19th ICCRTS: Paper Submission Cover Sheet with Abstract

Title of Paper: Network-Centric Operations Support: Lessons Learned, Status, and Way-Ahead

Primary Topic: Data, Information, and Knowledge (Topic 3)
First Alternate Topic: Cyberspace, Communications, and Information Networks (Topic 6)
Second Alternate Topic: Experimentation, Metrics, and Analysis (Topic 4)

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Abstract

The work reported herein focuses on how Model-Based Systems-of-Systems Engineering (MBSE/SOSE) methods and Enterprise Architecture and Service Oriented Architecture (EA/SOA) frameworks help to improve C2 agility. Of particular interest is development of highly-reconfigurable and dynamic frameworks that more effectively support distributed time-sensitive network-centric operations. From both the research and more operationally oriented perspectives, the paper addresses lessons learned from previous and ongoing efforts, reports on current status, and discusses the way-ahead for augmenting MBSE/SOSE with model-integration and qualification (I&Q) capabilities.

The progress reviewed includes three interdependent areas of work. The first focuses on business services (i.e. operations and workflow support) oriented MBSE/SOSE and associated EA/SOA data-modeling improvements. The second area focuses on the use of controlled-vocabularies within the context of business-logic, business-rule management systems (BRMS), and tactical mission operations support (e.g. data-synchronization, DIL[1] condition exception-handling). The last area of work focuses on use-cases and procedures for collaborative experimentation. Throughout the paper, footnotes are provided to assist readers with topics that may be domain specific and not more generally recognized[2].

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1   Disconnected/Disrupted, Intermittent, and Low-bandwidth (DIL)
2   Note to the reader: Technical references are enclosed in square brackets and listed at the end of the paper. The superscripted footnotes provide links that help facilitate an introductory understanding of concepts and topics that may be more common in one technology domain but otherwise not familiar or as applicable to the population at large.

1. Introduction and Executive Summary

For Network Centric Warfare (NCW), robust information-sharing services are an enabler for command and control (C2) agility.[3] In other words, as stated within the broader context of the Information Sharing Environment (ISE)[4], "the maximum value of information sharing occurs when the right workers share the right information with the right recipients to use at the right time" [1].

As illustrated in figure 1, agile NCW capabilities (e.g. agile C2) and supporting information-sharing services are based on interdependent standards and reference models (graphics from [2-4]). For example, figure 1 highlights the relationship between bottom-line NCW Warfighter operations-support services (i.e. business-services models [graphics from 4]) versus the systems engineering support models (e.g. Joint C2 Architecture [graphic from 2], DoDAF/DM2 [graphic from 3]). From a DoD Architecture Framework (DoDAF/DM2)[5] perspective, this is analogous to the DoDAF dichotomy of systems-versus-operational views. In terms of technology domains (e.g. systems engineering, business management), figure 1 highlights that families of models and standards are similarly developed and evolve within their respectively broader context (e.g. engineering versus business).

In terms of a conceptual model of Information Dominance (ID), figure 2 (from [5]) highlights the Warfighting value of effective net-enabled information sharing within a model-based operational perspective (i.e. operational view) of threat actors and threat vectors that apply to Navy cyberspace focus areas that span a number of operational domains (i.e. cyberspace, subsurface, surface/land, air, space). Thus, Figure 2 illustrates that within the Navy, a business-services model of NCW has evolved to incorporate cyberspace operations that address the emergence of cyber related threats.

Figure 1 Modeling Domains: Example of Engineering-vs-Business   Figure 2 Navy Cyberspace Ops: Desired End-State

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3   Network-centric warfare (http://en.wikipedia.org/wiki/Network-centric_warfare)
      Robustness (http://en.wikipedia.org/wiki/Robustness_%28computer_science%29)
      Information sharing (http://en.wikipedia.org/wiki/Information_sharing)
      Service (http://en.wikipedia.org/wiki/Service_%28systems_architecture%29)
      Command and control (C2; http://en.wikipedia.org/wiki/Command_and_control)
      Agility (http://en.wikipedia.org/wiki/Agility; http://en.wikipedia.org/wiki/Business_agility)
4   Information Sharing Environment (ISE; http://en.wikipedia.org/wiki/Information_Sharing_Environment)
5   Department of Defense Architecture Framework (DODAF; http://dodcio.defense.gov/dodaf20.aspx;
      http://en.wikipedia.org/wiki/Department_of_Defense_Architecture_Framework); DoDAF meta-model (DM2;
      http://en.wikipedia.org/wiki/Department_of_Defense_Architecture_Framework#Meta-model)

As highlighted within figure 1, figure 2, and the following sections, the cognitive domain of NCW operations and systems-engineering support services includes a broad range of topics/concepts that span a number of technology domains that apply to the challenge of addressing Warfighting capability gaps and new emerging threats. Thus, due to the breadth and depth of the applicable technology domains that continue to expand at unprecedented rates, footnotes are provided for facilitating information sharing in terms of the concepts and topics that apply to the work discussed herein. In other words, in addition to focusing on the value of effective information-sharing services, the need for more effective sharing of technical concepts is also addressed by providing footnotes throughout the paper.

The sections within the body of the paper work to address the multiplicities of domain models[6] that can arise from engineering and development activities that are otherwise isolated within their separate application domains (e.g. engineering-versus-business). Thus, section 2 discusses the families of operational-support (i.e. business-services) models that are the foundation and grounding of NCW efforts. More specifically, section 2 provides a short review of the NCW reference models that are the conceptual foundation for agile C2 and net-enabled information-sharing services. For example, figure 3 and figure 4 highlight what now may be considered more traditional views of NCW, in terms of the bottom-line operational-support objectives. Figure 3 and figure 4 conceptually illustrate how both the DISA/DoD and Navy NCW/ID business-services models of figure 1 and figure 2 are grounded within such foundational NCW reference models. The goal of section 2 is to communicate that the conceptual reference models of NCW provide this common grounding that continues to help align and unite a growing spectrum of disciplines, technologies, and families of services that must be integrated and support interoperability across a broad range of system-of-systems (SoS) boundaries.

Section 3 focuses on highlighting the families of engineering-support services that, in principle, apply to the engineering of NCW solutions. In other words, section 3 discusses the growing number of technology domains that support the engineering lifecycle process. Within section 3, figure 5 illustrates that the respective technology domains each have their own families of models and standards that have each evolved over time. The goal of section 3 is to communicate that NCW engineering challenges go beyond DoDAF/DM2 and DoD specific reference models (e.g. Joint C2 Architecture).

To further highlight the evolution of systems-engineering support models and standards, section 3 finishes up with a discussion of the current state-of-the-art in terms of the lifecycle and engineering support processes. In other words, evolutionary convergence of a variety of model-based technology-development methodologies is also discussed. In particular, engineering-versus-business aspects of Model-Based Systems Engineering (MBSE), System-of-Systems Engineering (SOSE), Enterprise Architecture (EA), Service Oriented Architecture (SOA), and cloud computing are highlighted.[7] Thus, this multiplicity of applicable engineering-support process models and standards further highlights the need for an improved overarching process that more explicitly manages the conceptual alignment, integration, and interoperability of reference models and standards.

Section 4 utilizes the Unified Profile for DoDAF/MODAF (UPDM) and associated Unified Modeling Language (UML) standards as examples of the naturally evolving complexity of systems-engineering support models and standards. Within this section, the goal is to further communicate the need to better

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6   Domain model (http://en.wikipedia.org/wiki/Domain_model)
7   MBSE (http://www.incoseonline.org.uk/Program_Files/Publications/zGuides_9.aspx; http://www.incose.org)
     System of systems engineering (SOSE; http://en.wikipedia.org/wiki/System_of_systems_engineering)
     Enterprise architecture (EA; http://en.wikipedia.org/wiki/Enterprise_architecture)
     Service-oriented architecture (SOA; http://en.wikipedia.org/wiki/Service-oriented_architecture)
     Cloud computing (http://en.wikipedia.org/wiki/Cloud_computing)

utilize standardized UML variants (i.e. SysML, BPMN, xUML) for addressing the full spectrum of software engineering (i.e. UML), systems engineering (i.e. SysML), business process (i.e. BPMN), and modeling/simulation (M&S) execution (i.e. xUML) lifecycle-support needs.

