Enterprise Analysis and Assessment of Complex Military Command and Control Environments

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1.0. Introduction

As military command and control (C2) applications evolve and become immersed within an growing net-centric operational environment, the complexity of interactions among component C2 enterprise capabilities will rapidly increase. The adoption of a Service Oriented Architecture (SOA) approach to C2 development, coupled with the incremental fielding of Internet Protocol (IP) based Global Information Grid (GIG) capabilities, will serve as the principal catalysts for this scenario. The sheer number of anticipated web service interdependencies, analysis and assessment of C2 behavior at the enterprise scale will be both necessary and challenging.

There are no long lists of programs that have performed analysis and assessment at the enterprise level for reasons related to the development or operational use of C2 systems or networks. There is no statistically based or anecdotally derived set of "tried and true" best practices from which to generate a few insightful recommendations. Enterprise analysis and assessment (EA&A), as it will be defined in this paper, is a new undertaking, but one that will be necessary in order to permit thoughtful, proactive, robust evolution of the C2 enterprise. For additional background, the concept of the C2 enterprise is discussed in [Rebovich 2006].

Why the assertion that there needs to be a new undertaking -- a new twist on the historical types of analyses performed in the past in support of systems engineering? We are moving into an era in C2 where our infrastructure and operational paradigms are changing in fundamental ways. As that GIG is implemented incrementally, and the Department of Defense (DoD) moves from message-based information exchanges between known entities over dedicated communications links to more of an internet-like approach, we must be able to assess how well our emerging net-centric C2 applications will perform under a wide variety of new operating conditions that neither lend themselves well to current methods of analysis and assessment, nor to the capabilities of the tools that we routinely use today in support of these efforts.

Given an emerging GIG infrastructure relying on IP standards, the introduction of highly interrelated C2 services distributed throughout the C2 architecture (vice traditional, more independent C2 applications) will have a major impact on mission performance considerations. This SOA approach to enterprise interoperability, leveraged heavily from the commercial information technology (IT) business sector, also doesn't exist today in any meaningfully deployed way within the DoD. Individual programs are just beginning to develop and field initial offerings of web-enabled C2 applications representing small pieces of their overall capabilities. Therefore, there has not yet been a burning need to perform analysis and assessment of net-centric C2 enterprise issues. But this need will arise soon, and there must be some thought dedicated now to enabling the emergence of possible methods and techniques that will be required by C2 developers and operators in the near future.

The fact that our threat environment is constantly morphing and becoming more complex over time will drive us to be more responsive to world events to the point of becoming increasingly proactive in examining potential operating conditions. In order to accomplish such a goal, we need a more flexible infrastructure that will enable users and developers to quickly assess the potential of emerging C2 capabilities to address new, potential and perceived threats. Finally, our users expect increased functionality and better performance from C2 systems and capabilities over time. Simply maintaining the status quo with respect to capabilities and execution performance will mean that we have not exploited the benefits of net-centricity.

Therefore, we need a way to ensure the stability, scalability and robustness of C2 capabilities as we progress toward net-centric operations. So, how can analytical needs be satisfied for enterprise scale C2 issues, and what are those issues? EA&A will be defined not as the ability to analyze the complete inner workings of an entire C2 enterprise at once, rather, EA&A will be defined as an ability to characterize the behavior of entities or capabilities that are immersed within an enterprise construct. EA&A will emphasize a robust "What if?" approach versus the traditional, highly scenario-dependent attempts at a more "predictive" approach. There will be shown to be a critical need to leverage modeling and simulation (M&S) capabilities, with a key role for real-time hardware-in-the-loop (HWIL) capabilities, though not necessarily the traditional systems engineering use of either of these.

2.0. The Need

C2 EA&A must ask and answer a different set of questions than traditional systems analysis. Emerging paradigms in the employment of C2 capabilities (e.g., net-centric operations), their associated information technology infrastructure (e.g., SOA) and the acquisition of those capabilities (spiral development) are significantly impacting traditional acquisition responsibilities such as risk management and test and evaluation (T&E). The diminishing utility of traditional T&E and certification processes and approaches when applied to quickly evolving net-centric applications motivates a need to steer programs toward supplementing these traditional approaches with more viable alternatives to ensure the achievement of desired behaviors at the C2 enterprise scale within an increasingly complex operational environment.

