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A Process Decomposition Approach for Evaluating Command and Control (C2) Functional Performance

Network-centric Metrics
C2 Modeling and Simulation
C2 Analysis

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ABSTRACT

This paper presents an approach developed by the Johns Hopkins University Applied Physics Laboratory (JHU/APL) to quantitatively evaluate the ability to successfully achieve command and control (C^2) by decomposing C^2 processes into measurable functions and then measuring how well those functions are executed. The hypothesis of this work is successful execution of C^2 functions structured within a well defined process is directly correlated with the achievement of successful C^2. That hypothesis will be tested in the context of an operational scenario. Our approach involves the development and execution of C^2 evaluation experiments based on formalized experimental design methods to evaluate the conduct of C^2 within the problem space defined by the scenario. We also plan to employ the use of modeling and simulation techniques to represent and execute the scenario with differing levels of fidelity. Simulation types include: constructive simulations, a C^2 models-only environment, and virtual simulations, which incorporate in-the-loop components to enhance simulation fidelity.

1. Introduction

1.1 Purpose

This paper presents an approach to quantitatively evaluate the ability to successfully achieve command and control (C^2) by decomposing C^2 processes into measurable functions, associating measures and metrics with those functions, and then measuring how well those functions are executed. The hypothesis of this work is successful execution of C^2 functions structured within a well defined process is directly correlated with the achievement of successful C^2.

1.2 Scope

This paper provides a high-level overview of several existent C^2 process models. It compares their structures and, based on that comparison, proposes an aggregated model structure that will serve as the basis for the top-level process decomposition work described in this paper. Additional work will be required over the next several months to fully decompose the process elements of the aggregated model to the point where measures and metrics can be associated with those elements. This paper concludes with a description of a scenario-driven C^2 experiment planned for FY06 that will use the measures and metrics associated with the functions defined at the lowest level of that process decomposition to evaluate the degree to which successful C^2 was achieved during the experiment.

2 Background

Command and control reflects the exercise of authority and direction by a properly designated commander over assigned and attached forces in the accomplishment of a mission. A commander performs command and control functions through an arrangement of personnel, equipment, communications, facilities, and procedures to plan, direct, coordinate, and control forces and operations in the accomplishment of the mission.[1] The first part of this definition refers to the "what" of C^2, the second part to the "how", from a high-level perspective. Key to both parts is "accomplishment of the mission". Based on that perspective, this portion of the document focuses on defining a set of high-level C^2 decision-making functions and associated controls needed to successfully accomplish a mission.

A number of process models have been developed that characterize decision-making functions necessary for C^2. The Observe, Orient, Decide, and Act (OODA) Loop, first articulated by Col. John Boyd[2], is an example of such a model. To successfully accomplish a mission, a commander must be able to achieve situational awareness and establish situational understanding. The lack of either increases the risk of mission

failure. The commander gains situational awareness by observing conditions related to the mission such as environmental conditions, cultural and political conditions, speed and effectiveness of the opponent's decision cycle, etc.

The key to transitioning from situational awareness (SA) to situational understanding (SU) is the ability to access the right information, at the right time and avoid information overload. With the right information, the commander can properly orient his/her thinking and the resources at his/her disposal towards accomplishing the mission.

Inherent to the process is establishing a plan to develop one or more courses of action (COA). The commander must evaluate each COA with regard to numerous factors such as percentage of mission objectives covered and their probability of successful execution. Through this evaluation, the commander selects the COA most likely to succeed in accomplishing the mission.

After additional detailed planning is conducted, the selected COA is executed and the cycle repeated to observe and assess the outcomes of COA execution. A representation of the OODA Loop is shown in Figure 1.