Section 5 highlights that MBSE/SOSE methods and best practices have already facilitated much progress towards the evolution and transformation from stovepiped systems to families of model-based net-centric reusable and interoperable services. Section 6 continues with this theme of progress by reviewing and discussing an effort that works to provide a new family of EA/SOA services that address C2 data-synchronization needs and capability gaps. The goal of this section is to highlight that as progress is being made towards addressing the complexities of NCW, the complexity and number of families of NCW information-sharing services also grows.

Section 7 discusses a current NCW related MBSE/SOSE effort that focuses on maritime wireless (i.e. RF) line-of-sight (LOS) communications and networking support. In particular, within the context of RF LOS link-management, the goal of the section is to communicate technical and organizational challenges associated with defining, assessing, and validating mission-driven measures of performance and measures of effectiveness (MOPs/MOEs). Thus, this section discusses a live example of the need for an overarching and more unified model-integration lifecycle support capability that enables different programs of record (e.g. RF LOS comms/networking, unmanned systems) to collaborate within the requirements, modeling, and conceptual design phases of the MBSE/SOSE lifecycle.

Section 8 and and section 9 further discuss the concept of a more unified MBSE/SOSE lifecycle support process in terms of existing resources and tools that may be considered candidate components within the proposed overarching lifecycle support process. More advanced and less mature technologies are also discussed in terms of future work and a longer term roadmap for the way ahead. Finally, sections 10-12 respectively provide a summary, acknowledgements, and list of references.

2. Evolving Models and Standards: NCW Business-Models for Agile C2 Net-Enabled Services

To further highlight the relative complexity and associated challenges, figure 3 and figure 4 (from [6]) are provided as examples of NCW reference models that focus on the operational objectives and context of agile C2 and associated net-enabled information sharing services. In terms of the vision and operational objectives of NCW and information dominance [7-8], the figures provide example views of the foundational reference models that currently drive DoD and maritime MBSE/SOSE lifecycle processes. In addition to the Observe-Orient-Decide-Act (OODA Loop)[8] pattern of decision making, other reference models may apply to a given operational context. For example, Sense-and-Respond and goal-modeling methods work towards similar objectives [9].[9]

Such collections of decision making and information dominance (e.g. OODA Loop, Sense-and-Respond) reference models provide a conceptual grounding that helps to unite the broad spectrum of disciplines, technologies, and families of services that must be integrated and support interoperability across a range of subsystem and SoS boundaries. In terms of the desired end-effects, the end-goal and desired effect of MBSE/SOSE and EA/SOA/Cloud lifecycle-support processes is to facilitate agile C2 capabilities that significantly enhance decision-making processes and help to more rapidly and seamlessly bridge interdependent physical, information, and cognitive domains.

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8   OODA loop (http://en.wikipedia.org/wiki/OODA_loop)
9   Sense and respond (http://en.wikipedia.org/wiki/Sense_and_respond)
      Goal modeling (http://en.wikipedia.org/wiki/Goal_modeling)

From a more traditional systems engineering perspective, this focus on end-user performance, versus systems and systems services, can be a particularly challenging task. From a more business process and workflow management perspective, end-user performance is typically tied to a return on investment (ROI)[10]. In other words, from a business perspective, the focus is on the bottom-line effectiveness of the services performed for the resources invested, versus the enabling technologies. Thus, further highlighting the multi-disciplinary (e.g. business versus engineering) challenges associated with developing more unified end-to-end enterprise engineering oriented product lifecycle management (PLM) processes.[11] Ideally, such a unified approach helps to better capture MOPs/MOEs in terms of the bottom-line improvements in ROI and end-user performance (e.g. decision making).
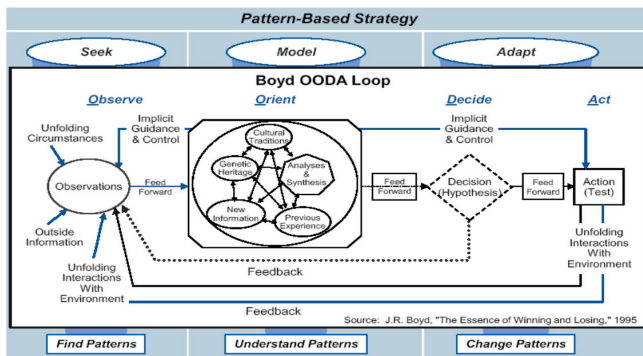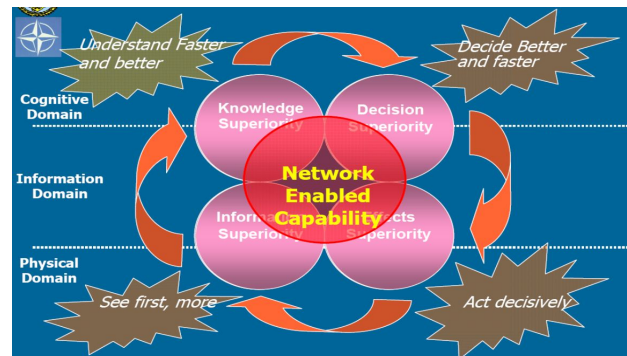

Figure 3 Boyd OODA-Loop Model

Figure 4 Net-Enabled Capability and Decision Cycles

3. Evolving Models and Standards: NCW Engineering-Support Reference Models and Standards

Figure 5 highlights that within NCW related technology domains, there are a range of standardized families-of-models that each have their own family histories [10], in terms of their own evolution over time (figure diagrams from [11-14]). Thus, the ongoing and growing need to more explicitly manage such technical standards and reference models within the overall lifecycle process. In other words, the figure highlights that NCW applications are inherently multi-disciplinary and employ interdependent technology domains, such as EA/SOA, systems engineering, software engineering, information and communications technology (ICT), complex systems, and computational modeling/simulation.[12]

Figure 6 (from [15]) is an example of a Model-Based Systems Integration (MBSI) systems development process, wherein model integration and systems integration are both incorporated within an overarching MBSE/SOSE process. As highlighted within the figure, separately designed subsystems are brought within a collaborative model-integration and qualification (I&Q) resource that facilitates a more unified model-integration, qualification, and build capability. Within [15] and this paper, the term qualification includes verification, validation, and acceptance. In principle, this focus on I&Q improves development of the requirements and specifications that drive subsequent phases of the the SE process.

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10 Return on investment (ROI; http://en.wikipedia.org/wiki/Return_on_investment)
11 Enterprise engineering (E2; http://en.wikipedia.org/wiki/Enterprise_engineering)
    Product lifecycle management (PLM; http://en.wikipedia.org/wiki/Product_lifecycle_management)
12 Systems engineering (SE; http://en.wikipedia.org/wiki/Systems_engineering)
    Software engineering (http://en.wikipedia.org/wiki/Software_engineering)
    Information and communications technology (ICT;
    http://en.wikipedia.org/wiki/Information_and_communications_technology)
    Complex systems (http://en.wikipedia.org/wiki/Complex_systems)
    Computer simulation (http://en.wikipedia.org/wiki/Computer_simulation)

As will be discussed in more detail in later sections, MBSI approaches are critical for ensuring that performance measurements[13], such as mission-thread driven measures-of-performance and measures-of-effectiveness (MOPs/MOEs), are correctly identified, assessed, and validated. For example, NCW C4ISR CONOPS that are expected to rely on unmanned systems (UxS), typically have time-critical information exchange[14] requirements (IERs) that must be anticipated and met during mission execution.
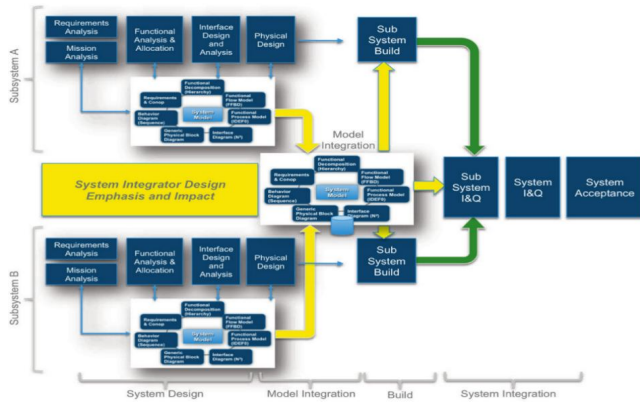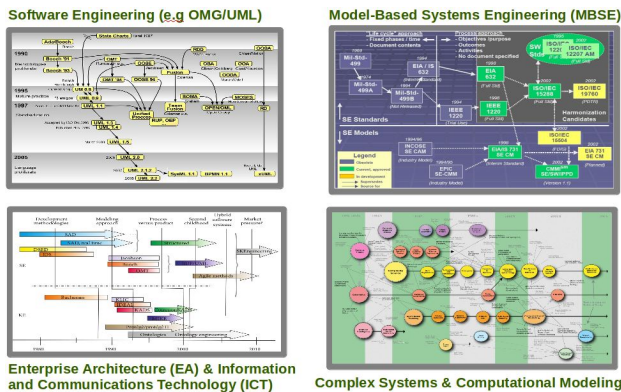