At the enterprise scale, it should be much more important to characterize behavior across a set of operating conditions, rather than performance in a specific scenario (or perhaps a few variants) with all the associated assumptions and caveats. The goal is to characterize the performance of the overall capability to execute the required mission under a wide range of operating conditions, no matter how they might be envisioned to occur. The analytical challenge is to consider the full range of possible conditions, even remote possibilities, that might occur to ensure robustness. This includes dealing with adversaries that could be acting to defeat the C2 capabilities under assessment. In fact, an environment that not only permits simulated attacks to occur, but actually facilitates this behavior by certain participants will allow users to quickly and concretely understand vulnerabilities of current or proposed capabilities. This example points out the need for early and continuous operator-in-the-loop (OITL) involvement.

If operational personnel can begin to understand under which sets of conditions they will experience difficulties executing their missions, they can proactively develop temporary, emergency workarounds and explore other means of accomplishing critical tasks within an operationally safe environment. During subsequent deployments, not only will they be better prepared for the uncertainties of real world operations, but they might even be able to identify impending problem situations to become more proactive.

While the need for C2 EA&A is not critical today, it is coming. Key stakeholders are making progress toward IP-based network operations. Surrogate, near-term, scaled-down concepts and initial implementations of future wideband IP networks are blossoming in the interim while the major building blocks of the GIG are in development. C2 programs are incrementally web-enabling certain portions of their capabilities. Finally, industry is moving ahead with concepts such as Enterprise Service Bus prototypes. Within the next few years, there could be enough fielded SOA-based capability riding on a "GIG-lite" infrastructure that C2 EA&A issues could begin to be thrust to the forefront within both the operational and acquisition communities.

What are the advantages of understanding how capabilities within a C2 enterprise behave under normal and unusual operating conditions? How will this knowledge help us? There are currently a plethora of strategy, policy and guidance documents that describe how to design and implement net-centric C2 capabilities. The sheer volume of this guidance, while well intentioned, becomes difficult to comprehend, apply and arbitrate at the C2 enterprise level. We ***do*** need a way to evaluate compliance with key design principles, but we ***don't*** have our acquisition personnel sufficiently enabled to identify these "needle in the haystack" key implementation strategies. A process and accompanying analysis environment to allow the most successful strategies, policies and guidance to emerge and be identified will be critical to the evolution of net-centric C2. Those applications that can work effectively under a wide range of operational conditions will have embodied the key principles of net-centricity and probably avoided many of the unnecessary ones. It will be become increasingly important to down-select within our continually growing set of strategy, policy and guidance documents to convey to developers what is critical and what is not. It will then be possible to evaluate compliance with only the most fundamental principles.

EA&A might ultimately enable the evolution of an entirely new business model for the acquisition of future DoD C2 capabilities. With the distinct (and perhaps likely) possibility of numerous web services being developed with overlapping functionalities, it will be almost impossible to continually dictate which are the "preferred" or "mandated" services to be used. A set of services might perform the exact same function others (e.g., targeting, data fusion, resource tracking, etc.), but some might be extremely inefficient for a particular community to use. On the other hand, another set of services might appear to provide the "gold standard" of capabilities to a wide user base, but end up providing lots of extra complication and headaches for users. Stable, basic services built on trusted, legacy software architectures (e.g., wrapped legacy code) might win out over less stable, embryonic services build on a more robust and extensible software backbone in the short term. However, the balance might very well shift over time as the legacy-based applications run into increasing development problems (cost, schedule and performance) as they climb the tough hill to adapt to new operational paradigms as underlying technologies evolve.

3.0. Essential Characteristics of EA&A

In order to characterize the *expected behaviors* of C2 capabilities over a wide range of operational conditions, EA&A must de-emphasize the utility of comparing detailed metrics against specific individual requirement values, whether the metrics are derived from measurement, simulation or estimation. EA&A must instead look for break points where capabilities are either significantly enhanced or critically disabled.

Since EA&A must identify sets of simultaneous conditions responsible for noticeable changes at the mission effectiveness scale, it must emphasize real-time OITL assessment within an environment that is almost identical to an actual operational setting. Interestingly, EA&A must go as far as actually encouraging proactive, asymmetrical threat attacks to occur under non-destructive, non-life-threatening conditions. It must also foster a culture amenable to publishing and encouraging the external use of system/capability representations (e.g., models). The remainder of this section describes the key characteristics of EA&A.

3.1. Multi-Scale Analysis

A C2 enterprise does not behave according to the rules of linear systems theory. A C2 enterprise is an inherently complex system and, therefore, should be analyzed as such. A much more in-depth treatment of this subject can be found in [Kuras 2004]. Traditional systems analysis approaches are generally inadequate for considering multiple "agent" (user, system, sub-system, etc.) interactions and multiple scales of resolution within the C2 enterprise. They often do not effectively consider the significant effects of human interaction with systems. Emergent phenomena will require a synergistic application of different approaches to address multi-scale analysis.

