric tactical picture management can be expected to yield the most significant performance impacts for manual processes such as ambiguous contact resolution in high-density cluttered target and background traffic environments and imagery and intelligence correlation and assessment. It is evident that the results of past-distributed fusion R&D can be applied to this problem.

Figure 2.3.1-1 provides a schematic for how Network Centric fusion might work, based on previous distributed data fusion prototyping efforts conducted for the Applied Physics Laboratory at Johns Hopkins University (APL/JHU) and elsewhere[13,14]. Under this approach, each command node in the network maintains a local picture as well as a shared common (networked) picture. The processing required for each local picture involves the following summary steps: (1) receive local/external data;

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[13] Fludzinski, M. T., Davidson, M. E., and Corwin, T.L., "Distributed Correlation and Tracking Study : Phase II", Metron Report to Applied Physics Laboratory, Johns Hopkins University (APL/JHU), 2 May 1984.

[14] Chrysostomou, A. K., and Maurer, D. E., "Measures for Attaining Consistent Tactical Pictures in Distributed Multiple-Hypothesis Correlation and Tracking Systems.", JHU/APL FS-92-004, January 1992.

(2) update the local picture; (3) compare the local picture with shared global picture; and (4) if differences exceed preset thresholds, communicate information "deltas" to others via the Joint Data

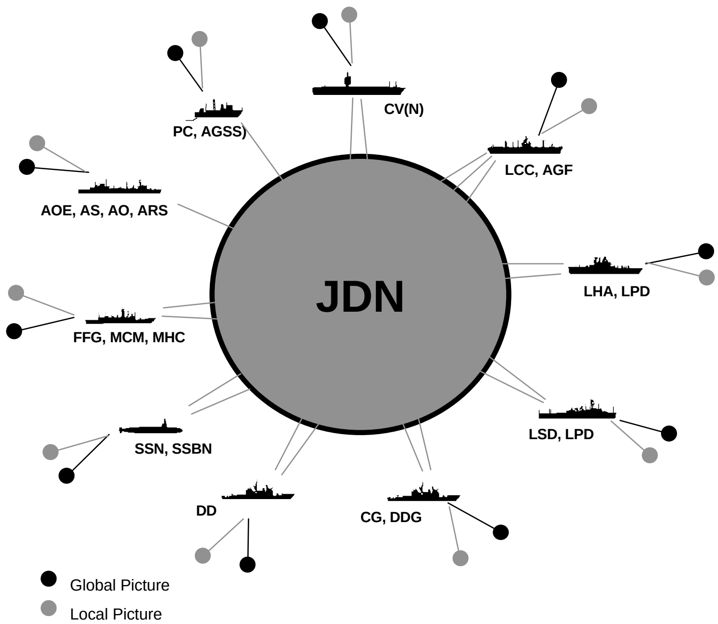

Figure 2.3.1-1. Network Centric Fusion.

network (JDN). Similarly, the processing steps for each shared picture involves a similar set of processing steps: (1) upon receipt of a tactical picture information "delta", update both the local and global pictures; (2) compare the local picture with the global picture; and (3) if differences exceed preset thresholds, communicate information "deltas" to others via JDN. In this way, local on scene commanders can manage the local picture while providing appropriately down-sampled updates of the local picture to the entire force via the network. Figure 2.3.1-2 provides a slightly different view of this network centric data fusion scheme. Other concepts for Network Centric distributed data fusion exist as well.

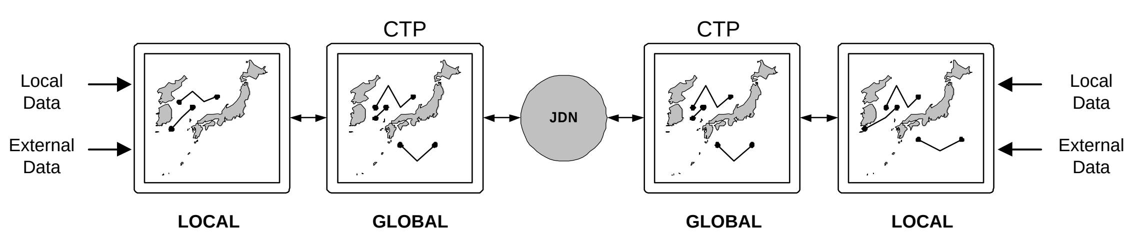

Figure 2.3.1-2. Another View of Network Centric Fusion.