Figure 5 Example Timelines of Model-Based Standards *Figure 6 Example of Model-Based Systems Integration (MBSI)*

Within such mission execution contexts, UxS subsystems may be expected to operate in contested areas during DIL (i.e. disconnected/disrupted, intermittent, low-bandwidth) conditions, where tactical communications and networking support services may be severely degraded. In other words, for tactical afloat and forward operating areas, ICT oriented RF communications and networking support services (e.g. tactical RF comms/networking information-sharing services) are expected to be robust to DIL conditions and gracefully degrade with respect the baseline mission-thread requirements (i.e. MOPs/MOEs). Such context dependent (e.g. mission-thread execution) RF comms/networking quality of service (QoS) requirements necessitate the development of MBSI types of engineering processes where subsystem level IERs can be assessed in terms of anticipated mission-thread MOPs/MOEs (e.g. operating under DIL conditions). Associated QoS requirements include threshold/objective information-exchange latencies, as well as, workflow-level exception-handling when QoS requirements are at risk. Thus, capability gaps may be more readily identified and addressed within the requirements engineering and early systems-design stages of the MBSE/SOSE lifecycle.

For MBSE/SOSE requirements management and engineering activities (i.e. tracing and assessment), the payoff for a collaborative model integration resource is the ability to better analyze and assess baseline vignettes (e.g. mission-threads) and possible excursions (e.g. operating under various DIL conditions).[15] This enables the analysis and assessment of a variety of possible conditions that can be addressed at the requirements level (e.g. MOP/MOE) and architectural design level. This type of collaborative requirements and system design capability helps to facilitate the development of the most effective and desired agile support services (e.g. RF comms/networking), as needed for net-centric tactical C4ISR operations (e.g. time sensitive targeting[16]).

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13 Performance measurement (http://en.wikipedia.org/wiki/Performance_measurement)
14 Information exchange (http://en.wikipedia.org/wiki/Information_exchange;
    http://en.wikipedia.org/wiki/Information_transmission; http://en.wikipedia.org/wiki/Communication_channel)
15 Requirements management (RM; http://en.wikipedia.org/wiki/Requirements_management)
    Requirements engineering (RE; http://en.wikipedia.org/wiki/Requirements_engineering)
16 JP 3-60 (cfr.org/content/publications/attachments/Joint_Chiefs_of_Staff-Joint_Targeting_31_January_2013.pdf)

4. Evolving Complexity of Models and Standards: Unified Modeling Language (UML) Example

As highlighted within the example time lines of figure 5, MBSE/SOSE related technology domains continue to mature, adapt, and evolve over time. Within the software engineering domain, for example, the Object Management Group (OMG) Unified Modeling Language (UML), which originated from the unification of competing object-oriented (OO) analysis and design methodologies, has continued to mature and develop to the present date.[17] With the introduction and subsequent adoption of the Unified Profile for DoDAF/MODAF (UPDM)[18], UML has become a more common standard for representing DoDAF architecture products. This has also enabled the incorporation of the OMG model-driven architecture (MDA) and associated model-driven engineering (MDE) standards for facilitating and augmenting MBSE/SOSE processes and best-practices.[19]

Within the context of UML, the relatively recent introductions of the OMG Systems Modeling Language (SysML) standard and OMG Business Process Model and Notation (BPMN) standard, have established separate interdependent visually-intensive modeling language variants wherein each serves domains (i.e. areas of concern) that respectively focus on systems engineering (SE) and business process management (BPM), versus OO software development.[20] Within the context of BPM and associated workflow[21] services, BPMN is a business process oriented standard that has a longstanding relationship within the more business oriented EA/SOA community. While both SysML and BPMN address multi-disciplinary engineering support needs, this nonetheless demonstrates the added complexities for developing and sustaining net-centric information sharing services.

The SysML standard provides an added example of the challenges associated with navigating across the variants of inter-related reference models and standards. As an extension of a subset of UML, SysML has been created due to the need to provide systems engineering (SE) improvements to the historically software-centric UML standard. For example, the definition of SysML requirements and parametric diagram types provides enhanced requirements engineering, performance analysis, and quantitative analysis support. Such SE oriented enhancements enable SysML to model a wide range of systems, which may include hardware, software, information, processes, personnel, and facilities. From a SE standards perspective, SysML extensions enable UML's architectural design and modeling capabilities to be better aligned with standardized methodologies for developing software-intensive systems (e.g. ISO/IEC/IEEE 42010[22] [16]). Thus, the relatively recent emergence of such SE oriented variants of historically software-only standards (e.g. UML), illustrates the current multi-disciplinary MBSE/SOSE requirement for knowing which variant is most appropriate within the respective process development context (e.g. software development, systems engineering, business process management). Business process and workflow management oriented variants (e.g. BPMN) similarly introduce challenges within the end-user operations-support context. Model-level interoperability across the respective variants of UML based standards (e.g. SysML, BPMN) is an additional challenge.

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17 Unified Modeling Language (UML; http://en.wikipedia.org/wiki/Unified_Modeling_Language)
    Object-oriented analysis and design (OOAD; http://en.wikipedia.org/wiki/Object-oriented_analysis_and_design)
18 UPDM (http://en.wikipedia.org/wiki/UPDM)
19 Model-driven architecture (MDA; http://en.wikipedia.org/wiki/Model-driven_architecture)
    Model-driven engineering (MDE; http://en.wikipedia.org/wiki/Model-driven_engineering)
    Best practice (http://en.wikipedia.org/wiki/Best_practice)
20 Systems Modeling Language (SysML; http://en.wikipedia.org/wiki/Systems_Modeling_Language)
    Business Process Model and Notation (BPMN; http://en.wikipedia.org/wiki/Business_Process_Model_and_Notation)
    Business process management (BPM; http://en.wikipedia.org/wiki/Business_process_management)
21 Workflow (http://en.wikipedia.org/wiki/Workflow)
22 ISO/IEC 42010 (http://en.wikipedia.org/wiki/ISO/IEC_42010)

For MBSE/SOSE lifecycle support, another recently introduced variant of UML is of interest. Executable UML (xUML)[23] "combines a subset of the UML (Unified Modeling Language) graphical notation with executable semantics and timing rules" [17]. As noted within a recent survey of modeling and simulation of systems-of-systems [18], recently introduced enhancements to the DoDAF specification [19-20] contain modeling and simulation (M&S) as a tool for developing "executable architecture" and providing detailed DoDAF to discrete-event system specification (DEVS)[24] mapping in simulation and feasibility analysis. The result is an improved system lifecycle development that contains model-continuity based design and testing in an integral form. Other references further discuss the value of methods and tools that support "executable architecture" capabilities (e.g. xUML, DEVS) [21-22]. In the context of the work described herein, the key point is that the value added by such M&S oriented variants of UML (and consequently DoDAF), further complicates the MBSE/SOSE process.

Separate from UPDM and UML, the DoD Architecture Framework (DoDAF) emerged from the original C4ISR Architecture Framework, which separately emerged from the context of the Zachman and NIST EA models and Enterprise Resource Planning (ERP) (circa 1990s).[25] Thus, the evolution of DoDAF has primarily been in conjunction with the congressionally mandated Clinger-Cohen Act and associated federal enterprise architecture (FEA).[26] DoDAF 2.0 is an upgrade of DoDAF (circa 2009) that addresses the need to further align with the evolution and maturity of EA/SOA methodologies and best-practices. This is another example of the variety of standards legacies and associated variants that are commonly encountered within particular technology domains. For multi-disciplinary engineering activities (e.g. MBSE/SOSE), this type of standards and reference model variability is compounded by the potential lack of familiarity and inability to cross disciplinary boundaries. Thus, the need for more explicit model management and integration support for the overall lifecycle process (e.g. MBSI).