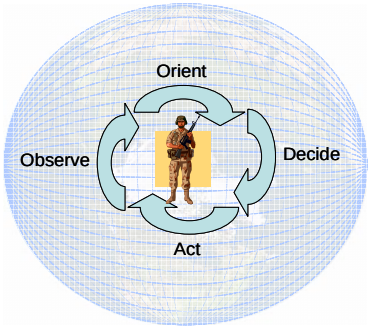

Figure 1. Representation of the OODA Loop

The OODA Loop is referenced in a number of military documents, (e.g. US Air Force AFDD 2-5[3] and Navy NDP 6[4] documents) as a simple representation of the command and control decision-making process. However, as pointed out in Rousseau and Breton[5], the OODA Loop is limited in a number of ways: it lacks feed-forward and feedback loops to account for the dynamic nature of decision-making; it is too overly simplistic to be used as an effective analytic tool for improving the decision-making process; and its sequential flow lacks the necessary cross connections among loop processes to reflect the complexity of real-world decision making.

A variation of the OODA Loop model, referred to as the Monitor, Analyze, Access, Plan, Predict, Execute, and Report (MAAPPER) process[6], is used by USSTRATCOM to represent their decision-making process (Figure 2). The Monitor function of MAAPPER is analogous to the Observe function in the OODA Loop. Analyze, Access, Predict, and Plan functions are a further decomposition of the Orient process in the latter model. The Execute function is equivalent to the Act function and the Report function in MAAPPER is an augmentation to the OODA process. The series of interconnecting lines among the

functions imply a many-to-many feedback loop structure among the MAAPPER functions, which is not explicitly defined in the OODA Loop.

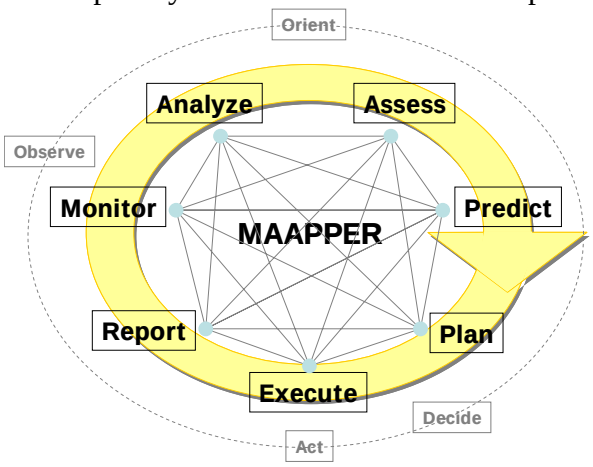

Figure 2. The MAAPPER Process and its Relationship to the OODA Loop

A third perspective, provided in a paper by David Noble[7] and shown in Figure 3, identifies elements of a C2 Operational Architecture. These include Situational Assessment, Understanding, and Planning, which maps to the OODA Observe and Orient functions. Decision and Execution are equivalent to the OODA Decide and Act functions, respectively. Feedback, which is the information needed to determine the degree to which the Execution function was successfully completed, is equivalent to restarting the OODA loop at the Observe process.

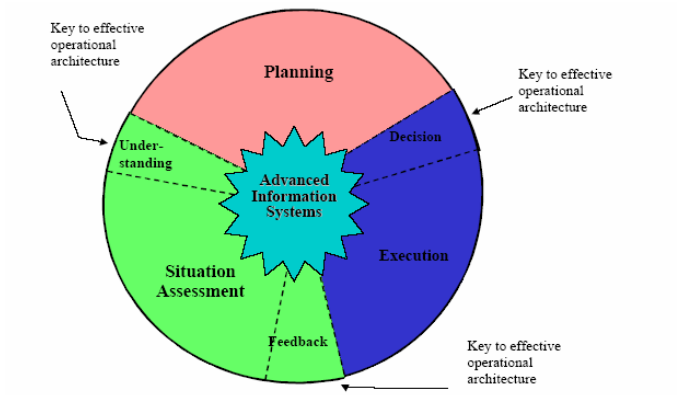

Figure 3. Elements of C2 operational architecture

A fourth perspective, presented by Jay Bayne[8], represents the OODA functionality as three top-level service functions, which include Situational Awareness (SAS), Plan Generation (PGS), and Plan Execution (PES) Services. Each of these is further decomposed into a set of processes, which include Filter, Triage, and Analysis for SAS, Policy and Resource for PGS, and Command and Control for PES. That representation is shown in Figure 4. In addition, each element of that decomposition is controlled within the context of the loop depicted in Figure 5.