In a similar fashion, network centric decision making will attempt to distribute tactical planning and decision functions throughout the C2 network. E.g. under network centric operations, force strike planning will be conducted as a collaborative, iterative process between the Joint force, component, and wing levels of command. As an example, the network centric decision making process might be characterized as follows. The force-level commander defines global and local mission goals and devises initial component-level plans. These initial plans are then disseminated to the component level. The component-level commanders then optimize the component-level plans based on local goals and information and then communicate refined plans back to force-level commander. The force-level commander resolves conflicts among multiple component-level plans and initiates a second round of iterations as required. Significant automation of this process, employing mathematical optimization techniques has been shown to be possible and R&D demonstration systems exist.

Figure 2.3.1-3 provides a schematic for how network centric command and control (C2) might work, based on previous distributed C2 prototyping efforts conducted for the Naval Research Laboratory (NRL) and elsewhere[15,16]. Under this approach, the common operational/tactical picture supports coordinated decision-making across multiple levels of command. Each node in Figure 2.3.1-3 represents decision making at a single command level, which itself may be distributed over a large network of computer workstations. Tasks, in the form of targeting objectives, resource availability, and planning constraints, flow down the chain of command, and responses, in the form of subplans that accomplish each commander's assigned tasks, flow up the chain of command. Appropriate plan generation algorithms can be invoked by commanders at any level. At the unit level, the algorithms apply a mixture of classical mathematical programming techniques in order to produce attack and suppression plan recommendations. At the command level, conflicts among the subplans received from subordinates are identified and a combination of classical and heuristic deconfliction algorithms are used to recommend changes in subordinate tasking. Tasking is the mechanism by which each commander controls the planning process of his subordinates. Detailed planning is performed as far down in the chain of command as possible. Consensus plans, i.e. best feasible deconflicted plans currently available, can be generated at any point in time as the current response from one command level to the next. The entire system is recursive, i.e. additional layers add no further complication. Other concepts for network centric command and control (C2) exist as well.

2.3.2 *Representation Requirement*

The representation requirements for evaluating Network Centric Warfare (NCW) concepts and the associated warfare process re-engineering (WPR) initiatives alluded to above depend strongly upon the NCW concepts and WPR initiatives in question. Required representations might range from the federation of actual NCW fusion or C2 decision support systems with the modeling and simulation environment to employing simplified analytic representations of the fusion and C2 approaches. Figure 2.3.2-1 illustrates the range of options which might be employed. This Figure anticipates that there might be four phases associated with the quantitative evaluation of NCW systems and concepts: pre-experiment analysis; pre-experiment wargaming; experimental evaluation; and post-experiment analysis. In the pre-experiment analysis phase, baseline performance is assessed for current systems and procedures within the context of relevant warfighting scenarios. Analytic representation of NCW IT and WPR initiatives are also assessed as excursion cases and the potential value-added of these initiatives are assessed. Given sufficient predicted valued-added, existing or planned C2 systems supportive of the NCW initiatives are also identified during this first phase.

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[15] "Weapon Target Allocation for Force Level Strike Planning", by R. Jakobovits, D. Carroll, and J. Hofmann, Proceedings of the 62nd MORS Symposium, June 1994.

[16] *"Distributed Resource Allocation for Strike Planning",* by R. Jakobovits, and J. Hofmann, presented to the AFCEA/NRaD Joint C4I Symposium, May 1995.