The primary focus of EA&A is on the highest scale (i.e., level of resolution) applicable to C2, which is at the mission effectiveness scale. At this scale, the emphasis is on non-traditional analysis issues such as robustness, flexibility, fitness, etc. A critical

objective is to identify operating ranges for systems and capabilities operating at lower scales that enable acceptable mission execution. In other words, there are normally wide ranges of system/capability performance at lower scales within which no discernable effects can be observed at the highest scale or resolution (mission effectiveness scale). Even significant deviations in communications throughput, sub-system reliability, platform processing speed, node architecture make-up, choice of web service provider, etc., will often not noticeably affect a user's ability to execute a particular mission. It might be impossible to usefully decompose operational effects into a unique set of detailed metrics at lower scales/resolution, since there are likely multiple causes for many observable effects.

A potential implication is that performance metrics at the first scale down from the operational effectiveness scale might be the most important to capture from an EA&A perspective. Another possible implication is that some lower level measurements might not be worth collecting at all, or at least only in very stressing circumstances. However, some lower scale conditions may transcend many others to have major impacts at even the highest scale. This implies that there is a need to identify catastrophic or cascading failure combinations that can ripple up to affect mission execution. There will likely also be a need to identify combinations of lower scale situations that enable significantly ***enhanced*** operating conditions.

3.2. Early and Continuous Operator Involvement

Warfighters are often overloaded just trying to cope with the operational demands of each day in the field. It is difficult, without sufficient time, travel and training, to expect operational personnel to be able to properly critique new capabilities in any one venue. However, if personnel at any of a number of CONUS locations could log onto periodic, widely-announced evaluation activities at their convenience, the likelihood of a wide range of inputs over a period of time would be substantially increased. The commercial internet gaming industry has been particularly successful in this area, permitting thousands of simultaneous on-line users to role play in highly realistic, real-time, distributed combat simulations.

One important component to enable continuous operational assessments within a C2 enterprise is the existence of operational scenarios and use cases. However, at the enterprise scale, it is much less important to "get it right" with any particular scenario than it is to devise ways to understand and characterize the "fitness" of the enterprise through constant exposure to diversity. EA&A at the C2 enterprise scale will certainly require injection of pieces of scenarios and use cases for increased realism, but the emphasis must be on more generic, highly-flexible representations of wide ranges of employment options, from austere to robust, with typical uses for stakeholder systems incorporated into the mix. Repeated exposure of the C2 enterprise to complexity is critical to effectively characterize the fitness of the enterprise, especially its ability to adapt to stressing and/or unforeseen circumstances. Practically, this can be accomplished via injection of a wide range of operating conditions (as implemented in scenarios and use case vignettes) into on-line operational situations if those situations are not regularly occurring, such as major attacks by hostile forces. This analytical

practice will not only enable characterization of the fitness of the enterprise to day-to-day situations, but to stressing situations as well.

Integrated Testing is replacing the separate development/operational test event paradigm. EA&A will enable this trend. The morphing of traditional test events to a more periodic (and ultimately nearly continuous) assessment can occur over a relatively short time with the right perspective in place.

3.3. Lightweight C2 Capability Representations

Despite the best efforts of a entire program or project team, it is not possible to identify and unambiguously state all of the requirements of a C2 system in a specification prior to the awarding of contract, due to the inherent complexity of C2 systems. At the enterprise scale, with dependencies among many programs needed to provide important capabilities to the warfighter, it is critical to develop effective and efficient mechanisms for collaboration among key stakeholder programs within the enterprise.

Experimenting in novel ways by using "lightweight and portable" representations of C2 systems that can be rapidly accessed by the development and test environments of peer systems is highly desirable. Such a capability would provide opportunities to understand issues and identify opportunities for collaboration as early as possible in program acquisition and fielding schedules without the need to synchronize activities of different programs, which is impossible. Large, highly detailed models with complex interface requirements and extensive re-hosting issues squelch opportunities for collaboration. Early, small footprint models or prototypes of a system can give other programs insight into the evolving functionality of peer systems.

From a methodology perspective, programs could develop and post lightweight representations of emerging capabilities to make them available to other programs without having to understand in advance which programs might want to investigate or take advantage of these new functions. Other programs could quickly discover what any what is implemented or planned to be implemented. This method of interaction could lead to new opportunities for collaboration.

3.4. Developmental Versions Available for Assessment

It will be necessary to expose users/consumers of information and services (operational personnel and software applications) to both the diversity of other peers and the novelty of emerging capabilities. The aspect of novelty is a fundamentally distinguishing characteristic from distributed T&E environments and system integration lab networks. Traditionally, only official, released version of software applications are eligible to be used in test or integration events. Experimental venues, while making use of early version of capabilities, have neither the persistence of an EA&A environment nor the breadth of scope to encompass an enterprise perspective.