Situational Assessment Service (SAS)			Plan Generation Service (PGS)		Plan Execution Service (PES)	
Filter	Triage	Analysis	Policy	Resource	Approval	Execution

Figure 4. C2 Process Stages

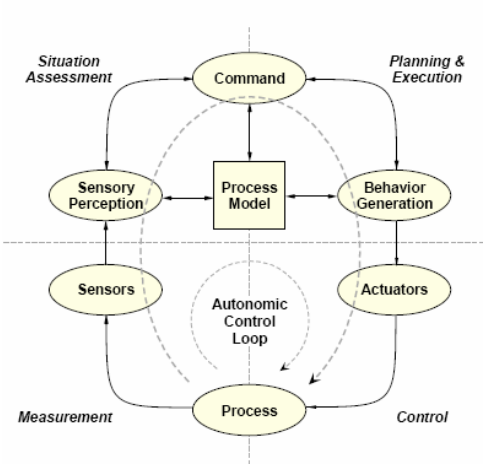

Figure 5. C^2 Control Loop

A fifth approach for representing C^2 is presented in the C^2 Joint Integrating Concept (JIC)[9] Document as a detailed set of capabilities that commanders need to demonstrate to achieve effective and efficient command and control. Each capability is associated with a set of functional tasks that collectively comprise the capability. Each task is decomposed into a set of attributes and metrics by which the task could be measured to determine the degree to which the task is successfully executed. An example of that decomposition is shown in Figure 6. The JIC asserts its collective set of capabilities addresses all of the C^2 functions specified in Reference 1 and are consistent with the C^2 functions identified in the C^2 Joint Functional Concept Document[10], with several minor exceptions; however, those capabilities and associated tasks don't directly flow from a decomposition of those top-level C^2 functions and therefore, are not directly traceable to those functions. It is a supposition of this paper that each of those capabilities and associated tasks can be represented as a decomposed component of one of the C^2 Key Elements discussed in the next section of this document. Such a representation allows them to be linked backed to an originating function. That traceability is particularly important when trying to establish functional relationships in a top-down manner.

3 Aggregate C^2 Process Model

The challenge for those attempting to use an existing C^2 process model as the basis for evaluating C^2 is determining which of these representations is correct, complete and best describes command and control given the fact DOD has not selected or endorsed any particular decision-making process or its associated functional decomposition as a standard representation of C^2.