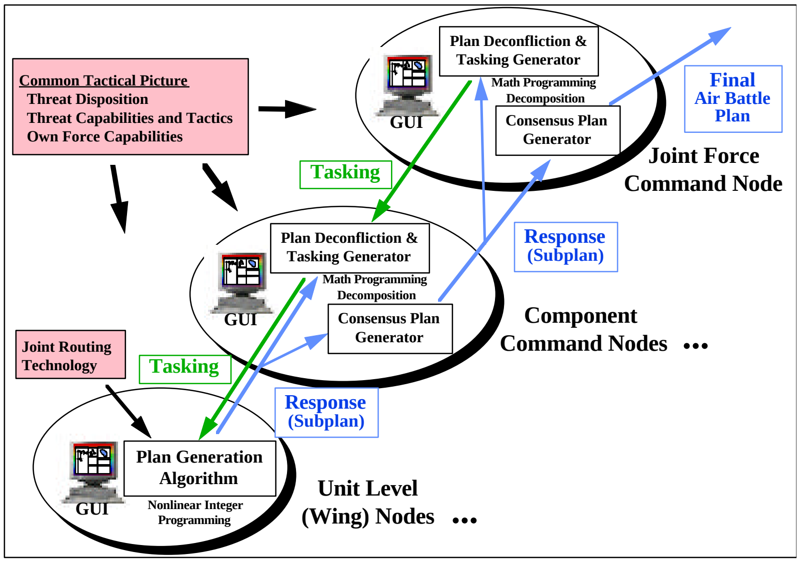

Figure 2.3.1-3. Network Centric C2.

In the pre-experiment wargaming phase, the existing or planned C2 systems supportive of the NCW initiatives in question are federated with simulation systems in order to support laboratory wargaming evaluation of the NCW concepts and WPR initiatives to be evaluated during the experimental phase. Simulations are employed to appropriately stimulate the selected C2 systems in order to assess the effectiveness on man-in-the-loop (MITL) decision-making. The objectives of this phase are experiment (phase 3) rehearsal, scenario refinement, and preliminary identification of the existing or planned C2 systems most supportive of the NCW concepts and WPR initiatives in question. The result of this phase is the nomination of scenarios and C2 systems for employment during the experiment phase.

In the experiment phase, the laboratory MITL wargaming environment is transitioned to the operational environment. The laboratory local area network (LAN) is in effect replaced with corresponding operational local/wide area networks (LANs/WANs). Simulation systems may be again employed in this phase as necessary to augment live play. The aggregate of live and simulated warfighting activities and associated message and data flows are used to stimulate the manned C2 systems selected during phase 2. The conduct of the operational experiment mirrors phase 2 wargaming, with military operators and operational communications systems and data links replacing their laboratory equivalents. The result of this phase is an operational assessment of the value-added of the NCW concepts and WPR initiatives proposed, taking into account as many of the complexities associated with the actual operational environment as is possible. An important by-product of this activity is the calibration of poorly understood simulation inputs such as key operator decision delays (e.g. time to resolve ambiguous contact reports, time to allocate fire assets to targets, etc.).

In the post-experiment analysis phase, the results of the three previous phases can be collected and augmented to form a complete assessment of the likelihood that the proposed NCW concepts and WPR initiatives will satisfy relevant operational requirements. In this final phase, re-calibrated model input values derived from phase 3 experimentation can be used to re-compute baseline performance and to re-assess the expected marginal improvements derived from the proposed NCW concepts and WPR initiatives. Analytic stress testing of the results for larger-scale scenarios is also possible in this phase.