5. The Evolving Complexity of MBSE/SOSE: Examples of Progress to Date

Within the last decade, there have been a number of efforts that address the need to deconstruct and transform monolithic stovepiped legacy systems into families of reusable and inoperable services. The progress to date with such efforts helps to establish a foundation for developing model-based I&Q approaches within lifecycle support processes and best-practices. Figure 7 illustrates ongoing efforts to evolve and transform tightly-coupled monolithic legacy systems into families of net-enable services (diagrams from [23, 4]). As previously highlighted within the context of a proposed Enterprise Engineering Reference Model (E2RM) [24], figure 8 (diagrams from [24]) illustrates the goals and objectives of an ongoing PEO-C4I Enterprise Engineering and Certification (E2C) support activity that shares this vision of maximizing reuse and interoperability [25]. The focus of the E2C has been towards systems interoperability assessment and validation processes for mitigating potential interoperability risks that cross program of record (POR) boundaries. Thus, MBSE/SOSE and EA/SOA/Cloud methodologies, reference models, best-practices, and standards are fast approaching the ability to develop a more cohesive and rigorously managed end-to-end lifecycle-support process.

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23   Executable UML (http://en.wikipedia.org/wiki/Executable_UML)
24   DEVS (http://en.wikipedia.org/wiki/DEVS)
25   Sowell, P., "The C4ISR Architecture Framework: History, Status, and Plans for Evolution," 2006.
      (http://www.dtic.mil/dtic/tr/fulltext/u2/a456187.pdf)
      Enterprise architecture framework (http://en.wikipedia.org/wiki/Enterprise_Architecture_framework#History)
      Enterprise resource planning (http://en.wikipedia.org/wiki/Enterprise_resource_planning)
26   Clinger–Cohen Act (http://en.wikipedia.org/wiki/Clinger-Cohen_Act)
      Federal enterprise architecture (FEA; http://en.wikipedia.org/wiki/Federal_enterprise_architecture)

For agile C2, this type of tactical C4ISR operations support is critical for the way ahead. This is especially true due to emerging non-kinetic threats, such as cyber and electronic warfare. With the emergence and proliferation of a growing range of standards that apply to a growing variety of different inter-dependent technology domains, there is an additional need for more explicitly supporting the integration and model-level management of different families of net-centric EA/SOA/Cloud services.

In particular, for supporting afloat/forward tactical C4ISR IERs (e.g. UxS information-exchanges), the assessment and derivation of mission-level requirements (e.g. MOPs/MOEs) requires collaborative model-based requirements engineering (e.g. analysis, assessment, validation) and systems design activities. Thus, the value and payoff for further developing and utilizing MBSI types of approaches.
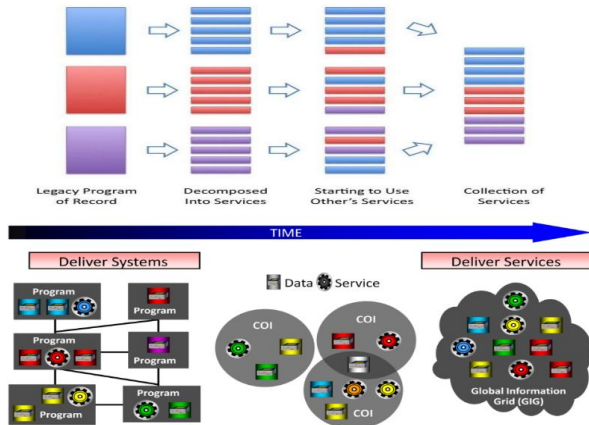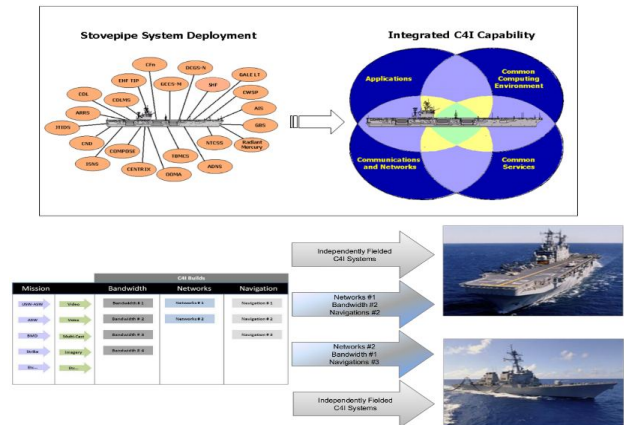

Figure 7 Evolution from Systems to Services

Figure 8 Enterprise Engineering (E2) MBSE Objectives

6. Evolving Complexity of Models and Standards: Example from Previous Work

As highlighted and discussed in the previous sections, agile C2 capabilities are critically dependent upon the synchronization of dataflows that support the IERs of the respective net-centric operational workflow (e.g. mission-thread execution). From a EA/SOA perspective, a generic set of interfaces can be defined for establishing a functional taxonomy of the types of services that are typically associated with data-synchronization[27] needs and requirements. Most generally, much of the functionality associated with data-synchronization typically relates to distributed computing requirements, as they relate to distributed concurrency control and distributed transaction management.[28]

Figure 9 and figure 10 are from recently reported progress towards establishing an initial family of C2 data-synchronization services (C2SS) [26]. The goal of the C2SS effort can be viewed as including a refactoring of Quality of Service (QoS) and non-functional requirements that need to be addressed as distributed computing challenges that span the respective layers of an EA/SOA services stack (e.g. presentation layer, services layer, business layer, data layer).[29] This type of conceptual and logical restructuring is another example of the evolution towards a services-oriented design perspective.

Conceptually, from a NCW "cognitive domain" and business-services perspective, C2SS can be viewed

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27 Data synchronization (http://en.wikipedia.org/wiki/Data_synchronization)
28 Distributed computing (http://en.wikipedia.org/wiki/Distributed_computing)
    Distributed concurrency control (http://en.wikipedia.org/wiki/Distributed_concurrency_control)
    Distributed transaction (http://en.wikipedia.org/wiki/Distributed_transaction)
29 Quality of service (http://en.wikipedia.org/wiki/Quality_of_service)
    Non-functional requirement (http://en.wikipedia.org/wiki/Non-functional_requirement)
    Multilayered architecture (http://en.wikipedia.org/wiki/Multilayered_architecture)

as an encapsulation of services within a logically defined data-layer. Thus, figure 9 (from [26]) illustrates this new family of services. In terms of the deployment of C2SS service components, a variety of techniques can be utilized, such as dependency injection patterns, to provide specific information-sharing support services within specific dataflows (e.g. IP packet flow).[30] In other words, C2SS functions are intended to provide enhanced ongoing support for C2 mission-level IERs and associated information-exchange MOPs/MOEs. As highlighted in figure 10 (from [26]), C2SS functionality can be implemented using sets of adapters, for which application programming interfaces (APIs) and service descriptions (e.g. IDL, RSDL, OSID) can be defined and supported.[31] Through the development of such EA/SOA functionality, C2SS services perform data-synchronization operations within the data paths that logically connect information sources (e.g. data streams, data stores) and end-user workflow-support applications (e.g. C4ISR apps and user-interface widgets).[32]

Figure 10 lists an example of "eventual consistency"[33] at the top of the partial list of candidate C2SS functions. Generically, eventual consistency "informally guarantees that, if no new updates are made to a given data item, eventually all accesses to that item will return the last updated value" (quote from reference in footnote 59) This type of C2SS function enables resynchronization after communication channels[34] are disconnected or intermittently interrupted. In this case, for geo-replicated instances of shared data elements, the values of the replicated data elements eventually become consistent. Thus, the term "eventual consistency." Within the context of document management, distributed revision control[35] is another example and way of describing this type of data-synchronization functionality. From a C2SS perspective, the goal is to decouple implementation details from baseline platform-independent service descriptions. Thus, service instances are not bound to specific implementations. Furthermore, instances of such services can be tailored to address context-specific IER needs.
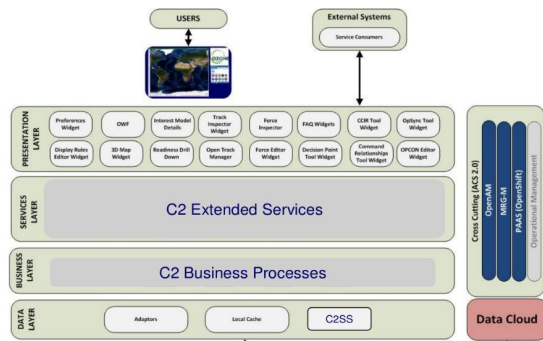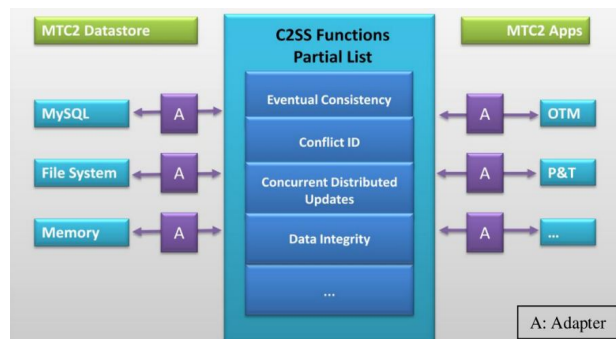