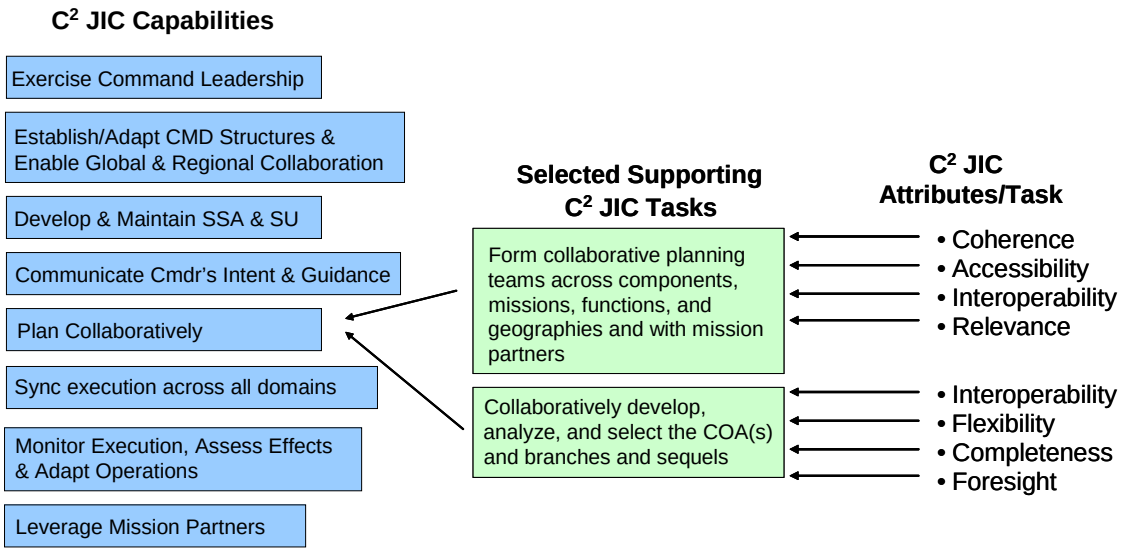

Figure 6. Example C^2 JIC Capability Decomposition

Common to all of these representations are three key elements (KE) necessary for achieving C^2, which include Situational Assessment (SA), Planning (P), and Execution (E). Functional elements, other than those three, can be viewed as a decomposition of one of the KEs. For example, monitoring, analysis, and prediction, as specified in the MAAPPER model, can be considered a decomposition of Situational Assessment. Based on that assertion, a proposed set of high-level C^2 functions and a first order decomposition of those functions are shown in Table 1. The relationship of those KEs to a proposed multi-level command and control loop structure is provided in Figure 7 and described below.

The loop structure depicted in Figure 7 represents multiple levels of command and control although only two levels are explicitly shown. Lower levels of C^2 are accomplished through recursion, i.e. the subordinate commander becomes the superior if that commander has subordinates to command and all commanders executes the same C^2 functions at each level of command. The outermost ring of the structure represents the control loop of a superior commander, the inner loops of subordinate commanders. The superior commander performs the functions located on the outer loop.

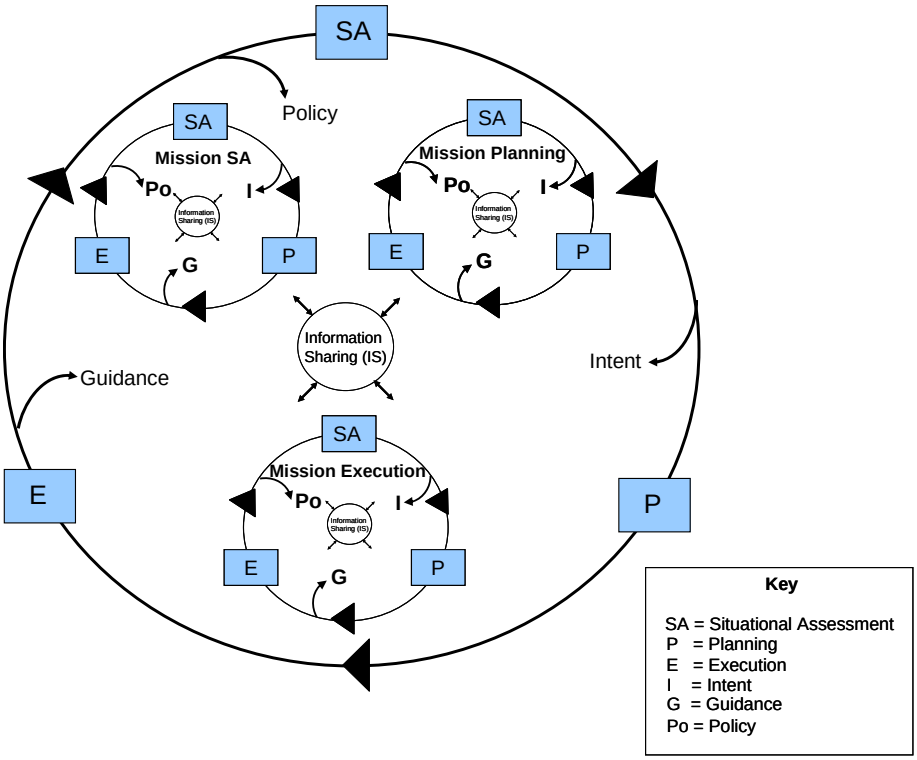

Figure 7. Multi-level Command and Control Loop

Those functions are focused on monitoring and controlling all activities within the domain of the superior commander and are depicted as rectangular blue boxes. He/she monitors activities within his/her command domain via the Mission Situational Assessment (SA) function. If all activities are being performed as planned with outcomes as needed no action is required. This is sometimes referred to as "command by negation" Alternatively, if desired activities or outcomes are not being performed or achieved as expected, the superior commander develops and /or revises the current plan, the Mission Planning (P) function, which is constructed in the form of the commander's intent, guidance, or policy, and executes the plan, the Mission Execute (E) function, by disseminating that information to subordinate commanders via the Information Sharing (IS) function.