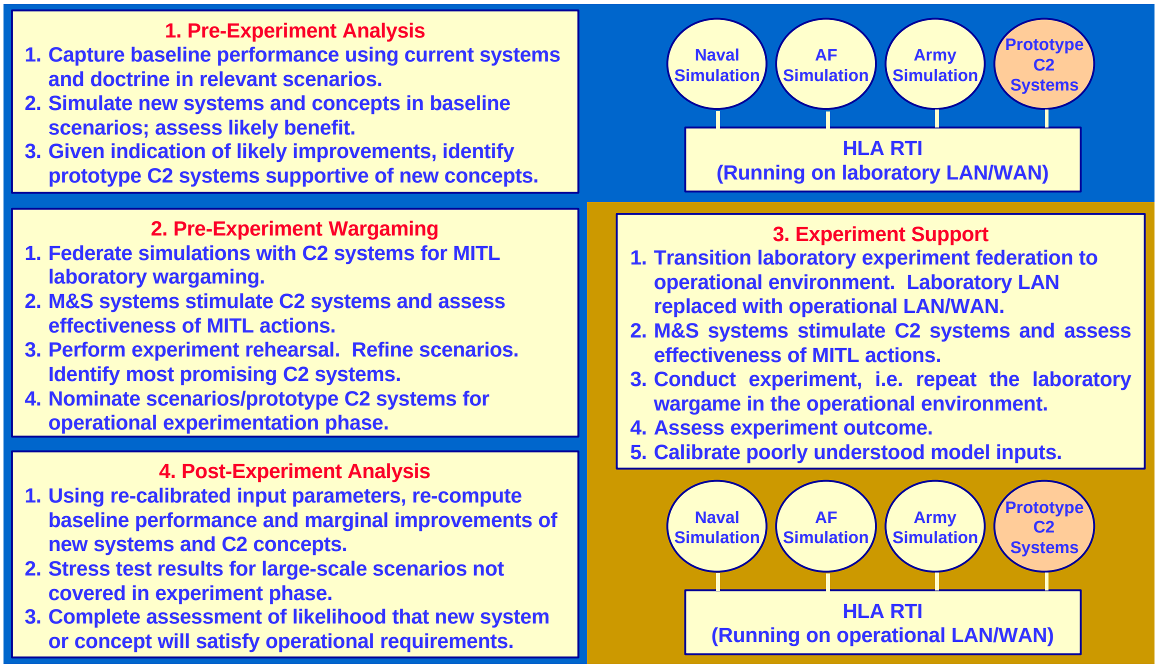

Figure 2.3.2-1. Four Phases of NCW Evaluation.

2.4 *Information Superiority (IS) Metrics*

The entity-based, Monte Carlo, discrete-event simulation approach described in the paper has proven to provide one means to directly measure relevant Information Superiority (IS) metrics in mission-to-campaign level scenarios. The key enabler of this IS metric capability is the explicit, entity-based representation of C4ISR effects including explicit representation of platforms, systems, and commanders; representation of detailed aspects of the command organization; commander's plans and doctrine including responsive behavior; information collection; information dissemination; tactical picture processing; and resultant warfighting interactions. Metrics computed with this approach can be used to quantify the impact of information technology (IT) infrastructure improvements and warfare process re-engineering (WPR) initiatives on warfighting outcome. This approach hence provides a perhaps unique means to capture, simulate and dynamically view, and quantify the performance of alternate C4ISR architectures and warfighting plans.

2.4.1 *Metrics and Statistics*

Typical Monte Carlo metrics are random variables which are computed once for each Monte Carlo replication of each warfighting scenario of interest. Examples of these metrics (X_n = value of metric X in replication number n) can include: (1) the percentage of threat subsurface units of a particular country/type tracked (or trailed or killed) on a particular day and time; (2) the average positional area of uncertainty of mobile missile launcher units of a particular country/type on a particular day and time; and (3) many others pertaining to the ability of a C4ISR architecture to observe, orient, decide, and act. Monte Carlo simulations can and should provide the following basic statistical outputs for each of these C4ISR metrics.

The estimated mean (μ) of X provides an estimate of the typical value of each metric X over some number N of Monte Carlo replications. See equation 2.4.1-1 below.

$$\mu \cong m = \frac{1}{N}\sum_{n=1}^{N} X_n \qquad \text{(Equation 2.4.1} - 1\text{)}$$

The estimated variance (σ) of X provides an estimate of the variance of X. E.g. for a normally distributed random variable metric X, 95% of its values lie within 2σ of μ. See equation 2.4.1-2 below.

$$\sigma^2 \cong s^2 = \frac{1}{N-1}\sum_{n=1}^{N} \left(X_n - m\right)^2 \qquad \text{(Equation 2.4.1} - 2\text{)}$$

The estimated variance of μ is approximated by the variance of m and (for normally distributed X) provides a 95% confidence bound on the estimated mean value of X. See equation 2.4.1-3 below.

$$\text{Variance}[m] = \frac{\sigma^2}{N} \cong \frac{s^2}{N} \qquad \text{(Equation 2.4.1} - 3\text{)}$$

1.1.2 *Sensitivity and Excursion Analysis*

Monte Carlo runs can be organized in the form of multiple excursions of a baseline scenario plus multiple excursion cases. Excursion cases can be organized so as to support systematic investigation of variations of key study parameter values (e.g. variations in the assumed probability of kill of a threat surface-to-air missile site or sites) or of force composition (e.g. variations in squadron mix associated with an aircraft carrier or airbase). Evaluation of a common set of metrics across the baseline and excursion scenario cases permits the sort of sensitivity analysis pictured below in Figure 2.4.2-1.

Pictured in Figure 2.4.2-1 are notional results illustrating the possible sensitivity of a key metric (number of BLUE fighters killed) to variations in threat surface-to-air missile system probability of kill (Pk) and BLUE squadron mix. It is this type of sensitivity or excursion analysis which is normally of most interest to C4ISR analysis customers. It is also the case that metric sensitivities and trends arising from important parametric and force composition variations can be reported with a higher level of confidence than can the absolute values of individual metrics.