Figure 9 C2 Data-Synchronization Services (C2SS)

Figure 10 Dependency Injection and Adapter Patterns Example

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30 Dependency injection (http://en.wikipedia.org/wiki/Dependency_injection)
    Traffic flow (computer networking) (http://en.wikipedia.org/wiki/Traffic_flow_%28computer_networking%29)
31 Adapter pattern (http://en.wikipedia.org/wiki/Adapter_pattern)
    Application programming interface (API; http://en.wikipedia.org/wiki/Application_programming_interface)
    Interface description language (IDL; http://en.wikipedia.org/wiki/Interface_description_language)
    RSDL (RESTful Service Description Language; http://en.wikipedia.org/wiki/RSDL)
    Open Service Interface Definitions (OSIDs; http://en.wikipedia.org/wiki/Open_Service_Interface_Definitions)
32 Data stream (http://en.wikipedia.org/wiki/Data_stream)
    Data store (http://en.wikipedia.org/wiki/Data_store)
    Web widget (http://en.wikipedia.org/wiki/Web_widget); Software widget
    (http://en.wikipedia.org/wiki/Software_widget); GUI widget (http://en.wikipedia.org/wiki/GUI_widget)
33 Eventual consistency (http://en.wikipedia.org/wiki/Eventual_consistency); Eventually consistent
    (http://dl.acm.org/citation.cfm?doid=1435417.1435432)
34 Channel (communications) (http://en.wikipedia.org/wiki/Channel_%28communications%29)
35 Distributed revision control (http://en.wikipedia.org/wiki/Distributed_revision_control)

The initial work highlighted in figure 9 and figure 10 has been carried forward and adapted to more specifically address a need for developing a MBSI type of process for I&Q of mission-based MOP/MOE related requirements. More specifically, the focus of current efforts (i.e. FY14) addresses data-synchronization challenges for wireless (e.g. RF) line of sight (LOS) ad-hoc comms/networking support for afloat/forward area tactical C4ISR operations. An example of a key issue for this specific use-case, relates to the use of Internet Protocol (IP, IPv6) based information-exchange standards (e.g. TCP, UDP) for satisfying mission-task IERs.[36] Within this context of RF LOS comms/networking IP-based information-sharing support services, the challenge is to determine the relative timing requirements for reshaping the physical RF LOS network topology, as a function of the mission-based IP-based data-exchange MOPs/MOEs (e.g. UxS IERs during DIL conditions).

7. Need for Requirements and Model-Integration Support: Example from Current Work

For maritime blue-ocean and ship-to-shore operations, ad-hoc wireless (i.e. RF) networking presents a number of challenges. Ideally, for RF LOS ad-hoc networks, the dynamic shaping of the physical network topology[37] (i.e. allocation and deallocation of links) should be coordinated with the logical connections and associated dataflows supported by the respective RF LOS links and infrastructure components (e.g. routers, switches). Furthermore, as discussed earlier, the operational end-user workflow support requirements and QoS objectives should drive the link management process.

In addition to a number of open technical challenges associated with developing this type of mission-driven RF comms/networking support capability, there is also an organizational need for collaboratively defining, assessing, and validating MOPs/MOEs that quantify the range of associated data-synchronization requirements (e.g. information-exchange latencies). In other words, a MBSI type of process is needed for developing best-practices (e.g. SOPs[38]) that help to establish mission-dependent objective and threshold values that drive link-management policies and requirements.

Figure 11 and figure 12 are diagrams that were created to illustrate this RF LOS comms/networking link-management challenge. As seen in figure 11, the EA/SOA oriented services stack parallels the comms/networking oriented OSI model (i.e. protocol stack).[39] Note that due to the focus on "data in motion" and "data in use", a EA/SOA data-layer (data-services layer) for managing "data at rest" (e.g. data persistence) is assumed but not shown.[40] In terms of mission performance (i.e. operations workflow support) and associated mission-dependent information-exchange requirements (e.g. MOPs/MOEs), the RF LOS link-manager is a number of layers removed from the end-user. In other words, there is a need for logical-layer and application-layer support services that enable and augment misson-driven link-management services.

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36 Use case (http://en.wikipedia.org/wiki/Use_case)
    Internet Protocol (http://en.wikipedia.org/wiki/Internet_Protocol)
    IPv6 (http://en.wikipedia.org/wiki/IPv6)
    Transmission Control Protocol (TCP; http://en.wikipedia.org/wiki/Transmission_Control_Protocol)
    User Datagram Protocol (UDP; http://en.wikipedia.org/wiki/User_Datagram_Protocol)
37 Network topology (http://en.wikipedia.org/wiki/Network_topology)
38 Standard operating procedure (SOP; http://en.wikipedia.org/wiki/Standard_operating_procedure)
39 OSI model (http://en.wikipedia.org/wiki/OSI_model)
    Protocol stack (http://en.wikipedia.org/wiki/Protocol_stack)
40 Data in Use (http://en.wikipedia.org/wiki/Data_in_Use)
    Data at Rest (http://en.wikipedia.org/wiki/Data_at_Rest)
    Persistence (computer science) (http://en.wikipedia.org/wiki/Persistence_%28computer_science%29); Persistent data (http://en.wikipedia.org/wiki/Persistent_data)

As highlighted within the more detailed block diagram (figure 12), there are a number of logical-layer services that are needed for facilitating mission-driven connectivity management and logical IP-based dataflow management. Thus, within these middleware layers, the respective application-layer tasks, such as Warfighter tasks (e.g. C2, ISR) and mission-support tasks (e.g. data-synchronization, entity management), need to work collaboratively with physical-layer oriented RF LOS link-management tasks to established objective and threshold values for link-management MOPs/MOEs that can most effectively support Warfighter policies and needs (i.e. QoS, IERs).
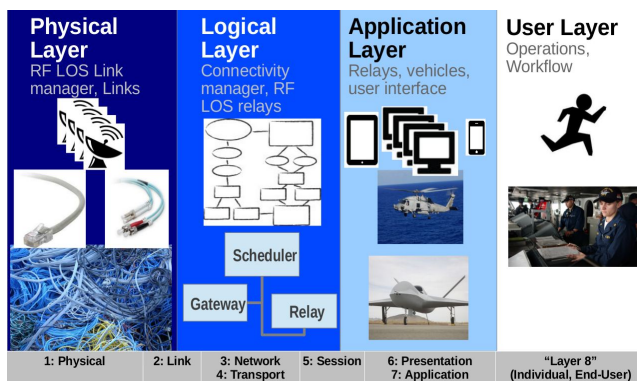
Figure 11 EA/SOA Layering of Link-Management Services   *Figure 12 Systems View of RF LOS Link-Management*
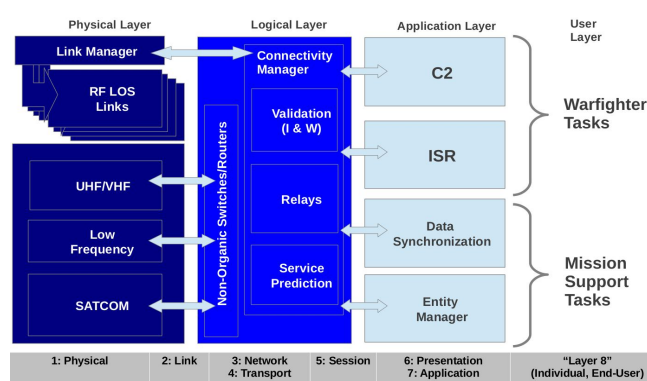
Figure 13 illustrates how existing standards can be leveraged for developing an initial RF LOS link-management capability. The logical-layer services highlighted within figure 12 are encapsulated into a connectivity-manager that functionally decouples the physical-layer services (e.g. link-manager) from the various application-layer entities (stakeholders) that may concurrently participate within a specific commonly-understood task (e.g. element of the UJTL[41] taxonomy). Using standardized sequencing diagrams (e.g. UML sequence diagram[42]), the operational and technical details for how processes need to operate with one another and in what order, can be collaboratively determined and documented.