The functions performed by subordinates within the domain of the superior commander are represented by the inner control loops of Situation Assessment (SA), Planning (P), and Execution (E) and are focused on accomplishing the Mission. The functions performed within their respective domains are shown in Table 1. Each subordinate commander will perform the same supervisory functions for their respective command domains as described above if each has subordinates of their own to command. In that sense, they become the superior commander of their domain. Each decomposed function within that domain, e.g. the Monitor function within SA, could in turn be controlled by a lower level subordinate commander thereby causing the control loop to become further nested in a recursive fashion.

The Information Sharing (IS) function is the means by which a superior commander's intent, guidance, and policy are conveyed to subordinates. It is also the means by which subordinate commanders exchange information among the functional areas they control within the superior commander's domain, e.g. between Mission SA and Mission P

functional areas. An underlying assumption is that there exists a core set of services and network infrastructure to support and facilitate the execution of IS functions.

Table 1. First Order Decomposition of Key C^2 Elements

Key Elements of Command and Control					
Situational Assessment		**Planning**		**Execution**	
Monitor	Observe and record characteristics of the physical, political, social, and economic environments as they pertain to own and adversary forces	Define	Define mission requirements based on the characteristics of the emerging situation	Allocate (Resources)	Apportion necessary forces and assets to accomplish the mission
Analyze	Investigate the details of those observations	Develop (Plan)	Develop one or more Courses of Action (COA) to address the needs of the current situation/mission taking into account as many contingencies as time permits	Assess Readiness	Determine if all required elements are ready and prepared to execute the selected COA plan
Assess	Evaluate the impact of analysis results on current plans	Evaluate	Analyze each COA to ensure it is consistent with the commander's intent and addresses all mission objectives	Execute (Plan)	Carry out the selected COA
Predict	Use estimation results to forecast possible and likely outcomes based on the characteristics of the situation as it is currently understood	Decide	Analyze the probability of success for each COA and select the plan most likely to succeed given the set of assumptions most likely to occur	Evaluate	Perform battle damage assessment and evaluate the degree to which the COA plan was or is being executed successfully; adapt plan accordingly
		Disseminate	Develop detailed plan and distribute to appropriate superiors, subordinates and partners	Report	Report mission execution findings

Combining the multi-level C^2 loop from above with the process decomposition elements in Table 1, we arrive at an aggregate C^2 process model, which is depicted in Figure 8. It is that model that will serve as the basis for the subsequent detailed C^2 process decomposition, i.e. the work of this paper, to be conducted during the second quarter of FY06. An example of that decomposition process is shown in Figure 9. Following decomposition, one or measures and metrics will be associated with each of the lowest level decomposed functions. Those measures and metrics will be used to support the evaluation experiments described below.

4 C^2 Evaluation Experiment Description

We plan to conduct a series of experiments to evaluate net-centric C2 using the C2 process decomposition and associated measures and metrics discussed above. The problem(s) to be investigated for each experiment will be defined within the context of an operational scenario. One or more hypotheses will be developed and evaluated for each problem. As an example, one of the candidate scenarios involves a time sensitive targeting operation against a target of interest. One problem associated with preparing for operational execution is the ability to synchronize execution preparation activities within and across joint echelons of command. The hypotheses we're investigating for this problem are a workflow management tool will 1) contribute positively to the commander's overall ability to prepare for and to synchronize mission execution and 2) allow the commander to effectively share the dynamic state of execution readiness with the planning participants, all of whom are operating in a highly distributed environment. A series of similar experiments will be conducted for three other operational scenarios.