1.1.3 *Cause-and-Effect Analysis*

It is also the case that often times the most desired output of a C4ISR analysis is the answer to the following set of questions: “Did the proposed new C4ISR architecture yield a significantly improved warfighting result?” If so, what specific aspects or features of the proposed new C4ISR architecture were responsible for this improved warfighting result? What was the marginal contribution of each relevant aspect or feature of the C4ISR architecture to the overall improved warfighting outcome? While an automated approach for answering these questions is not available for Monte Carlo discrete-event simulation tools, there does exist a semi-automated, cause-and-effect analysis approach which can be used to address many questions of this type.

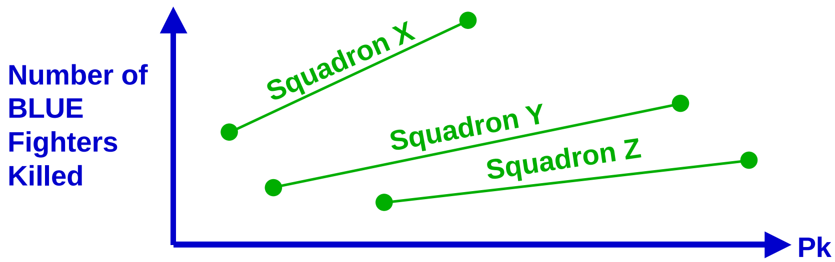

Figure 2.4.2-1. Excursion Analysis.

Pictured below in Figure 2.4.3-1 is a schematic diagram illustrating the cause-and-effect analysis approach employed in Naval Simulation System studies and analyses. For each C4ISR operational sequence (see left third of Figure 2.4.3-1) there can be associated sets of automated cause-and-effect metrics at the individual threat present level (see middle third of Figure 2.4.3-1), at the force level (see right third of Figure 2.4.3-1), and others. In addition, high-level metrics are computed to measure the ability of the C4ISR architecture to meet commander's objectives such as threats killed, own forces killed, resources expended, and the degree to which specific objectives were achieved. Given a high-level outcome (e.g. all commanders objectives achieved within desired time, resource, and own-force attrition constraints), the automated sets of cause-and-effect metrics can be examined to determine what specific aspects or features of the C4ISR architecture gave rise to the high-level result.

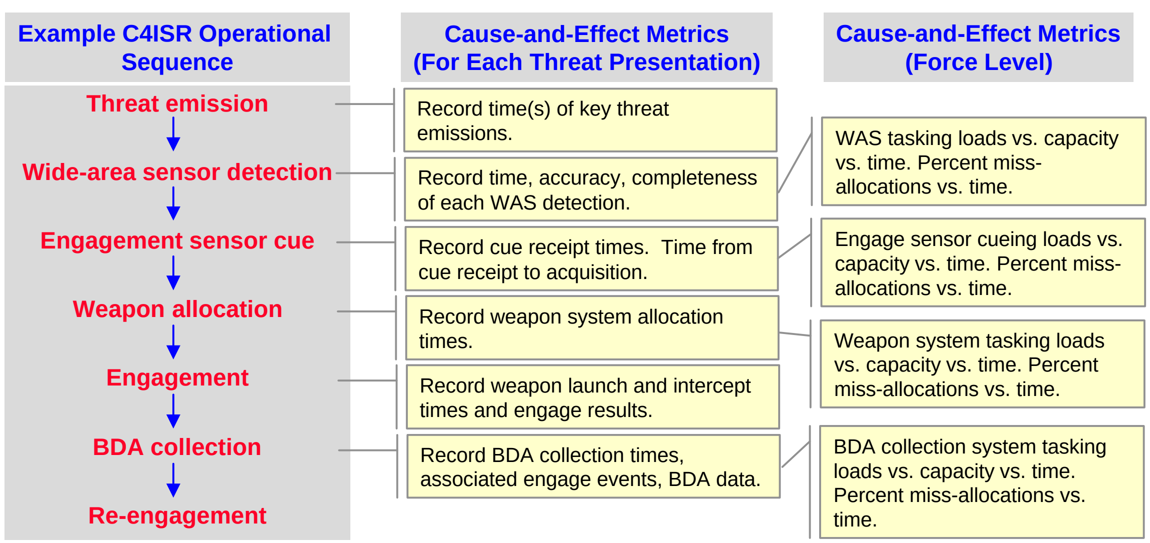

Figure 2.4.3-1. Cause-and-Effect Analysis.