Families of possible variations of event scenarios can be generated, relative to a given baseline use-case. Furthermore, using standardized information-exchange taxonomies (i.e. controlled vocabularies), such as the National Information Exchange Model (NIEM), unambiguous information sharing, relative to a specific mission-task context, is possible for a broad range of possible ad-hoc virtual-teaming situations.[43] Thus, through the utilization of established standards (e.g. UML sequence diagrams, UJTLs, NIEM), mission-task specific information-exchange MOPs/MOEs can be determined, assessed, and ultimately validated by collaborative experiments and operational exercises.

Figure 14 is a dataflow diagram for an initial data-collection experiment that works to document the variability of information-exchange events that represent the types of IERs that are associated with UxS tactical C4ISR scenarios (i.e. CONOPS). Thus, this type of standardized experimentation process augments and enhances the early MBSE/SOSE lifecycle processes that support model-integration and executable-architecture[44] capabilities. The payoff is collaborative mission-thread analysis, assessment, and validation within the early phases of the respective MBSE/SOSE lifecycle. In other words, the experimentally derived information-exchange statistics facilitate higher fidelity collaboration

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41 Universal Joint Task List (UJTL; http://en.wikipedia.org/wiki/UJTL)
42 Sequence diagram (http://en.wikipedia.org/wiki/Sequence_diagram)
43 Controlled vocabulary (http://en.wikipedia.org/wiki/Controlled_vocabulary)
    National Information Exchange Model (NIEM; http://en.wikipedia.org/wiki/National_Information_Exchange_Model)
44 Executable architecture (http://en.wikipedia.org/wiki/Executable_architecture)

opportunities that ensure correct system designs are in place before the respective subsystems are built and deployed to an operational EA/SOA/Cloud framework for interoperability testing and validation. Most importantly, much needed MOP/MOE estimates can be generated within the respective design phases of the inter-dependent subsystems (e.g. RF LOS link management, UxS mission-area applications). This type of data-collection experiment is scheduled for the Trident Warrior 2014 (TW14) experiment. These initial IER related statistics are intended to provide a working baseline for collaborative assessment and validation of mission-driven link-management MOPs/MOEs.
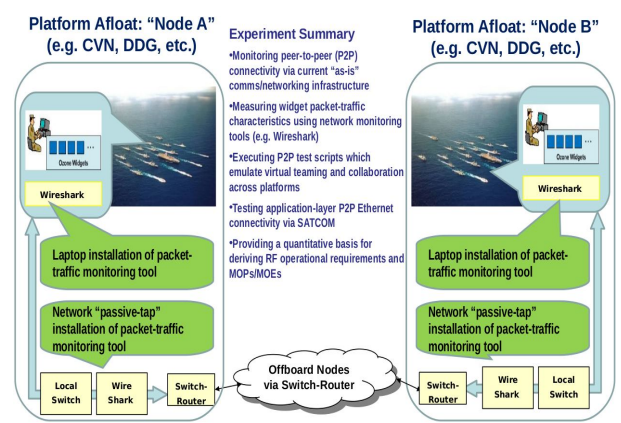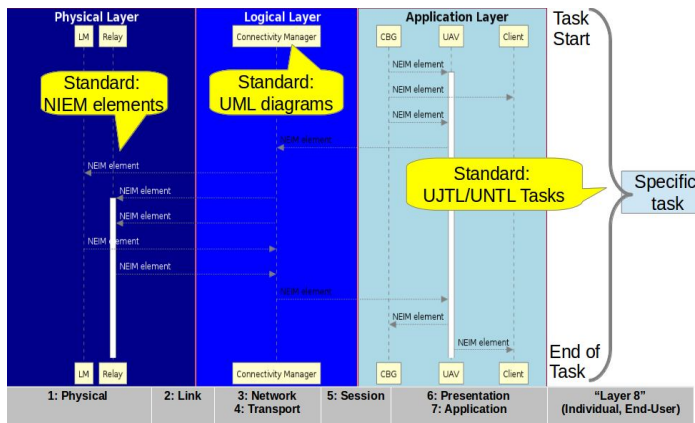
Figure 13 Example Seq. Diagram Using Task & Data Standards *Figure 14 Example Data-Collection Exp. for IER Analysis*

From a standardized task management (e.g. UJTL/UNTL driven workflow) perspective, the IER related information collected at TW14 (e.g. latency distributions for prototypical information-exchange events) helps to identify and assess the parameters and respective objective/threshold values that determine the risk status for a specific mission task (e.g. UJTL/UNTL) or collection of tasks (e.g. METL[45]). This type of task-execution information is critical for the business-logic aspects of battle management, and recently developed battle management language capabilities [27-28]. For example, risks due to information-exchange delays (e.g. DIL conditions), can be represented and managed at the stakeholder workflow-level of mission-support services. Within the commercial sector, business-rules approaches are another example of this type of management of dynamic work environments. Business rules are especially useful for establishing and managing policies for how to manage situations that are outside normal (i.e. baseline) operating conditions. From a systems design perspective, this type of information is useful for assertion oriented methodologies (e.g. exception handling, design-by-contract) that utilize conditional-execution specifications (e.g. precondition, postcondition, invariant).[46]

The collaborative development of link-management MOPs/MOEs enables the development of the logical content (e.g. QoS policies, service assurance requirements, business-rules) needed for COTS/GOTS business-rule management system (BRMS) approaches to workflow support.[47] This is of

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45 Joint Mission Essential Task List (JMETL) Development Handbook (www.dtic.mil/dtic/tr/fulltext/u2/a331999.pdf)
46 Assertion (software development) (http://en.wikipedia.org/wiki/Assertion_%28software_development%29)
    Exception handling (http://en.wikipedia.org/wiki/Exception_handling)
    Design by contract (http://en.wikipedia.org/wiki/Design_by_contract)
    Precondition (http://en.wikipedia.org/wiki/Precondition)
    Postcondition (http://en.wikipedia.org/wiki/Postcondition)
    Class invariant (http://en.wikipedia.org/wiki/Class_invariant)
47 Service assurance (http://en.wikipedia.org/wiki/Service_assurance)
    Business rule (http://en.wikipedia.org/wiki/Business_rule)
    Business rule management system (BRMS; http://en.wikipedia.org/wiki/Business_rule_management_system)

particular interest due to the availability of standards (e.g. OMG SBVR), methodologies (e.g. business-rule approach), and BRMS resources (e.g. business-rule engines, inferencing engines, JBoss Drools).[48] The payoff for utilizing BRMS resources is the potential flexibility in dynamically managing context-dependent business logic[49]. Ideally, for managing operational workflow, a BRMS supports the dynamic business-logic aspects of tactical operations support (e.g. data-synchronization, DIL-condition related workflow-level exception-handling).

With the growing availability and use of controlled vocabularies and common terminologies (e.g. UJTL/UNTL, NIEM), BRMS approaches provide opportunities to enable semantic interoperability[50] within both the MBSE/SOSE and end-users' information and cognitive domains. In particular, controlled-vocabulary and content management services can enable responsive lexicon-support for tactical mission execution support [29-31]. Thus, further enhancing C2 agility.

In addition to the incorporation of more technical and specialized resources for enabling semantic grounding[51] and augmenting multi-disciplinary technical dialog, commonly available resources have also been explored for addressing the need for MBSE/SOSE lexicon-support services. For example, globally accessible, openly reviewed, and collaboratively-edited encyclopedic resources (e.g. Wikipedia) are being evaluated and assessed for enhancing and augmenting technical dialog. Thus, as demonstrated herein, footnoted encyclopedic references may be utilized to communicate concepts and topics common to one technology domain, but otherwise not necessarily more generally known.