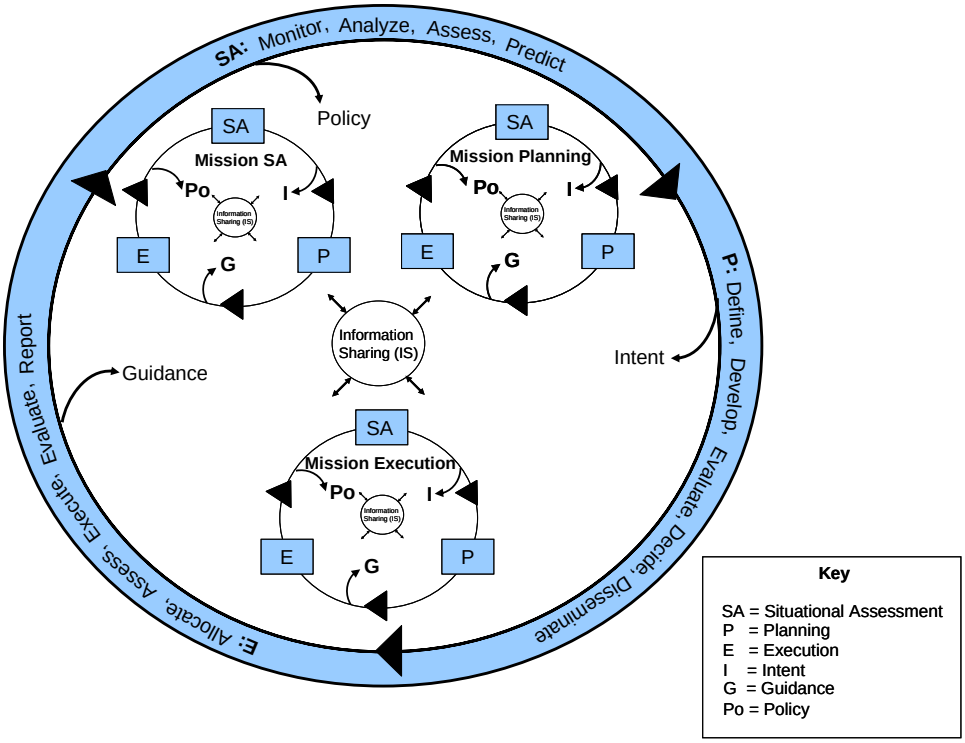

Figure 8. Aggregate C^2 Process Model

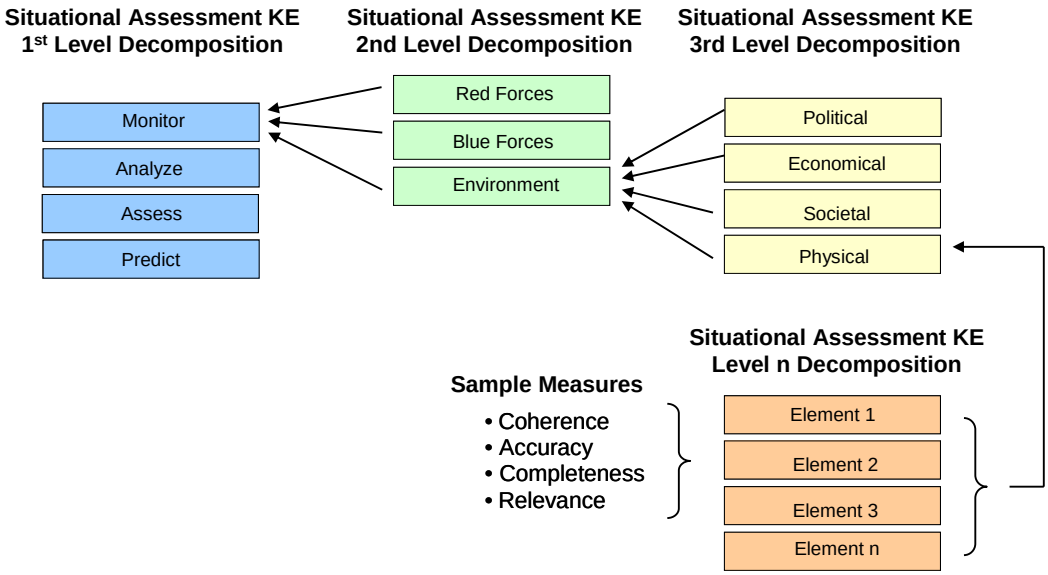

Figure 9. Example decomposition of the SA Monitor process

A second aspect of experimentation will involve modeling and simulating the execution of one or more of the scenarios using the Multi-resolution Modeling (MRM) Evaluation Framework (MRMEF)[11], which was documented in a previous paper and is described in Appendix A. MRM has been used successfully in the past because it has the characteristics needed to solve difficult analysis problems by integrating information