Marginal analyses can be conducted using a combination of sensitivity analysis and cause-and-effect analysis techniques. Suspected key performance drivers or collections of drivers are selectively added/removed from the baseline architecture. Differences in the high-level warfighting outcome measures provide quantification of the marginal value of the selected C4ISR drivers.

3. **Case Study Results**

This section describes recent advances in the application of modeling and simulation (M&S) techniques to the problem of quantifying the force-level warfighting value-added of IS and NCW in the context of realistic scenarios including Operational War Plans (OPLANs). Section 3.1 describes analysis results obtained addressing the value-added of certain IT-21 improvements on strike effectiveness in an operational war-plan. Similarly, Section 3.2 describes experimental and post-analysis results obtained addressing the value-added of the same IT-21 improvements on counter special operations forces (CSOF) effectiveness in an operational war-plan.

3.1 ***IT-21 Study***

In this IT-21 Study, it was shown that under the postulated IT-21 improvement plan, dramatic improvements in the ground picture available to key command nodes could be expects as shown in Figures 3.1-1 and 3.1-2. Figure 3.1-1 shows the number of ground tracks in the air component commander's (ACC) picture vs. time. Plotted is both the number of total tracks and the number of tracks with classification information including Unknown (i.e. no classification data), Mechanized, Artillery, Armor, and Infantry. Figure 3.1-1 shows this data for the current architecture, while Figure 3.1-2 shows this same information as predicted for the planned IT-21 improvements. Apparent from these two Figures is the implication that under IT-21 the ground target ID rate is expected to increase from roughly 90% unclassified in the current architecture to virtually 100% classified after the first 5-10 hours of the war. Hence the planning IT-21 improvements in this case results in more ground tracks with significantly more (10% increased to essentially 100%) tracks with classification data.

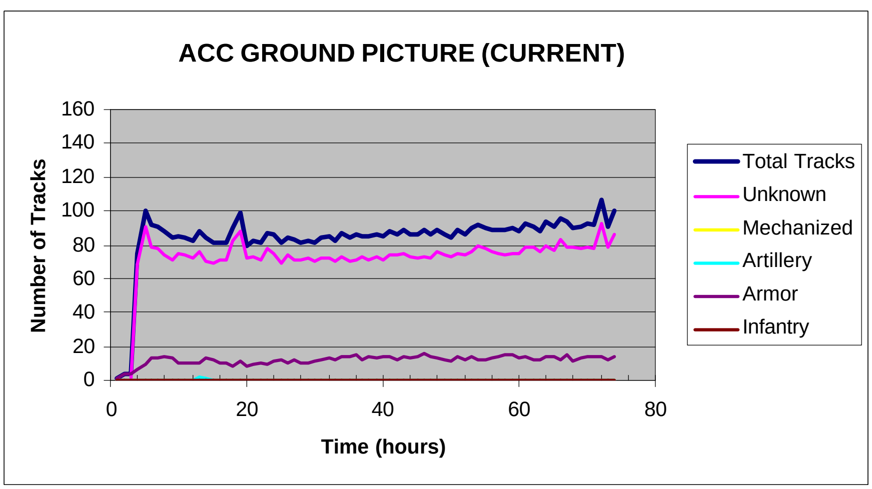

Figure 3.1-1. Ground Picture Current.