As an additional step towards developing a MBSI type of collaborative mission-driven link-management development capability, the current FY14 RF LOS link-management effort is working closely with UxS development efforts that are scheduled to utilize the RF LOS infrastructure within their tactical ISR mission-threads (i.e. CONOPS). In particular, the CONOPs of interest include near-realtime content delivery/distribution network (CDN) and "push technology" types of net-enabled services (e.g. full-motion video processing and distribution).[52] Previous micro/miniature UxS[53] related efforts have similarly explored CDN UxS CONOPS [32-34]. Figure 15 is a dataflow diagram for a planned TW14 experiment that assesses current "as-is" CDN capabilities. In this scenario, a rotorcraft platform is acting as a surrogate-relay for beyond line-of-sight (BLOS) C4ISR UxS platforms.

As an example of architecture reuse, Figure 16 (from [4]) highlights the value of standardized model-based EA/SOA approaches. Within a separate context, a platform independent Multi-Intelligence Distribution Architecture (MIDA) was developed and published in the open literature [4]. Much of the platform independent modeling (PIM)[54] aspects of the CDN CONOP is captured in the available MIDA architecture. Thus, the reuse of the MIDA modeling results provides an example of the value and

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48 Semantics of Business Vocabulary and Business Rules (SBVR; http://en.wikipedia.org/wiki/Semantics_of_Business_Vocabulary_and_Business_Rules)
    Business rules approach (http://en.wikipedia.org/wiki/Business_rules_approach)
    Business rules engine (http://en.wikipedia.org/wiki/Business_rules_engine)
    Inference engine (http://en.wikipedia.org/wiki/Inference_engine)
    Drools (http://en.wikipedia.org/wiki/Drools)
49 Business logic (http://en.wikipedia.org/wiki/Business_logic)
50 Semantic interoperability (http://en.wikipedia.org/wiki/Semantic_interoperability)
51 Symbol grounding (http://en.wikipedia.org/wiki/Symbol_grounding)
52 Content delivery network (http://en.wikipedia.org/wiki/Content_delivery_network)
    Push technology (http://en.wikipedia.org/wiki/Push_technology)
53 Micro air vehicle (MAV; http://en.wikipedia.org/wiki/Micro_air_vehicle); Miniature UAV
    (http://en.wikipedia.org/wiki/Miniature_UAV)
54 Platform-independent model (PIM; http://en.wikipedia.org/wiki/Platform-independent_model)

benefit of common standardized models and best practices.

Of particular value is the use of a number of interrelated reference models within the development of the MIDA reference model. For example, in the creation of the MIDA services taxonomy, the Process-Exploit-Disseminate (PED) model helps to reinforce commonality across reference models. Also, the incorporation of the Department of Defense Discovery Metadata Specification (DDMS) standard ensures model-level (i.e. PIM) compatibility with DoD/DISA Net-Centric Enterprise Services (NCES) and information-exchange standards (e.g. NIEM).[55]
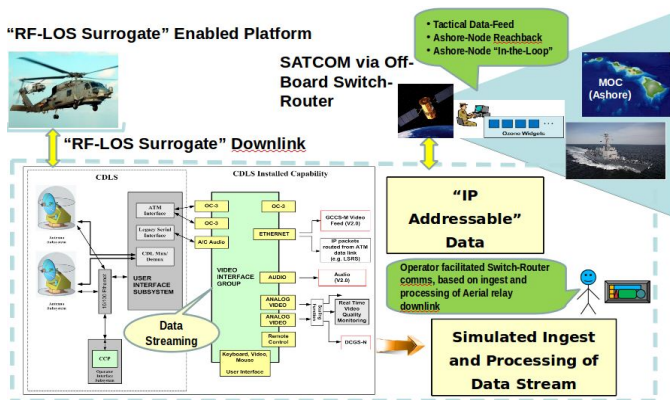
Figure 15 Content Delivery Network (CDN) Related CONOP
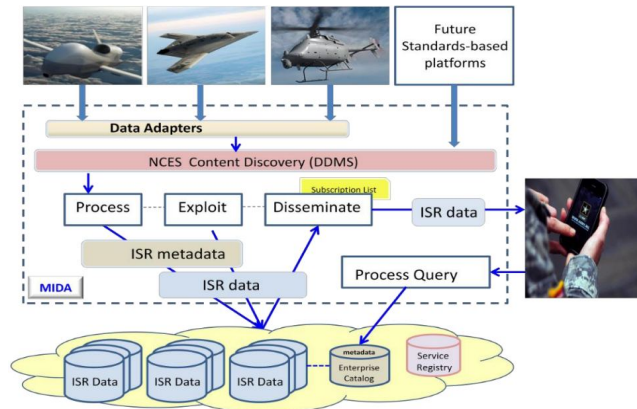
Figure 16 MIDA CONOP (OV-1)

Figure 17 (from [4]) illustrates how common terminology and standardized reference models enable semantic agreement and model-based reuse. In this case, the MIDA services taxonomy (SvcV-4) provides a baseline for the example use-case that is the focus of the current RF LOS link-management effort (i.e. CDN CONOP). Figure 18 (from [35]) illustrates how CDN services can be incrementally developed within an agile development process. In this example, an agile development process can be combined with standardized widget frameworks (e.g. OWF) for developing reusable UxS widgets (e.g. platform control, CDN, analysis) and widget-based applications (e.g. mobile apps) that are available via a logically centralized application store (e.g. PEO C4I marketplace).[56] The reusable architecture framework[57], as developed and demonstrated, supports current EA/SOA frameworks while anticipating the evolution towards the Naval Tactical Cloud (NTC) afloat and ashore [36]. The results of this effort provide a foundation for future cloud-based UxS model-integration and development capabilities. Note that emerging model-based UxS standards (e.g. FACE, UCS, JAUS, ACS) are additional examples of UxS reference models that further complement a model-based I&Q approach to UxS lifecycle support and model-level platform-independent interoperability [37].[58]

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55 Department of Defense Discovery Metadata Specification (DDMS; http://en.wikipedia.org/wiki/Department_of_Defense_Discovery_Metadata_Specification) Net-Centric Enterprise Services (NCES; http://en.wikipedia.org/wiki/Net-Centric_Enterprise_Services)

56 OZONE Widget Framework (OWF) home page, last access 7 Feb 2014 (https://www.owfgoss.org) Mobile app (http://en.wikipedia.org/wiki/Mobile_app) Application store (http://en.wikipedia.org/wiki/Application_store)

57 Architecture framework (http://en.wikipedia.org/wiki/Architecture_framework)

58 Future Airborne Capability Environment (FACE; https://www.opengroup.us/face/; http://en.wikipedia.org/wiki/Future_Airborne_Capability_Environment; UAS Control Segment (UCS), UCS Architecture home page, last access 7 Feb 2014 (https://ucsarchitecture.org/) Joint Architecture for Unmanned Systems (JAUS; http://en.wikipedia.org/wiki/JAUS; http://jaustoolset.org/) Autonomous Capabilities Suite (ACS; http://www.public.navy.mil/spawar/Pacific/Robotics/Pages/ACS.aspx)

In summary, RF LOS link-management services that focus on end-user IER MOPs/MOEs, need collaboration capabilities provided by MBSI types of MBSE/SOSE processes. For mission-dependent data-synchronization requirements, the ability to engage within the model-based systems design phases of the systems lifecycle, enables early specification and design changes that address capability gaps relative to mission-driven IER needs and priorities, reinforcing the need for MBSI types of processes.
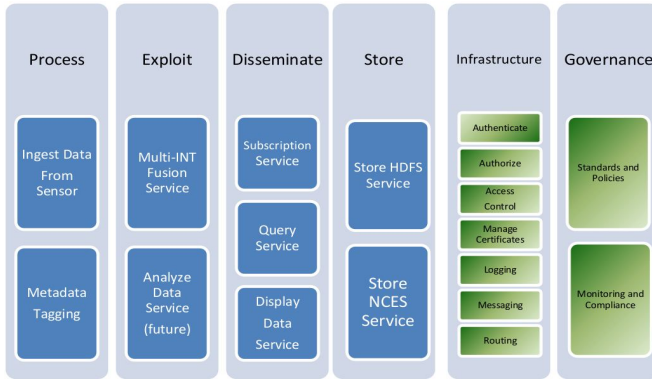

Figure 17 CDN Services Taxonomy (SvcV-4; from [6])
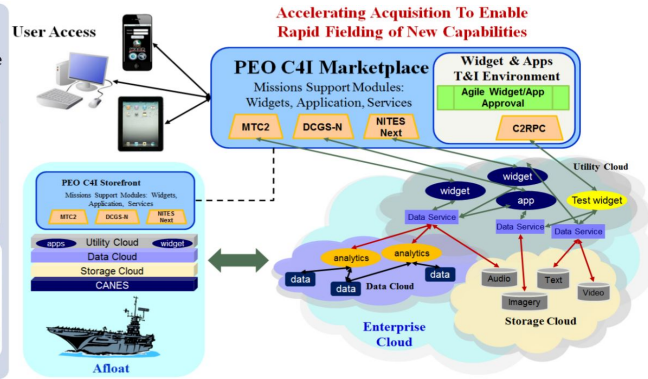
Figure 18 Example of A Model for Reusable UxS Widgets within EA/SOA/Cloud Frameworks

8. Establishing a Unified Model-Integration Oriented Lifecycle Process: Candidate Components

As discussed in earlier sections, there is an immediate payoff from simply adopting a MBSI type of approach to MBSE/SOSE applications that are targeted for EA/SOA/Cloud frameworks. An additional benefit is the incorporation and more rigorous management of a growing number of candidate components that help establish a more end-to-end unified MBSI type of lifecycle support capability.