achieved with high-fidelity models and generalizing the results and implications via a low-resolution model (Smith 1998). The MRMEF allows us to develop and execute a simulation representing a scenario from an “as-is” or non net-centric perspective and compare those results with a one which represents an equivalent environment but enhanced with net-centric capabilities, i.e. a “to-be” simulation. This type of representation would allow us to compare, for example, the efficacy of mission execution preparation with and without shared data from a net-centrically distributed workflow management tool in a simulated environment.

4.1 Experiment Objectives

The objectives of this effort are to:

- Demonstrate how the measures and metrics associated with the lowest levels of C2 process decomposition, the first level of which is shown in Table 1, can be used as the basis for evaluating net-centric C2 in the context of one or more scenario-driven experiments
- Show how those measures and metrics can be incorporated into MRMEF simulations and used to compare and evaluate “as-is” and “to-be” operational environments in a time effective manner.

4.2 Experiment Approach

The approach for these experiments involves:

- Developing scenarios to serve as the operational basis for the experiments and the simulations
- Performing a detailed process decomposition of the C2 process depicted in Figure 8.
- Developing a set of measurements and metrics for the lowest level functions of that process decomposition.
- Developing and conducting a set of experiments via formalized experimental design techniques using the measurements and metrics from above to evaluate the hypotheses associated with the problem areas identified in each scenario
- Repeating the experiments but in a simulated environment by 1) developing a low-fidelity simulation to characterize the current (as-is) C2 processes associated with the experiment’s scenario; 2) developing a second “to-be” simulation to characterize the same environment but with the inclusion of the real net-centric software components used in the experiments defined above; and 3) executing the two simulations and comparing their results to quantitatively evaluate the hypothesis of the experiment, e.g. the inclusion of a net-centric workflow management tool positively effected the synchronization of mission preparation in the simulated environment.

5 Conclusions

This paper proposes developing a detailed decomposition of the C^2 functions depicted in Figure 7, associating one or more measures and metrics with each of the lowest level functions of that decomposition, and using those measures and metrics as a basis for evaluating net-centric C2 in the context of a scenario-driven experiment. A subsequent paper will provide the experimental results of this work.

6 References

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Appendix A. Multi-resolution Modeling Evaluation Framework

A significant challenge to evaluating net-centric C2 is to develop an approach that facilitates evaluation of C2 capabilities in a complex hybrid architecture environment. Our approach, referred to as the Multi-resolution Modeling Evaluation Framework (MRMEF), uses constructive, virtual, and live simulations and hardware-, software-, and humans-in-the-loop where appropriate. Multi-resolution Modeling (MRM) has many advantages that are needed to analyze C2. MRM has been successful because it has the characteristics needed to solve difficult analysis problems by integrating information achieved with high-fidelity models and generalizing the results and implications via a low-resolution model (Smith 1998). An overview of the MRMEF is shown in Figure A-1.