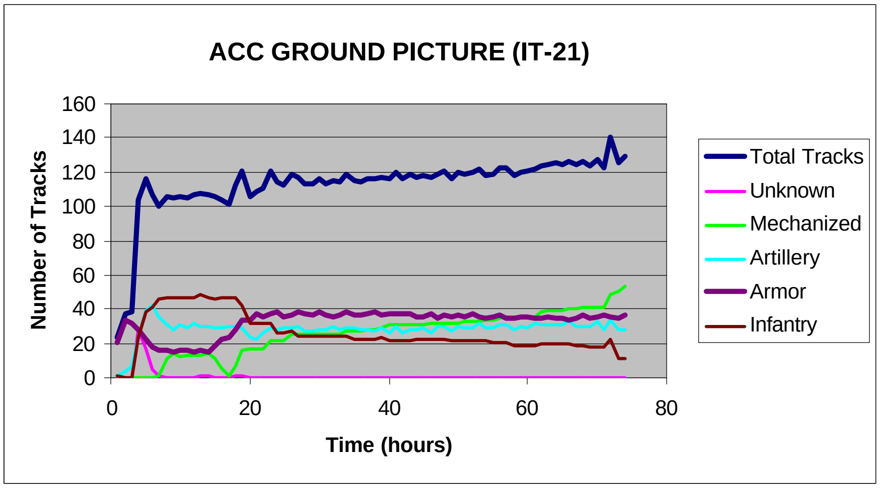

Figure 3.1-2. Ground Picture Under IT-21.

The key question to be answered was hence, *"Does this increase in the number and ID rate of ground tracks translate into increased strike warfighting effectiveness?"* The possibly surprising initial answer for the first three days of the war-plan for which air tasking orders (ATO's) have been pre-planned was "no". The reason for this is that these pre-planned ATO's have the vast majority of sorties flying against known, fixed targets with only a small percentage of the total sorties flying against fixed "kill boxes". Hence improving the strike commander's knowledge concerning ground targets during this period does not result in improved performance, since the strike planning in the first three days of the war is not sensitive to information which might be collected during that time. Based on the results shown above in Figures 3.1-1 and 3.1-2, it was hypothesized that if the strike commander were to change his procedures so that ground picture information was employed to adapt the ATO during the firs three days of the war, that strike performance would be enhanced. The results of an investigation to test this hypothesis are shown in Figure 3.1-3. Pictured here are the numbers of sorties flown, engagements, kills, and counter surface-to-air missile (SAM) attacks for the current war-plan (labeled fixed kill-boxes) and for a new hypothesized ATO in which a high percentage of sorties fly to holding points and may be vectored to targets by the strike commander (labeled on-the-fly ATO). What this figure shows is that with the same number of sorties flown, there are more engagements, more kills, and fewer SAM counter attacks under the new "on-the-fly" ATO approach. This is an example of a warfare process re-engineering (WPR) initiative which proved to be necessary to reap the benefits provided by IT infrastructure improvements and resultant improved situational awareness for the strike commander and his staff.

This assessment went on to analyze "speed-of-command" improvements for these strike operations. It was shown that given the IT-21 improvements plus the "on-the-fly ATO" WPR initiative, that: (1) strike prosecution timelines were reduced from an average of 13.5 to 5.5 hours for the prosecution of high priority targets (here prosecution means time from initial detection opportunity to detect to classify/ID to engage to battle damage assessment); (2) the artillery attrition goal was achieved in 34 vs. 64 hours, and (3) 50% more critical mobile targets were killed in the first three days of the war. Hence in this case it was judged that the IT-21 infrastructure improvements plus the "on-the-fly

ATO" warfare process re-engineering (WPR) initiative combined to yield significant warfighting value-added in this specific operational war-plan.

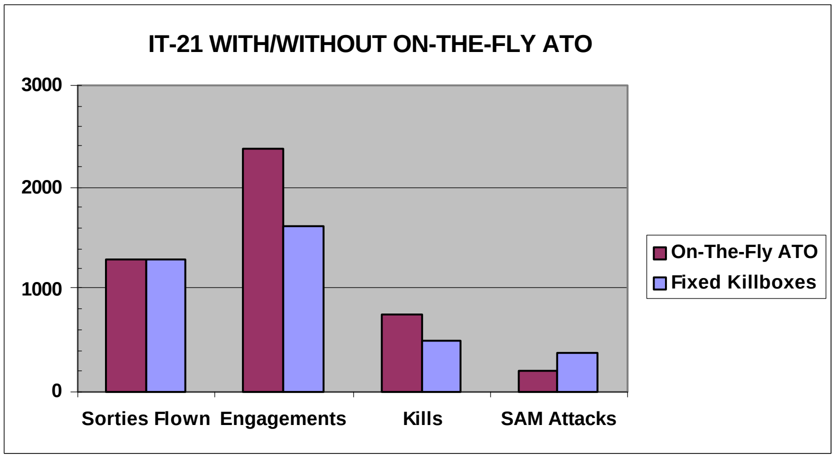

Figure 3.1-3. On-the-Fly ATO Warfare Process Re-Engineering Initiative.