A candidate component that facilitates reuse and product line engineering (PLE) capabilities, for example, is illustrated in Figure 19 (from [38]). In this case, a PLE framework can potentially be leveraged. In principle, this augments the previously highlighted E2C facilities and interoperability certification processes (highlighted in figure 8). Figure 20 (from [39]) is another example of a potential component of a unified end-to-end MBSE/SOSE lifecycle process. In this case, the Rapid Integration and Test Environment (RITE) diagram highlights a DoDI 5000.02[59] compatible agile development process for rapid development and delivery of net-enabled (i.e. EA/SOA) Warfighter support services.

- Common, managed set of features that are developed from a common set of core assets.
- Improvements in time to market, cost, productivity, and quality.
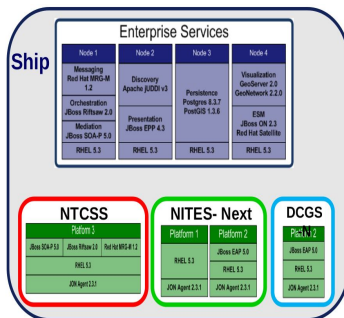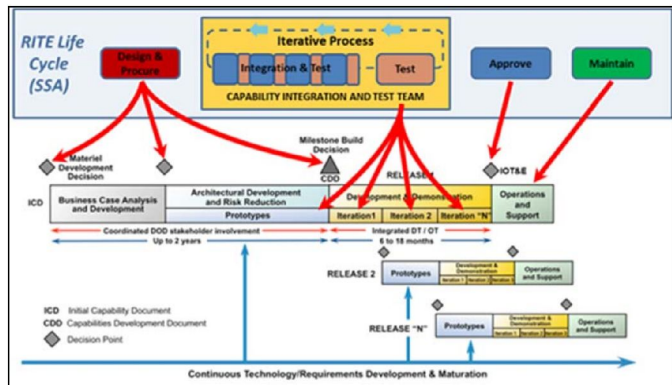

Figure 19 Example of Reusable Enterprise Services

Figure 20 RITE Lifecycle Process for Agile Development

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59 Interim DoD Instruction 5000.02, "Operation of the Defense Acquisition System," 25 Nov 2013 (http://www.dtic.mil/whs/directives/corres/pdf/500002_interim.pdf)

There are a number of other examples of potential components. Such examples include DoD/DON, SPAWAR, PEO-C4I, PMW/POR, SSCPAC, and academically developed (e.g. NPS) methods, frameworks, resources, and tools. In principle, the following are other example capabilities that can be brought together and integrated within an overarching collaborative lifecycle support process: (i) System Maturity Models (SMM) (e.g. Littoral Combat Ship SMM process [40]); (ii) DoD/DISA M&S tools (e.g. GOTS Joint Communications Simulation System [41]); (iii) NPS M&S Virtual Environment open-source tools and resources (e.g. AUV Workbench [42-43]). Due to the breadth and depth of MBSE/SOSE activities across DoD/DISA/OSD, intelligence community (IC), and coalition partners, the list of candidate components can quickly expand to include a broad array of resources.

The above listed resources are a sampling of resources that can be adapted and tailored towards a common "collaboration sandbox" capability. This early collaboration facilitates model integration and co-design between EA/SOA/Cloud services. Furthermore, this type of unified lifecycle support process can potentially provide a common basis for a more cohesive workforce development and training process that also addresses variance reduction needs within challenging budgetary climates.

9. Establishing a Unified Framework for Model-Level Integration: Candidate Technologies

Maturing technologies, along with new and emerging technology developments, are anticipated for further addressing more comprehensive model-level integration and interoperability needs. For example, a number of MBSE/SOSE developments are occurring within the technology domains of autonomic computing, cyber-physical systems, neuromorphic engineering, cognitive architecture, agent architecture (e.g. software agent, mobile agent, autonomous agent, intelligent agent) and multi-agent system (MAS) technology domains.[60] Model-level integration of agent-based reference-models with software-defined radio (SDR) reference-models (e.g. SCA), is also of interest due to recent availability of SCA compliant reference implementations (e.g. REDHAWK).[61]

For MBSI related lifecycle-support technologies, software product line (SPL), product family engineering, and MAS product-line related methods (e.g. agent-oriented software engineering) are considered high-payoff emerging capabilities that need to be further considered.[62] The near-term goal is to evaluate reference models (e.g. ASRM) and frameworks (e.g. JADE) for incorporation into an MBSI type of approach that is currently being explored as a new proposal effort.[63] The longer-term goal is to potentially establish best-practices for the integration of agent-based reference models and standards. The intent is to address the need for standardized model-based distributed control[64] solutions (e.g. hierarchical control, supervisory control, SCADA, intelligent control).

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60 Autonomic computing (http://en.wikipedia.org/wiki/Autonomic_computing)
    Cyber-physical system (CPS; http://en.wikipedia.org/wiki/Cyber-physical_system)
    Neuromorphic engineering (http://en.wikipedia.org/wiki/Neuromorphic_engineering)
    Cognitive architecture (http://en.wikipedia.org/wiki/Cognitive_architecture)
    Agent architecture (http://en.wikipedia.org/wiki/Agent_architecture)
    Multi-agent system (http://en.wikipedia.org/wiki/Multi-agent_system)
61 Software-defined radio (SDR; http://en.wikipedia.org/wiki/Software-defined_radio)
    Software Communications Architecture (SCA; http://en.wikipedia.org/wiki/Software_Communications_Architecture)
    REDHAWK home page, last access Feb 2014 (http://redhawksdr.github.io/Documentation/)
62 Software product line (http://en.wikipedia.org/wiki/Software_product_line)
    Product family engineering (http://en.wikipedia.org/wiki/Product_family_engineering)
    Multiagent systems product lines (http://en.wikipedia.org/wiki/Multiagent_systems_product_lines)
63 Agent systems reference model (http://en.wikipedia.org/wiki/Agent_systems_reference_model)
    Java Agent Development Framework (JADE; http://en.wikipedia.org/wiki/Java_Agent_Development_Framework)
64 Distributed control system (http://en.wikipedia.org/wiki/Distributed_control_system)

10. Summary and Conclusion

In summary, C2 agility requires timely and robust net-enabled information-sharing services. As discussed and reviewed, MBSE/SOSE and EA/SOA/Cloud lifecycle-support processes provide a basis for a collaborative model-integration oriented approach that addresses the need to collaboratively define, assess, and validate mission-task driven IER MOPs/MOEs. This type of collaborative model-based engineering process enables the growing and rapidly evolving complexities of MBSE/SOSE and EA/SOA/Cloud technologies to be more readily addressed. This includes improvements in alignment, reuse, and integration of multiplicities of reference models and standards that need to be applied and tailored to NCW/ID Warfighting domains. For RF LOS communications and ad-hoc networking, this type of approach is a critical enabler for the requirements engineering and systems design aspects of effective link-management services that provide robust and gracefully degrading workflow support.

For the way-ahead, a number of additional emerging MBSE/SOSE related capabilities were reviewed for potential incorporation within a unified model-integration oriented lifecycle support process. This further illustrates how a more cohesive overarching set of resources can establish a basis for innovative, responsive, and agile MBSE/SOSE workforce improvement possibilities.

11. Acknowledgements

12. Technical References

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