Having access to the developmental versions of C2 applications within an EA&A environment might ultimately enable the evolution of an entirely new business model for the acquisition of future DoD C2 capabilities. With the likely possibility of

numerous web services being developed with overlapping functionalities, it will be impractical to continually dictate which are "preferred" or "mandated" services. An EA&A environment could lead to a highly competitive situation where emerging net-centric web services are posted in an operationally realistic evaluation arena and users migrate to those that best satisfy their needs. Those services that are widely used (or are needed by high-profile users) would thrive and receive additional resources for evolution, while those that are seldom used would be left to wither.

There are two principal types of innovation, revolutionary and evolutionary, as discussed in [Johansson 2004]. Evolutionary innovation is the normally occurring type and would be expected to occur even if no synthetic environment existed for EA&A. For revolutionary innovation to occur, there must be opportunities for very different types of agents to interact. The exposure of existing and emerging capabilities to the C2 enterprise environment could encourage revolutionary innovation, leading to significant increases in capability. Innovation within a C2 enterprise is critical because the requirements imposed on the enterprise are constantly morphing and can change quite dramatically and quickly, as was demonstrated by the radical impacts of the 9/11 terrorist attacks on homeland security requirements. Perpetual experimentation is critical to enabling this innovation to occur.

3.5. Minimal Infrastructure Supporting Communities of Interest (COIs)

In order to support assessment that enables innovative activities to progress while implementation decisions are being made, either a replication of the operating environment or access to the operating environment would be required. For some systems, this can be quite practical, as evidenced by the existence of many program testbeds at Government and contractor locations. However, attempts to replicate the detail inherent in significant portions of operating environments, even for a single mission area (e.g., missile defense) inevitably begin to accumulate heavy logistical requirements (hardware, software, facilities, networks, etc.) and often come with high levels of initial investment and large recurring costs.

From a C2 enterprise perspective, the key is to begin pulling together distributed programs with vested interests into loose collaborative COI frameworks to address critical operational issues with minimal recurring communications infrastructure costs. Establishing a small, high-use, core COI network that can effectively leverage existing connectivity within the DoD and/or short-term commercial leased circuits will provide both necessary connectivity among stakeholders, as well as flexibility for future endeavors with other partner COI organizations.

3.6. Flexible M&S, OITL and HWIL

At the enterprise scale, it will be impossible to predict which critical issues will need to be addressed in which particular order (or in parallel). Therefore, the development of a flexible and extensible analytical framework is an important consideration. Pursuing a goal of operational breadth first, then technical depth only on an as-needed basis will provide analytical capability earlier and permit evolution of that capability over time that will be tailored to its true intended use.

Many large-scale simulations, and especially federations of simulations, have experienced run time performance issues as the fidelity within models increases over time and/or additional higher fidelity models have been added. For maximum flexibility at the mission effectiveness scale, it will be critical to establish analysis methodologies that can capture results of high fidelity models in effects-based models. *Models will likely need to be implemented as web services to achieve the desired goals.*

3.7. In-Line, Continuous Performance Monitoring and Selective Forensics

As more work is dedicated toward defining and understanding the relationships among the various scales of C2, it will become increasingly apparent that much of what we are able to easily measure and collect today in tests and experiments will not be useful for EA&A purposes. Today, we routinely insert third-party hardware or software "probes" into our infrastructure. A result of these intrusions is a perturbation of the actual flow of information itself, including generating additional data traffic, creating other ripple effects within the network. Another problem is trying to make the logical connection between measurements and situations that are only indirectly related to these measurements. Information is often collected "downstream" from where it is generated, having been manipulated along the way in some manner. Data that can be automatically archived where it is produced (within each C2 application) and collected either later or off-line, in an operational sense, for analysis is highly preferred.

As operations proceed normally, some automated statistics generation over an extended period of time would characterize the normal operating ranges of component systems and capabilities, probably requiring the development or augmentation of tools. When problems (or new opportunities) are observed at the mission effectiveness scale, forensic analysis would be required. It will be necessary to identify the critical situations, states, activities, parameters, etc., that contribute to noticeable impacts on mission performance, either positive or negative. A goal is the establishment of "tripwire" values for metrics that are seen to influence mission effectiveness.

4.0. Way Ahead

Currently, The MITRE Corporation has undertaken an effort to look at the application of EA&A principles to C2 programs under development at the Air Force's Electronic Systems Center, Hanscom Air Force Base, MA. Both historical case studies and forward-leaning pilot activities will be documented during FY2006. Lessons learned from these case studies and pilots will help evolve EA&A concepts and implementation suggestions in the next year and beyond.

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