3.2 *Fleet Battle Experiment Delta (FBE-D)*

In this Fleet Battle Experiment, it was hypothesized that distributed surface picture management and distributed localization/ prosecution asset allocation, leveraging planned IT-21 improvements, would result in significant improvements in counter special operations forces (CSOF) mission effectiveness. Modeling and simulation (M&S) was employed to model the CSOF threat and friendly force surveillance, localization, and prosecution assets. Live operators interacted with the simulation by making surveillance, localization, and prosecution asset allocations. These asset allocations were fed into the simulation in order to provide operator feedback and for the purpose of assessing the effectiveness of the experimental distributed C2 architecture. See Figure 3.2-1 for a schematic of the experimental concept of operations.

The warfare process re-engineering (WPR) initiative to be evaluated hence involved postulating a distributed network of surface picture management nodes and battle management nodes. These decision nodes were supported with Land Attack Warfare System (LAWS) workstations manned by live operators during the experiment.

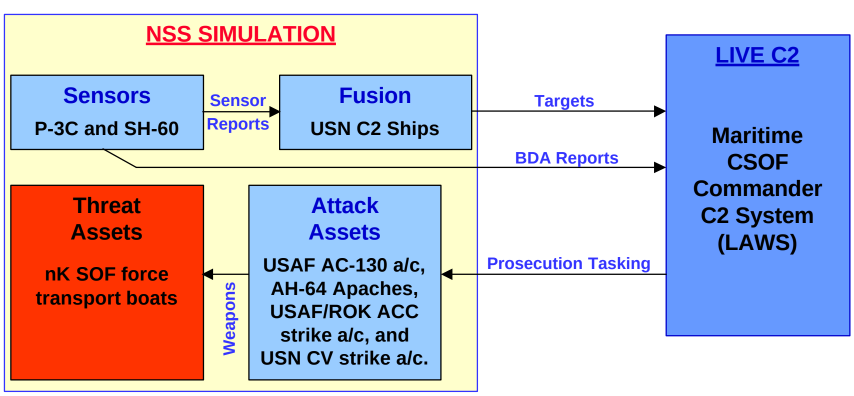

Figure 3.2-1. FBE-D Experimental Concept of Operations.

The FBE-D distributed C2 architecture plus certain new in-theater attack asset capabilities yielded the surprise result that the assessed CSOF threat could be countered in Day 01 of the operational war-plan in question. This result constituted a dramatic improvement over previously assessed friendly capabilities for this warfare mission area in the scenario. Modeling and simulation (M&S) based post-analysis was employed to assess the sensitivity of this result to different force laydowns. Hence in this case too it was judged that the IT-21 infrastructure improvements plus the distributed surface picture management and distributed battle management warfare process re-engineering (WPR) initiatives combined to yield significant warfighting value-added in this specific operational war-plan.

4. **Lessons-Learned**

In this paper we have discussed how the quantitative evaluation of Network Centric Warfare (NCW) systems and concepts will typically involve both the representation and evaluation of information technology (IT) infrastructure improvements required to achieve information superiority (IS) plus the warfare process re-engineering (WPR) initiatives required to translate IS into warfighting value-added. Most of today's NCW related initiatives are focused on the IT/IS part of this problem. Surprisingly little current effort is focused on identifying WPR requirements and beginning the job of designing, implementing, and fielding the needed set of next-generation NCW command and control (C2) decision support systems. A systematic, Department of Defense (DoD) focused effort is **required** to examine and, where necessary, re-formulate in NCW terms all Military decision processes in order to fully leverage ongoing IT/NCW investments.

From a simulation technology point-of-view, the first few examples of the quantitative evaluation of NCW systems and concepts (Involving both IT/IS improvements plus WPR initiatives) are just now emerging. Several of these first few examples are summarized in this paper. With the increasing recognition that simulation of the full C4ISR sensor-to-shooter decision chain is the key requirement for the next generation of DoD models, along with continued advancements in simulation software and hardware components, it is becoming increasingly feasible to conduct scientifically credible evaluations of relevant NCW systems and concepts. It is also the case, however, that significant challenges remain. Prominent among these challenges are model verification, validation, and accreditation (VV&A) and data verification, validation, and certification (VV&C). Nevertheless, there is good reason to believe that the future for the use of C4ISR entity-based, Monte Carlo, discrete event simulation to assess and iteratively improve upon NCW systems and concepts is bright.