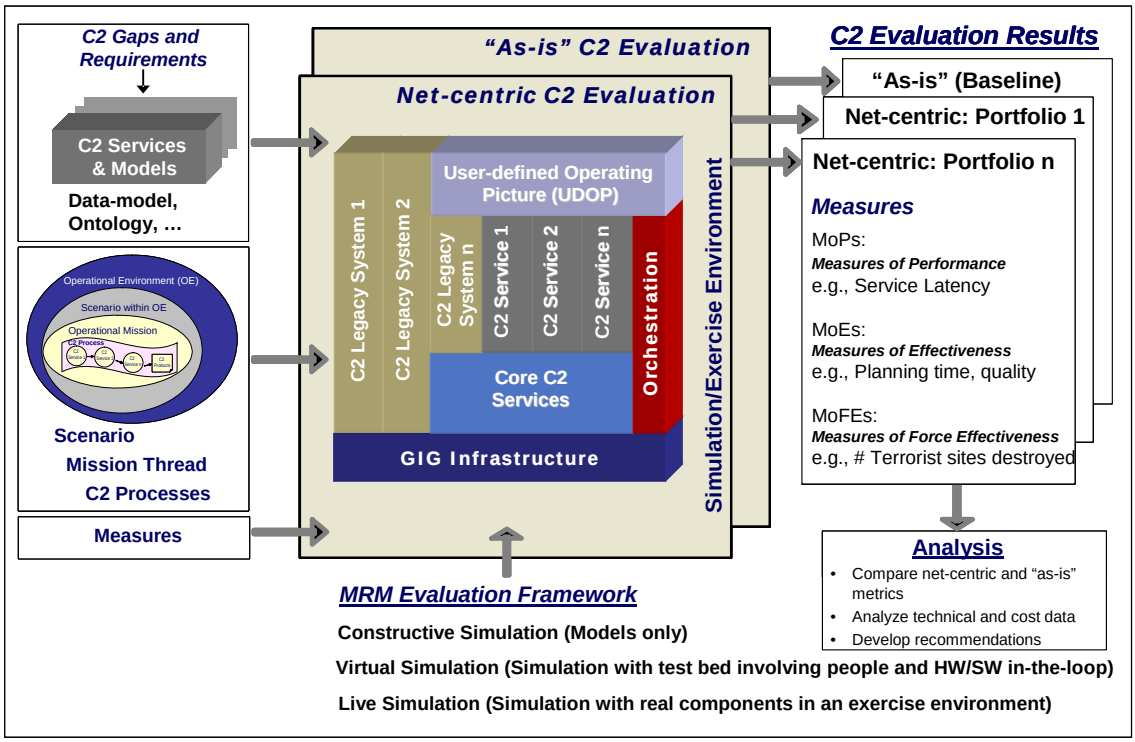

Figure A-1. Multi-resolution Modeling Evaluation Framework

The simulation/exercise environment of the MRMEF contains the entire hardware and software infrastructure needed to support the constructive, virtual, and live simulations of the framework.

The "cube" portion of the diagram represents real or modeled C2 or C2-related components. Inputs to the framework consist of a set of C2 services to be evaluated; the services were derived from C2 gap analysis, C2 requirements definition, data modeling, and so forth. A scenario defines the operational mission, i.e., the problem to be solved, and serves as the contextual basis for the evaluation. Measures to assess performance and

effectiveness are defined based on the context of the scenario. Evaluation of C2 capabilities is accomplished by executing the “cube” components, (real, simulated, or a combination of real and simulated) in the context of the appropriate MRMEF simulation/exercise environment. C2 evaluation results are generated as a result of executing the scenario.

An “as-is” evaluation is accomplished by developing a scenario-based model of the “as-is” process to be evaluated and executing that model as a constructive simulation within the framework. A second model is developed representing the net-centric equivalent of that process. The net-centric process, which may involve a hybrid of legacy and net-centric components, both real and simulated, is executed within the framework as a virtual simulation. When real components are used, they are interfaced with the simulation via a separate test bed, which allows the real components to interact as necessary with modeled components. The resulting simulation executes at a higher level of fidelity or resolution overall. The framework also encompasses a very high-fidelity live simulation executed outside the laboratory environment with real players and components.

Analysis consists of comparing the “net-centric” with the “as-is” results and analyzing the differences to determine, both qualitatively and quantitatively, whether the application of net-centric principles and components to an existing process has enhanced or degraded engineering, command and control, or mission-level performance as measured via MoPs, MoEs, and MoFEs, respectively. If cost information about deploying and maintaining net-centric C2 capabilities is available or estimated, those data can be combined with the technical evaluation results to help guide future architecture, acquisition, and deployment decisions.